THE PHYSICAL AND PHYSIOLOGICAL CHARACTERISTICS OF ELITE FEMALE SOCCER PLAYERS

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i. ABSTRACT

Despite the growing popularity and professionalism of female soccer in recent years, a physical analysis of elite female players has not been thoroughly conducted. The activity profiles of male soccer players during matches and training have been well documented, and coaches of female teams often rely on data from men's soccer to prescribe conditioning programs and develop training load monitoring benchmarks. Therefore, the aim of this thesis was to investigate the physical and physiological characteristics of elite female soccer players during training and competitive matches. The physical and physiological characteristics of elite female soccer players were analysed across a playing season (including a week of preseason training), during a sample of small-sided training games, as well as during competitive Australian national league (W-League) matches. The key findings of this research were: 1) sprint performance and training demands declined across the course of a playing season, 2) total and exercise energy expenditure was 11,692-12,242 kJ and 2,695-2,538 kJ, respectively, 3) smaller small-sided (training) games can be used to develop repeat acceleration ability and aerobic capacity while larger small-sided (training) games can be used to develop maximal speed, 4) the high-speed and sprint characteristics vary according to playing position and time period of the match, and 5) the acceleration and deceleration profiles vary according to playing position and intensity. The findings from this research thesis can be used to develop match-specific conditioning and change of speed programs, as well as develop training load monitoring benchmarks.

iii. ACKNOWLEDGEMENTS

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iv. PUBLICATIONS

Peer Reviewed Publications

1. **Mara, J.,** Thompson, K. G, Pumpa, K. L, Periodisation and Physical Performance in Elite Female Soccer Players. International Journal of Sports Physiology and Performance. 2015. 10(5): 664-669.
2. **Mara, J.,** Thompson, K. G, Pumpa, K.L Assessing the Energy Expenditure of Elite Female Soccer Players: A Preliminary Study. Journal of Strength and Conditioning Research. 2015. 29(10): 2780-2786.
3. **Mara, J.,** Thompson, K. G, Pumpa, K.L. The physical and physiological characteristics of various-sided games in elite female soccer. International Journal of Sports Physiology, 2016, In press.

Conference Communications

1. **Mara, J.,** Thompson, K.G, Pumpa, K.L Physical Performance of Small-Sided Games in Elite Female Soccer Training. World Congress on Science and Football Conference, Copenhagen, Denmark, 2015.
2. **Mara, J.,** Thompson, K.G, Pumpa, K.L Training Phase and High-Speed Performance in Elite Female Soccer. Exercise and Sports Science Australia Conference, Adelaide, Australia 2014.
3. **Mara, J.,** Thompson, K.G, Pumpa, K.L Assessing the Energy Expenditure of Elite Female Soccer Players. Sports Medicine Australia Conference, Canberra, Australia, 2014.

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1.0 INTRODUCTION

1.1 Description of Soccer

A soccer game consists of two 45 minute halves, separated by a 15 minute half-time intermission. Two teams of 11 players (10 field players and 1 goalkeeper) compete on a 105 x 68 m field at one time. Positions typically consist of defenders, midfielders and attackers and the allocation of each is determined by the formation of the team. For example, a formation of 4-3-3 consists of 4 defenders, 3 midfielders and 3 attackers. Positional units can be further categorised into central and external positions (i.e. central defenders and external defenders, and central and external attackers) as the tactical roles within a positional unit can be quite varied (figure 1.1). Players can be substituted during a stoppage (e.g. the ball has gone out of play), however only three substitutions can be made and a player is not permitted to re-enter the field of play once they have been substituted.

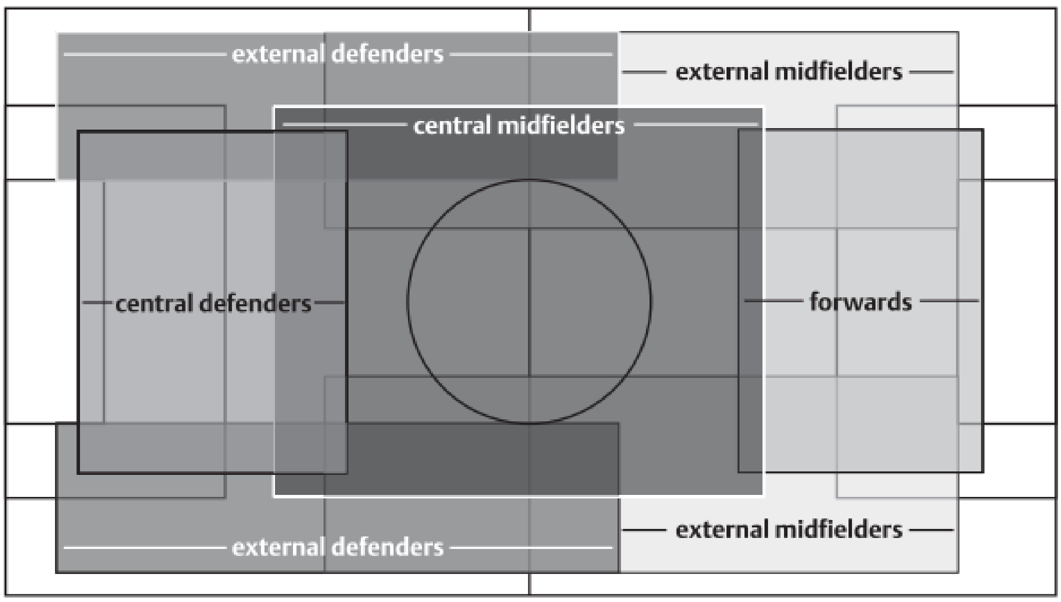


Figure 1.1: Tactical assignment of different positions in soccer. From Di Salvo et al 2007 (119).

1.2 Female Soccer

The popularity and professionalism of female soccer in Australia has grown substantially in recent years, with an 11 % increase in player participation in just two years between 2013 (89,686 registered female players) and 2015 (99,161 registered female players) (Personal Communication, Football Federation Australia, 2015). Further, 71 % of all Member Associations of the Asian Football Confederation (of which Australia is a member) have a national women's soccer league (FIFA Women's Football Survey, 2014). It should also be acknowledged that the most recent 2015 Women's World Cup final between the United States of America (USA) and Japan in Canada attracted a record USA television soccer audience of 25.4 million viewers (FIFA, 2015). This was 39 % higher than the previous record set in 2014 when 18.2 million television viewers watched the USA men's team play against Portugal in Brazil.

1.3 Thesis Aim

Despite the growing popularity of female soccer in recent years, research concerning the applied sports science of female soccer is still in its infancy. As such, fundamental aspects such as the physical and physiological characteristics of players and their responses to matches and training have not been well documented. Physical load monitoring is common-practice among elite male soccer teams and the physical demands of matches and training have been thoroughly investigated (chapter 2). The disparity in the depth of research between male and female soccer could be attributed to the expensive nature of player tracking systems (e.g. PROZONE®) and until recently, more affordable player tracking devices were not permitted in competitive matches. Regardless, the increased attention given to female soccer warrants the conduct of research that aims to optimise training strategies and subsequently maximise on-field physical performance. Therefore, the aim of this thesis was to investigate the physical and physiological characteristics of elite female soccer players during training and competitive matches. The findings of this research will provide objective information which can be used to: 1) design conditioning programs, 2) develop training load benchmarks to improve player load monitoring practices and, 3) ensure training demands are effectively replicating match demands.

2.0 LITERATURE REVIEW

2.1 Introduction

The growing popularity of female soccer in recent years has contributed to an increase in scientific investigations related to the physiological characteristics of female soccer players. The increased competitiveness and professionalism of both national leagues and international competitions has warranted the need for research related to optimising training strategies in order to maximise on-field performance. While the attention given to female-specific research is continuing to grow, investigations related to male soccer players are still well in excess of those conducted with their female counterparts. This review discusses the recent literature detailing the physical attributes of female soccer players, as well as the physical and physiological characteristics of training and matches. This review also considers the methodology used to monitor and quantify training and match loads. Future directions for research that investigates elite female soccer players are identified and recommended.

2.2 Player Characteristics

Body Composition

The anthropometric characteristics described in previous research are summarised in table 2.1. Mean body mass and stature of elite female players ranged from 58.5-65.0 kg and 164-170 cm, respectively, which is similar to those reported for collegiate level players (59.9-64.2 kg and 163-167 cm). In addition, percent body fat has been reported to be 14.6-18.5 % for elite, 15.7-20.7 % for sub-elite and collegiate, and 26.5-28.2 % for regional level players (table 2.1). Studies typically showed no differences in body composition variables from the start to the end of the regular season (34,114) with the exception of one study that interestingly reported an increase in percent body fat mass from the end of preseason to the end of the competitive season (100). It was suggested that this increase in fat mass was likely due to a decrease in resistance, sprint and agility training during the competitive season.

Collectively, these findings are in contrast to those from samples of male players by which percent body fat declined throughout the playing season (22,76,107). It has been shown that mean body mass and stature of youth male soccer players was 67.7-70.1 kg and 175.0-178.8 cm, respectively (58). Percent body fat, determined by calculations applied to skinfold measurements, was 11.8-13.3 % (58). When compared with the body composition of non-athletic control participants representing the general population, youth male soccer players were shown to be taller in stature, heavier in total body mass, but had less percent body fat (58). Mean body mass and stature of professional male players was 74.2-79.4 kg (22,35,76,107) and 178 cm (± 6.0) (22,34). Percent body fat, determined by calculations applied to skinfold measurements, was 8.3-14.5 % (22,76,107), which was lower than their female counterparts (34,100,112).

Aerobic Capacity

It has been demonstrated that maximal oxygen uptake ($\dot{V}O_{2max}$) was strongly correlated (r = 0.81, p < 0.05) with the amount of high-intensity running performed during a female soccer game (79). The $\dot{V}O_{2max}$ of female soccer players has been reported to be 49.4-55.4 ml·kg^{-1}·min^{-1} for elite players and 43.2-49.2 ml·kg^{-1}·min^{-1} for collegiate players (table 2.1). In addition, it was observed that $\dot{V}O_{2max}$ declined across the course of the competitive season in collegiate players (100).

It has been shown using portable spirometry that average and peak $\dot{V}O_2$ during a friendly match of a second division female German team was 28.3 and 53.0 ml·kg^{-1}·min^{-1}, respectively. This corresponded to 52 % and 98 % $\dot{V}O_{2max}$ (96). Average and peak $\dot{V}O_2$ has also been estimated during a first division female Danish League match using the heart rate-$\dot{V}O_2$ relationship algorithm (79). It was shown that average and peak $\dot{V}O_2$ was 37.6 and 47.4 ml·kg^{-1}·min^{-1}, respectively, which corresponded to 77 % and 96 % $\dot{V}O_{2max}$. Unfortunately, investigations related to aerobic capacity and oxygen consumption during matches are limited due to the impracticality, high cost and laborious procedures required to conduct this type of analysis.

Intermittent High-Speed Running Ability

Field-based tests, such as the Yo-Yo Intermittent Recovery (YYIR) test (levels 1 and 2), are commonly used to measure the intermittent high-speed running ability of soccer players. The YYIR test consists of two 20 m shuttle runs at progressively increasing speeds with a 10 s active recovery period between runs (12,78). Players continue to run until two consecutive failed attempts to reach the markers by the audio prompt. These tests provide a practical sport specific alternative to laboratory testing and can be easily implemented in the training environment.

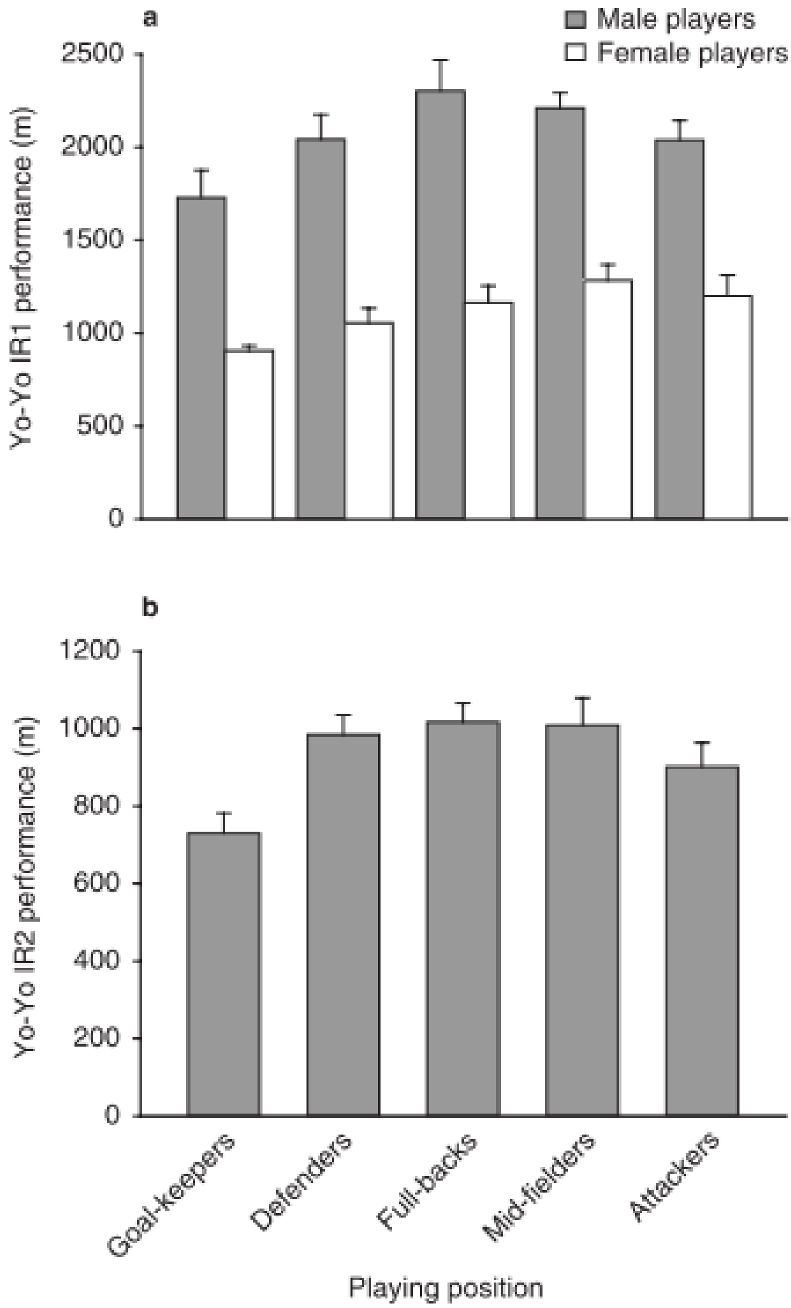


Figure 2.1: Yo-Yo IR (Level 1 and 2) performance for male and female soccer players of different positions. From Bangsbo *et al* 2008 (12).

Research has observed a relationship (r = 0.76) between the distance achieved in the YYIR and the amount of high-speed running performed in matches (79). Elite female players tend to perform better in the YYIR (1,213-1,774m) than their sub-elite (994–1,051 m) counterparts (table 2.1), which indicates that YYIR scores are useful for determining level of performance. Further, YYIR scores differ according to positional role for both male and female players, as shown in figure 2.1.

In an elite training environment it is commonplace for teams to undergo baseline testing at the beginning and end of preseason and then again on a number of occasions during the season to determine if a high physical level is being maintained (76). Despite this practice, published research on seasonal variations in intermittent high-speed running ability in female players is limited. One study has shown that following the preseason training phase Yo-Yo Intermittent Endurance (YYIE2) test performance improved in elite female soccer players (19). These results are similar to seasonal improvements in YYIR performance found in male players (78). Further research is required to draw more meaningful conclusions about the seasonal changes of intermittent high-speed running ability in female players.

Speed

The distance covered at high speed during games has been shown to be a valid indicator of performance, with players of a higher competition level covering greater distances at high speeds when compared with players of lower competition levels (79). The ability to develop and maintain high speed running is an important factor during games as it can offer a clear advantage over opponents during one-on-one contests. Speed and acceleration characteristics of soccer players are often tested using distances that reflect the mean distance of sprints during games (134,135). Time to complete a 20 m sprint has been reported as 3.17 s (± 0.03) in elite female players (8), with slower times observed among division 2 players (3.8 s ± 0.35) (110) and youth players (3.56 s ± 0.21) (125). It has also been shown that over distances of 5, 10, 20 and 35 m high-level players achieved average speeds of 15.1, 18.0, 21.2 and 23.4 $km \cdot h^{-1}$, respectively (135). It is interesting to note that even over 35 m, players did not reach an average speed of 25 $km \cdot h^{-1}$, which is considered the lower threshold for "sprinting" in a number of studies (9,79,101). This may indicate that the lower limit for sprinting thresholds for female players is too high and should be revised.

Table 2.1: Anthropometrical, physiological and performance characteristics of female soccer players

Author, Year	Level (N)	Age (Years)	Stature (m)	Mass (kg)	Body Fat (%)	$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	YoYo IR (m)	Sprint (s)	CMJ (cm)
Alexiou, 2008(5)	Elite (15)	19.3 ± 2.0	169.0 ± 5.1	64.8 ± 7.7		50.8 ± 2.7			
Andersson, 2008(9)	Elite (21)	24.3 ± 4.9	1.70 ± 0.02	62.9 ± 4.9					
Andersson, 2008(8)	Elite #	22.6 ± 4.2	167.1 ± 5.7	63.3 ± 7.1		55.4 ± 3.6		(20m) 3.18 ± 0.03	30.5 ± 1.2
	(22)	21.6 ± 2.6	167.2 ± 4.7	65.0 ± 4.0		53.8 ± 2.3		(20m) 3.17 ± 0.03	29.8 ± 1.2
Andersson, 2010(9)	International (17)	27 ± 1	168.2 ± 1.5	61.0 ± 1.4					
Bradley, 2012(19)	Elite Senior (92)	23 ± 2	1.68 ± 0.07	61.9 ± 5.6			1774 ± 532!		
	Elite Youth (42)	19 ± 1	1.67 ± 0.06	59.9 ± 4.1			1490 ± 447!		
	Domestic (46)	22 ± 3	1.69 ± 0.05	60.9 ± 3.4			1261 ± 449!		
	Sub-Elite (19)	23 ± 4	1.65 ± 0.05	58.2 ± 4.8			994 ± 373!		
Castagna et al., 2013(31)	Elite (62)								
	FNAT	25.8 ± 3.9	1.67 ± 0.03	59.9 ± 3.8					31.6 ± 4.0
	U19	16.9 ± 0.9	1.66 ± 0.04	61.7 ± 3.6					34.3 ± 3.9
	U17	14.7 ± 0.4	1.64 ± 0.05	58.0 ± 6.4					29.0 ± 2.1
Esco et al., 2013(49)	Collegiate (15)	21.5 ± 1.8	1.67 ± 0.06	64.2 ± 7.4		43.2 ± 2.8			
Gravina et al., 2012(56)	Elite (14)	25 ± 5		61 ± 7.4	15.5 ± 2.9				
	Sub-elite (14)	18.3 ± 1.5		61.9 ± 9.8	18.4 ± 3.3				

Author, Year	Level (N)	Age (Years)	Stature (m)	Mass (kg)	Body Fat (%)	$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	YoYo IR (m)	Sprint (s)	CMJ (cm)
Grieco et al 2012(57)	Collegiate (15)	19.0 ± 0.7	1.67 ± 0.1	59.9 ± 6.7	18.2 ± 1.7[SF]	49.1 ± 4.2			
Gabbet, 2008(54)	Elite (13)	21 ± 2				51.4 ± 5.4			
Haugen et al., 2012 (61)	International(85)	23.5 ± 3.6		63.7 ± 5.2				(40m) 5.64	30.7 ± 4.1
	1st Division (47)	21.2 ± 3.6		62.4 ± 6.6				(40m) 5.75	28.1 ± 41.1
	2nd Division (29)	22.3 ± 4.8						(40m) 5.93	
	Junior Elite (34)	18.1 ± 2.9		61.7 ± 5.9				(40m) 5.77	28.5 ± 4.1
Haugen et al., 2014(60)	International(76)	22.8 ± 3.5	1.69 ± 5.5	63.2 ± 5.5		3.58 ± 0.37 (L)			
	1st Division (53)	21.1 ± 3.5	1.67 ± 5.0	60.6 ± 5.9		3.25 ± 0.30 (L)			
	2nd Division (28)	20.9 ± 3.4		61.6 ± 8.6		3.08 ± 0.35 (L)			
	International Junior (11)	17.1 ± 1.1	1.68 ± 5.3	61.2 ± 4.9		3.39 ± 0.36 (L)			
	Juniors (17)	17.5 ± 1.7	1.68 ± 7.1	62.7 ± 8.3		3.23 ± 0.38 (L)			
Krustrup, 2005(79)	Elite (14)	24 (19-31)	1.67 (1.56-1.80)	58.5 (49.0-70.7)	14.6 (9.3-21.9)	49.4 (43.4-56.8)	1379 (600-1960)		
Krustrup, 2010(81)	Elite (23)	23 (18-29)	1.69 (1.59-1.80)	60.1 (53.3-69.5)	18.5 (12.7-27.6)	52.3 ± 1.3	1213 ± 90[!]		
Martinez-Lagunas 2014(95)	Elite DIV 2 (18)	21.5 ± 3.4	1.66 ± 0.07	63.3 ± 7.4		55.0 ± 5.3 (45.9-67.1)	1051 ± 399 (520-2080)		
McCormack 2013(97)	Collegiate (10)	19.5 ± 1.0 (18-22)	1.65 ± 0.05	62.1 ± 6.4		48.0 ± 3.8			

Author, Year	Level (N)	Age (Years)	Stature (m)	Mass (kg)	Body Fat (%)	$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	YoYo IR (m)	Sprint (s)	CMJ (cm)
Miller, 2007(100)	Collegiate (26)	18-21		62.0 ± 5.2	15.7 ± 2.9^{HW}	49.2 ± 4.4			
Milanovic et al 2011(99)	International (22)	23.9 ± 4.5	1.68 ± 0.07				880-930		
Mujika, 2009(105)	Senior (17)	23.1 ± 2.9	1.65 ± 0.04	56.8 ± 5.7			1224 ± 255	(15m) 6.3 ± 0.2^	32.6 ± 3.7
	Youth (17)	17.3 ± 1.6	1.64 ± 0.05	57.5 ± 7.6			826 ± 160	(15m) 6.17 ± 0.17^	28.41 ± 1.9
Ozbar et al 2014(110)	Division 2 (18)#	18.3 ± 2.6	163.1 ± 5.3	58.8 ± 7.8				(20m) 3.7 ± 0.3	39.8 ± 4.5
		18.0 ± 2.0	159.4 ± 5.1	54.4 ± 6.1				(20m) 3.9 ± 0.4	35.4 ± 4.6
Polman, 2004(112)	Regional (36) #	21.2 ± 3.1	1.63 ± 0.05	64.5 ± 6.2	26.5 ± 2.87^{SF}	39.4 ± 3.72*		(25m) 4.33 ± 0.12	38.8 ± 4.11
			1.64 ± 0.06	65.4 ± 10.4	26.8 ± 3.59^{SF}	38.3 ± 3.90*		(25m) 4.31 ± 0.09	39.9 ± 3.32
			1.65 ± 0.05	65.7 ± 7.5	28.2 ± 2.98^{SF}	38.1 ± 3.33*		(25m) 4.33 ± 0.12	39.3 ± 5.67
Taylor, 2012(125)	Youth U13 (10)	11.8 ± 0.7	148.1 ± 8.7	38.9 ± 7.6				(5m) 1.19 ± 0.09	
	Youth U15 (9)	13.4 ± 0.5	157.5 ± 8.0	48.8 ± 11.6				(20m) 3.56 ± 0.21	
Upton, 2011(127)	Collegiate (27)	19.6 ± 0.9	166.9 ± 5.9	63.4 ± 6.9	20.7 ± 4.0	46.1 ± 4.6		(5yd) 3.77 ± 0.11^	
								(5yd) 3.79 ± 0.16^	
								(5yd) 3.70 ± 0.29^	
								(15yd) 5.18±0.12^	
								(15yd) 5.16±0.10^	
								(15yd) 5.07±0.21^	
Vescovi, 2008(132)	High School (83)	15.1 ± 1.6	1.68 ± 0.06	54.6 ± 7.9				(9.1m) 1.37 ± 0.06	39.6 ± 4.7
								(18.2m) 2.67 ± 0.13	
	Collegiate (51)	19.9 ± 0.9	1.63 ± 0.07	64.8 ± 5.9				(9.1m) 1.38 ± 0.07	40.9 ± 5.5
								(18.2m) 2.75 ± 0.44	

Author, Year	Level (N)	Age (Years)	Stature (m)	Mass (kg)	Body Fat (%)	$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	YoYo IR (m)	Sprint (s)	CMJ (cm)
Vescovi, 2011(133)	Youth (78)	12.6 ± 0.5							37.4 ± 4.8
	High School (223)	15.3 ± 1.0							38.7 ± 5.0
	Collegiate (113)	19.4 ± 1.1							42.0 ± 5.0
Vescovi, 2012(135)	High-level (140)	23.9 ± 2.8	167.6 ± 6.1	62.5 ± 6.7				(5m) 15.1 ± 1.1^^ (10m) 18.0 ± 0.9^^ (20m) 21.2 ± 0.9^^ (35m) 23.4 ± 0.9^^	

All data are expressed as means ± SD unless otherwise stated.
** Estimated by MSFT*
^ Sprint performance expressed as $m \cdot s^{-1}$
^^ Sprint performance expressed $km \cdot h^{-1}$
 # Data taken from the pre-test of different conditions in an intervention design
! Data taken from Yo-Yo IE 2
L $\dot{V}O_{2max}$ data expressed in liters
SF Body Fat % measured by calculations applied to skinfold measurements
HW Body Fat % measured by hydrostatic weighing

2.3 Activity Profiles of Matches

Time-motion analysis in soccer has been used to quantify the physical load of players during matches in order to understand and replicate these demands during training. This section describes the activity profiles of soccer games in terms of distances covered, sprints, acceleration and decelerations, and discusses the main sources of variation of activity profiles.

Distance Covered in Matches

Female soccer players typically cover a total distance of 8.9-11.3 km during a 90 minute match, with variations observed between individual players and positional units (table 2.2). In general, midfielders covered the greatest distance, followed by attackers and defenders (9,51,54,62). However, quantifying the total distance covered in matches without providing context to the speed at which running has been performed offers limited practical applications and usefulness to coaches and conditioning staff. As such, the speed at which running is performed during matches has been recognised as an important characteristic of time-motion analysis. Previously, the distance covered at high-speed was widely acknowledged as a more valid indicator of training status and level of performance than total distance (79). However, a more recent study has suggested that elite male players perform less high-speed running than those in the division below (121). In addition, teams have been shown to run further high-speed running distances when the opponent is of higher quality (82).

Elite female players covered 1.3-2.8 km at high speeds (table 2.2) with the large variation being accounted for by individual game characteristics, inconsistency in speed thresholds used and the method of tracking (e.g. manual-based tracking, GPS). Similar to total distance, differences in high-speed running distance have been shown between positions, with midfielders covering the greatest distance, followed by attackers and defenders (62). Currently, research tends to categorise positional units as midfielders, attackers and defenders. However, modern team formations will often include wide defenders that have attacking roles (such as making runs to overlap midfielders in the wide channels of the field), in addition to their defensive duties. Therefore, it is suggested research includes more specific definitions of positions (e.g. wide defenders, central defenders, central attackers and wide attackers) in order to avoid large variations of time-motion characteristics within positions.

To provide further practicality from time-motion analysis, previous research has examined the fluctuations in physical performance within a match. When analysing female matches in 15 minute time periods, it was observed that ~ 24 % more high-intensity running was performed in the first 15 minute time period than the last 15 minute period for both international and domestic level players (9). In another study, high-intensity running declined by up to 41 % from the first to last 15 minute period in high-level players (101). Similarly, it was shown that the amount of high-intensity running declined by 30 % from the first to the last 15 minute period in the first half, and by 34 % from the first to the last 15 minute period in the second half (79). In addition, in top-class players it has been observed that after the peak 5 minute activity period during a game, the amount of high-intensity running during the next 5 minute period was 17 % lower than the average for all 5 minute time periods (101). The fluctuations in physical performance within a match may be due to a combination of factors such as physical and mental fatigue, game-specific factors or strategies (i.e. slowing the game down during the final minutes of play) and the possibility of players adopting pacing strategies (111,126). However, as it is difficult to isolate specific reasons for the variation in activity across the course of a match, fluctuations should be interpreted with caution (111).

Table 2.2 Match Activity Profiles of Female Soccer Players

Author, Year	Level (n)	Tracking System	Total Distance (km)	High-Speed Distance (km)	Sprinting Distance (km)	Speed Thresholds ($km \cdot h^{-1}$)
Andersson et al., 2008 (7)	Elite (21)	Manual Video-Based	10.19^ 10.33*	1.86^ 1.87*	0.31^ 0.32*	High-Speed = >18 Sprinting = 25
Anderrson et al., 2010 (9)	International (17) Domestic (17)	Manual Video-Based	9.9 ± 1.8 9.7 ± 1.4	1.53 ± 0.1 1.33 ± 0.9	0.26 ± 0.06 0.22 ± 0.05	High-Speed = >18 Sprinting = 25
FIFA (51)	International (>400)	Semi-automated Vision-based (AMISCO)	10.22 CD: 10.16 FB: 10.85 CM: 11.35 W: 11.28 A: 10.46	0.40 CD: 0.34 FB: 0.46 CM: 0.44 W: 0.54 A: 0.47	0.28 CD: 0.26 FB: 0.38 CM: 0.29 W: 0.44 A: 0.49	High-Speed = > 18-21 Optimum Sprinting = > 21.1-25 Max Sprinting = > 25
Gabbett et al., 2008 (54)	International (13)	Manual Video-Based	F: 9.61 ± 0.36 M: 10.67 ± 1.34 D: 9.62 ± 1.2	F: 1.18 ± 0.15 M: 1.94 ± 0.50 D: 1.33 ± 0.39	F: 1.18 ± 0.15 M: 0.98 ± 0.32 D: 0.82 ± 0.33	Speed Thresholds not specified – individualized.
Hewitt et al., 2014 (62)	International (15)	GPS	F: 9.44 ± 0.36 M: 10.15 ± 0.23 D: 8.76 ± 0.28	F: 2.27 ± 0.2 M: 2.8 ± 0.17 D: 1.74 ± 0.14	F: 0.39 ± 0.05 M: 0.39 ± 0.05 D: 0.19 ± 0.03	Running = >12 Sprinting = >19
Krustrup et al., 2005 (79)	Elite (14)	Manual Video-Based	10.3 (9.7-11.3)	1.31 (0.71-1.70)	0.16 (0.05-0.28)	High-Speed = >18 Sprinting = 25
McCormack et al., 2014 (97)	Collegiate (10)	GPS	8.95 ± 1.04	1.59 ± 0.59	4.7 ± 4.24 no. sprints per player	High-Speed = >13 Sprinting = > 22
Mohr et al., 2008 (101)	International (19) Domestic (15)	Manual Video-Based	10.33 ± 0.15 10.44 ± 0.15	1.68 ± 0.09 1.30 ± 0.10	0.46 ± 0.02 0.38 ± 0.05	High-Speed = >18 Sprinting = 25
Vescovi., 2012 (134)	Professional (71)	GPS			F: 657 ± 157 M: 447 ± 185 D: 545 ± 217	Sprinting = > 18
Vescovi., 2014 (131)	Collegiate (113)	GPS	F: 10.29 M: 10.13 D: 9.5	F: 0.93 M: 0.76 D: 0.75	F: 0.34 M: 0.2 D: 0.27	High-Speed = 15.6-20 Sprinting > 20

*Data are presented as means ± SD unless otherwise stated. ^ Authors specified that games were played on artificial turf; * Authors specified that games were played on grass. F: Forwards; M: Midfielders; D: Defenders; CD: Central Defenders; FB: Full-backs; CM: Central Midfielders; W: Wingers; A: Attackers.*

Table 2.3 Sprint Profiles of Female Soccer Players

Author, Year	Level (n)	Tracking System	HSR Duration (s)	Sprint Duration (s)	Sprint Distance (m)	RSA Bouts (n)	RSA sprints per bout (n)	Time between sprints (s)
Gabbett, 2008	Elite (13)	Manual Video-Based	F: 2.9 ± 1.7 M: 4.2 ± 2.5 D: 3.3 ± 2.1	F: 2.5 ± 1.5 M: 2.3 ± 1.6 D: 2.4 ± 1.5		F: 4.7 ± 4.0 M: 6.0 ± 3.2 D: 4.0 ± 1.9	F: 3.4 ± 0.8 M: 3.5 ± 1.0 D: 3.2 ± 0.4	F: 6.7 ± 3.8[b] M: 6.6 ± 4.0[b] D: 4.3 ± 3.7[b]
Gabbett et al., 2013[a]	Elite (13)	Manual Video-Based	2: 2.98 ± 0.66 3: 2.94 ± 0.72 4: 2.98 ± 0.76 5: 2.87 ± 0.65 6: 2.93 ± 0.67	2: 2.27 ± 0.56 3: 2.16 ± 0.60 4: 2.24 ± 0.77 5: 1.96 ± 0.51 6: 2.08 ± 0.19		2: 5.1 ± 5.1 3: 2.5 ± 3.0 4: 1.1 ± 2.0 5: 0.5 ± 1.2 6: 0.2 ± 0.7		2: 10.22 ± 4.42[b] 3: 12.95 ± 4.34[b] 4: 13.28 ± 3.99[b] 5: 15.11 ± 3.74[b] 6: 16.57 ± 2.49[b]
Vescovi, 2012	Professional (79)	GPS		F: 2.3 ± 1.5 M: 2.2 ± 1.4 D: 2.3 ± 1.5	F: 15.5 ± 9.6 M: 14.3 ± 9.1 D: 15.3 ± 9.4			F: 2.1 ± 2.0min M: 2.8 ± 3.0min D: 2.5 ± 2.4min

RSA = Repeated Sprint Activity; a = sprint data was expressed according to the number of efforts in each repeated sprint bout (ie. where 2 = 2 sprints with < 20 secs recovery between each, 3 = 3 sprints with < 20 secs recovery between each, 4 = 4 sprints with < 20 secs recovery between each, 5 = 5 sprints with < 20 secs recovery between each, 6 = 3 sprints with < 20 secs recovery between each; b = recovery expressed as recovery between RSA efforts

Sprint Profiles

The sprint profiles of female soccer players are reported in table 2.3. It should be acknowledged that sprint profiles are typically quantified by the distance achieved and time spent above the pre-determined sprint threshold (e.g. > 5.4 m/s). The average distance for sprinting efforts was ~ 15 m (134), lasting for 2.2-2.5 s (55,134), with ~ 150 s of lower intensity activity between efforts (134). Average maximum sprint speed has been reported to be 21.4-22.1 $km\cdot h^{-1}$ among professional female players (134), which is notably less than the lower speed threshold for sprinting used in previous research of female players (9,79,101). Sprint characteristics vary between playing positions, with midfielders covering less distance per sprint effort than forwards and defenders (55,134). Accordingly, sprint duration and maximum speed were also less among midfielders when compared with other positions. Some studies have also described repeat sprint efforts (RSEs), which are typically identified when 2 or more sprints are performed with less than 20 s recovery between each (55). The number of RSE bouts was 4-6 per game, with ~ 3 sprints per bout, and 4.3-6.7 s between each repeat sprint (55).

Acceleration and Deceleration Profiles

Summarising the distances covered in various speed ranges provides a valid method for quantifying the external load imposed on players during matches. However, it has been suggested that this method still underestimates the high-intensity efforts players perform, as it does not account for accelerating and decelerating actions (3). The ability to accelerate and decelerate are important aspects in soccer as they relate to match specific actions such as contesting for the ball over short distances (e.g. <10 m). While considered a precursor of maximal speed, acceleration has been shown to be an independent characteristic and therefore should be monitored and tested accordingly (86). It has been theorised that accelerating on flat terrain is energetically equivalent to running on an uphill terrain (106) and therefore is more energetically demanding than constant speed running, even at lower speeds. It has also been suggested that rapid decelerating actions may increase fatigue and thus may hinder performance (83). The ability to accelerate and decelerate is also related to change of direction ability (33). The ability to change direction efficiently in soccer allows players to recover quickly after a loss of ball possession and perform evasive cutting maneuvers during one-on-one situations.

Unfortunately, the acceleration and deceleration profiles of female soccer players in matches have not been reported within the current literature, and only limited research has been conducted using samples from male soccer players. Two studies have observed the total distance covered by male players whilst accelerating and deceleration in various thresholds (3,106). It was shown that players covered a total distance of 1,022-1,767 m accelerating (> 1 m·s^{2}) and 899-1,775 m decelerating (< -1 m·s^{2}). In addition, 178-180 m and 162-188m were performed at high acceleration (> 3 m·s^{2}) and deceleration (< -3 m·s^{2}) thresholds, respectively**.** Acceleration profiles have also been quantified according to the commencement and final velocities of maximal accelerations (> 2.78 m·s^{2}) (128). It was observed that the majority of maximal accelerations (78 %) were undertaken from a commencement speed < 2 m·s^{-1}, and only 4 % of efforts reached a speed that was equivalent to the sprint threshold. These findings demonstrate that examining distances covered in speed thresholds, without acknowledging acceleration profiles, does not provide an accurate quantification of the physical demands of soccer matches and only limited practical applications can be determined. Future research should aim to describe the acceleration and deceleration profiles of elite female soccer players during competitive matches.

Factors Affecting Match Activity Profiles

Research has shown that there are variations in the match activity profiles of female players between different levels of competition (9,101), quality of opposition (62) and when games are played in short succession of each other (e.g. 42 hours apart) (97). It has also been observed in male players that game-specific factors such as team formation (20,27), dismissals (24) and substitutes (25,102) affect activity profiles. While some of these factors have not been investigated in female soccer, this section discusses the sources of match activity variation and draws on information reported from male soccer.

The level of competition at which a match is played has been shown to influence the activity profile of female soccer players. In a study comparing 19 international and 15 domestic female players, it was observed that international players performed 28 % more high-intensity running and 24 % more sprinting than domestic level players (101). In addition, the peak distance covered in high intensity running in a 5 minute interval was 33 % longer for the top-class players than the domestic players.

Another study investigated whether international soccer games were more physically demanding than domestic league games for the same female players

(9). Video-based time-motion analyses were performed on 17 players and showed that distances covered in high-intensity running and sprinting were longer (13 % and 14 %, respectively) in international games compared with domestic league games. Although not further explored, these results indicate that players may not utilise their full physical capacity when competing in domestic games. This highlights the possibility that work-rate may be self-chosen when players compete at lower levels of competition and there is potential that a pacing strategy may be employed. Collectively, these results also indicate that the amount of high-intensity running is a distinguishing factor of level of performance, as has been suggested previously (79).

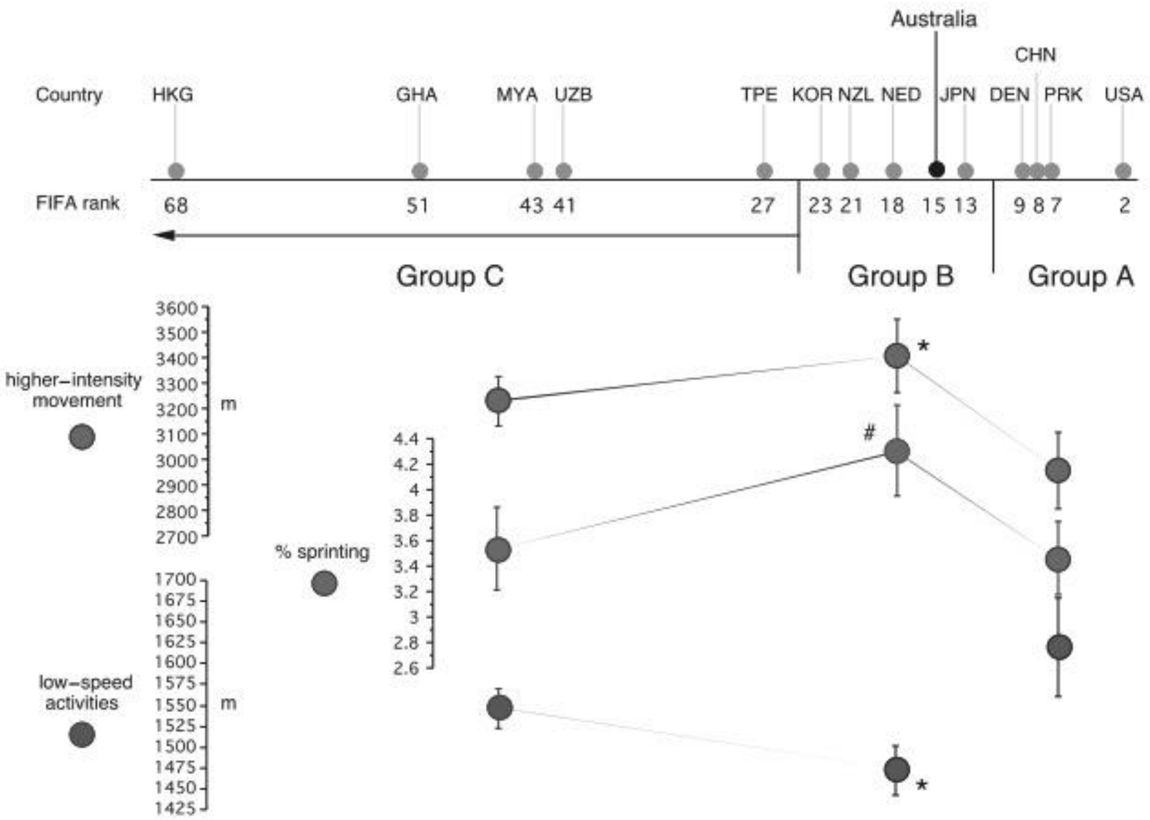


Figure 2.2. The effects of quality of opposition on the activity profile of the Australian women's soccer team. *From Hewitt et al 2014* (62). *Notes: * Significantly different from Group A. # Significantly different from Group C.*

A recent study of female international players showed that when competing against higher ranked opponents the amount of high-intensity running is less than when competing against opponents of similar ranking (62). However it was also found that the amount of sprinting performed increased when competing against similar ranked opponents, when compared with lower ranked opponents (figure 2.2). This study grouped opposition teams according to their official FIFA ranking based on past performance. However, it can be suggested that future studies determine quality of opposition by in-game match performance factors such as score-line, total shot ratio (i.e. team shots versus opposition shots), possession in the attacking third of the field or relative quality (i.e. the difference in team rank) (98) of the competing teams.

It has also been shown in a study of 10 collegiate female soccer players that the number of high-intensity efforts and high-intensity running distance decreased when a game is played 42 hours following the preceding game (97). These results are likely due to inadequate time to recover from neuromuscular fatigue developed in response to the first game (8). This is in line with a study of female players that observed knee flexion was inhibited for 51 hours and muscle soreness was present for 69 hours following a match (8). This study also showed that sprint performance was reduced prior to a second match, which succeeded the first match by 72 hours. The findings of the aforementioned study are in contrast to research conducted on male soccer players that examined the effect of two matches in one week (72-96 hours between matches) on physical performance

(45). It was observed that total distance covered, high-intensity running distance, sprint distance and the number of sprint efforts did not differ when players played one versus two games per week. However, the injury rate was significantly higher when players played two matches per week when compared with one match per week. The difference in findings between studies may be due to inconsistent recovery times between matches (i.e. 72-96 hours between matches (45) versus 42 hours between matches (97)). It appears 72-96 hours recovery between matches is sufficient to maintain the level of physical performance in male players, however future research should investigate this time course in female players as well as the effect that congested fixtures has on injury rate.

Recent studies of male players have explored the effect of team formation on player movement profiles and have shown that attackers in a 4-3-3 formation performed 30 % more high-intensity running than attackers in 4-4-2 and 4-5-1 formations (20). However, the limited significant findings among other positional roles suggested that overall team formation does not influence activity profiles of midfielders and defenders. Another study that examined the influence of opposition formation failed to deliver any significant differences between formations and it was concluded that none of the measures of physical performance across the individual playing positions were greatly affected by opposition team formation (27). However, it was highlighted in both of the aforementioned studies that the findings should be interpreted with caution as the small sample size only allowed for a basic division of the teams into three positional units; defenders, midfielders and attackers. Additionally, the process of determining team formations and ensuring that these were consistent throughout games relied solely on the subjective assessment of observers.

Soccer-specific factors such as dismissals have been partially explored in male players to determine whether they influence activity profiles. A novel study that explored the effect of an early dismissal (red card) on work-rate showed that following the dismissal, players covered a greater distance when compared with normal (11vs11 players) game conditions (24). This increase was particularly prevalent in moderate-intensity running. Subsequently, it was observed that recovery times between high-intensity efforts were substantially reduced when compared to normal game conditions. However, because of the relatively infrequent nature of an early dismissal, this study used only a sample of one match and a greater number of matches are required to draw more meaningful conclusions. Regardless, these findings suggest that elite soccer players may not always utilise their full capacity and work-rate could be self-chosen. As such, there is potential that players adopt a pacing strategy during a match to delay the onset of fatigue and subsequently maintain a high level of physical performance.

The strategic use of substitutes has been suggested to reduce the effects of fatigue that players succumb to in the second half of a football match (115). Regardless of playing position, substitute players have been shown to cover 25 % and 63 % more distance in high-intensity running and sprinting, respectively, in the last 15 minutes of a game than other players (102). When examining specific playing positions, it was observed that midfield substitutes tended to cover greater distances per minute than the player they replaced (24). Furthermore, midfield substitutes covered a greater overall distance and distance at high-intensity and had a lower recovery time between high intensity efforts, when compared with other midfield team-mates who remained on the field. Another interesting finding was that forwards covered less distance in their first 10 minutes as a substitute compared to their habitual activity profile in the opening 10 minute when starting matches. It was suggested that this observation might have been influenced by factors such as the specific tactical requirements of their position.

2.4 Activity Profiles of Small Sided Training Games

Soccer training constitutes approximately 80 % of total weekly player load, with matches contributing 20 % (13). Despite this, the majority of research on female players has focused on the activity profiles of matches and there is limited information detailing the physical and physiological characteristics of training. Small-sided games (SSGs) are modified training games used to improve physical, technical and tactical performance, without exposing players to the full physical load of a match. The effectiveness of SSGs as a conditioning stimulus for male players has been a topic of interest for researchers during the past decade, however the same attention has not been given to female players with only one published study that described the time-motion characteristics of female players (54)**.** This section discusses the physical, physiological and perceptual responses to various formats of SSGs, how these responses compare to competitive matches, and the effectiveness of SSGs as a conditioning stimulus in male soccer players.

Influence of Number of Players and Field Dimensions

Modifying the number of players per team and field dimensions of SSGs has been shown to elicit different physical, physiological and perceptual responses in male players. Typically, these studies show that SSGs with fewer players per team elicit a greater heart rate response when compared with more players (65,66,72,85,87). Accordingly, it has also been shown that SSGs with fewer players elicit a greater lactate response and rating of perceived exertion (RPE) than larger formats. However, contrasting conclusions have also been reported in terms of heart rate response (67,75,122). The disparity in findings may be the result of a lack of consistent formats used between studies, and the demographic of players used (i.e. youth male players versus professional male players).

Analysing the work-rate profiles of SSGs under various player number formats has not shown differences in total distance covered or total distances covered at lower intensity actions (e.g. walking and jogging) (65,66,75). However, there have been mixed findings when considering high-intensity efforts. One study showed that high-intensity efforts were increased with fewer players (75). However another study showed that maximum and mean sprint duration and distance were increased as the number of players involved also increased (64). These conflicting findings may be attributed to the lack of standardised high-intensity thresholds used among the research.

Similar to the influence of number of players on performance outcomes during SSGs, the influence that field dimensions have on physiological, perceptual and time-motion characteristics is relatively nonconsensual. This is likely due to research being conducted using an array of different field sizes, a varying number of players per team and effective playing time. A higher heart rate response was observed during SSGs played on a large pitch when compared to medium and small pitches (113). Accordingly, higher RPE and blood lactate values were reported by players following SSGs on medium and large sized pitches, when compared with smaller pitch sizes (113). On the contrary, another study reported no significant differences in heart rate values between pitch sizes (77). Anecdotal reports from players and coaches have suggested that athletes' work-rates increased as the relative pitch area per player increased (113). It is likely that this is due to a greater effective playing area, causing players to cover more ground, allowing higher speeds per run to be achieved.

Comparison of SSGs and Competitive Matches

Studies have compared the physical and physiological responses of SSGs and competitive matches in order to determine the effectiveness of SSGs as a soccer-specific conditioning stimulus. One study of a national women's team showed that 3v3 and 5v5 SSGs simulated the overall movement patterns of competitive matches, however they did not simulate the high-intensity and repeated sprint demands (54). Conversely, it has been shown in male players that the relative high-intensity demands during 5v5 SSGs was higher compared with competitive matches (6). In addition, in a sample of state premier league male players, it was observed that the exercise intensity of 2v2 formats exceeded that of competitive matches, while 4v4 were similar to, and 6v6 were below that of match intensity (66). Collectively, these reports show that SSG formats with fewer players can exceed competitive match intensity.

Comparison of SSGs and Interval Training

The effectiveness of SSGs as a soccer-specific conditioning stimulus when compared with generic interval running training has been a developing topic of interest in the recent literature. Studies have investigated this using a parallel matched-group design, allocating players to either a SSGs group or an interval training group (ITG) (72,116). One study implemented 6x4 minute intervals of 5v5 SSGs with a 3 minute active recovery period (50-60 % HR_{max}) into regular training times (116). The interval running duration matched that of the SSGs and had a target intensity of 85-90 % HR_{max}. The program was implemented twice a week for 6 weeks. Physical performance measures of countermovement jumps, 10-30 m sprints, 6x30 s anaerobic shuttle test, agility T test and the multi-stage fitness test all demonstrated similar changes when the SSGs group was compared to the ITG group. In another study, youth football players from Italian professional clubs performed 4x4 minute interval running efforts at a target intensity of 90-95 % HR_{max}, separated by 3 minute active recovery at 60-70 % HR_{max} (72). The duration and training intensity of SSGs matched that of the interval running efforts, however the SSGs involved a mixture of formats consisting 3v3, 4v4 and 5v5 players. Similar improvements in peak oxygen consumption ($\dot{V}O_{2peak}$), lactate threshold and running economy were observed for both the ITG and SSG groups. The results of these studies show that SSGs and generic interval training provide similar physiological adaptations in male players. Future research should aim to use samples of female soccer players to determine whether SSGs can be used as an effective conditioning stimulus in women’s teams.

2.5 Energy Expenditure of Soccer Players

The time-motion characteristics of elite soccer matches have been well documented in the scientific literature for both male and female players. Analysing the movement patterns of competitive games and training sessions has provided valuable information for coaches to prescribe soccer-specific conditioning programs to maximise training and on-field performance. However, the related energetic cost of performing the movements required of elite female soccer players has not been well established. As such, this section draws on data related to male soccer players in addition to the limited information on female players.

Total Energy Expenditure

It has been shown using the doubly labeled water (DLW) method that professional male soccer players can expend 14,834 kJ (± 1,714) of energy per day, significantly more than their reported daily energy intake (13,074 kJ ± 2,440) (47). However, as the DLW method does not provide information on specific non-exercise activity thermogenesis and exercise energy expenditure (130) the energy during soccer matches and training were not determined. The total energy expenditure of female soccer players has not yet been reported.

Exercise Energy Expenditure

One of the first studies to report energy expenditure in soccer matches suggested that male players expended up to 6,300kJ in a competitive match

(14). However, over the last 20 years there has been a dearth of research in this area despite the scientific study of the game evolving. In female soccer players, it was observed that training and game energy expenditure, measured by the equation suggested by Heyward (2010) (63) (EE = duration x [(MET's x 3.5 x weight) / 200)]) decreased over the course of a playing season. Exercise energy expenditure was reported to be 3,439 kJ (± 239), 2,696 kJ (± 109) and 668 kJ (± 117) during preseason, mid-season and post-season training sessions, respectively (114). In addition, it was observed that energy expenditure was in excess of energy intake, increasing the risk of low energy availability and subsequent metabolic, reproductive and bone related changes, collectively referred to as Relative Energy Deficiency in Sport (REDS) (104) (formerly the Female Athlete Triad) (71,89). On the other hand, it has also been shown that lower body fat percent is related to better sprint performance (22) and therefore an excessively positive energy balance leading to increases in fat mass can also be detrimental to high-speed performance. Understanding the energy expenditure of elite female players is important in attaining optimal body composition traits that are advantageous for speed, and do not predispose players to REDS.

2.6 Measuring Soccer Training and Matches

Traditionally, methods for tracking the physical loads of players were extremely time-consuming as data required manual input from an observer. As a result of technological developments, the design of recent tracking systems have been greatly enhanced which has enabled data generation to become more automatic and instantaneous. This section discusses the validity, reliability and application of device-based and vision-based tracking systems used to monitor and quantify the physical load of players.

GPS and LPM Tracking

Global positioning system (GPS) technology was originally designed to provide location information on military personnel (129), however these devices have been recently implemented in sport to quantify match and training loads. Players wear GPS receivers and location is determined when signals are received from at least four earth-orbiting satellites. Information regarding position and time are recorded, and distance and can be subsequently obtained. Speed of movements are automatically determined by the Doppler shift method (i.e. measurements of the changes in satellite signal frequency due to the movement of the receiver) (84). The most recent SPI HPU devices designed by GPSports (GPSports, Canberra, Australia) provide positional information 15 times per second (15Hz), despite being interpolated from a lower sampling rate of 10Hz. However, a recent study did not show an increase in validity of total distance measurements when comparing the 15Hz and 10Hz models (<1% error for both models) (74). MinixaxX 10Hz GPS models manufactured by Catapult (Catapult Sports, Melbourne, Australia) have also been shown to be valid for measuring constant velocity (% bias = 0.2-0.6), distances and accelerations (% bias = 2.9-3.6) (129). However, despite the reported validity of GPS technology for use in a sporting context, the accuracy of such technology when measuring short high-intensity running activities continues to be questioned (53) and interpretation of data should be conducted with caution.

Similar to GPS in terms of mathematical position calculations, the local position measurement (LPM) system provides a reportedly more accurate solution to motion analysis (53). To obtain positional information, players are required to wear an electrotransmitting device, however unlike conventional GPS technology, electromagnetic waves travel from the electrotransmitter to local base stations that are systematically placed around the playing area. The position of the player is determined by calculating the time-of-flight (TOF) and time difference of arrival (TDOA) of the electromagnetic waves travelling from the transmitting device to the base stations. As well as providing distance and speed data, the LPM system developed by Inmotio (Inmotio Object Tracking BV, Amsterdam, The Netherlands) can provide valuable movement information such as accelerations, decelerations and changes in direction at high frequency (1000Hz) (124) and within 1.6 % of actual position and speed on average (23).

Vision-Based Tracking

Conventional methods of vision-based player tracking have involved filming players individually throughout the course of the match from an appropriate vantage point (20-30 m high) (9,54,79,101). Following the game, the video footage was then replayed on a monitor for manual coding of pre-determined movement categories (table 2.4). The distance covered by each individual player was estimated as the product of time spent in the different movement categories and the estimated speed of each movement. However, it can be argued that the subjective nature of human movement recognition could cause variability and error in the data input. Furthermore, manual vision-based techniques do not provide real-time feedback for coaches and the analysis of data is laborious and time-consuming.

Table 2.4. Match-Play activities used during time-motion analysis of female soccer players. *From Gabbett & Mulvey, 2008* (54).

Match-Play Activity	**Definition**
Standing	No locomotor activity
Walking	Movement involves at least one foot being in continual contact with the ground
Jogging	Movement involves a flight phase and minimal arm swing
Striding	Movement is similar to jogging but involves a longer stride and more pronounced arm swing
Sprinting	Maximal effort with a greater extension of the lower leg during forward swing and higher heel lift relative to striding

The increased attention towards the monitoring of player's movement profiles during competition has encouraged further technological advancements to make the tracking of players more efficient and instantaneous. The first system to achieve simultaneous monitoring and physical analysis of all players throughout the entire course of a match was the AMISCO Pro system (AMISCO, Sport Universal, Nice, France). The AMISCO system, along with its former competitor PROZONE® (Prozone Sports, Leeds, United Kingdom) involve the installation of a multi-camera system (up to 8 cameras per stadium) to capture the entire field at once, with each area of the field covered by at least two cameras for accuracy (figure 2.3) (120). A number of experienced operators conduct the analysis in real-time throughout the duration of the match, enabling instantaneous and post-game feedback for coaches regarding physical, tactical and technical aspects of the game.

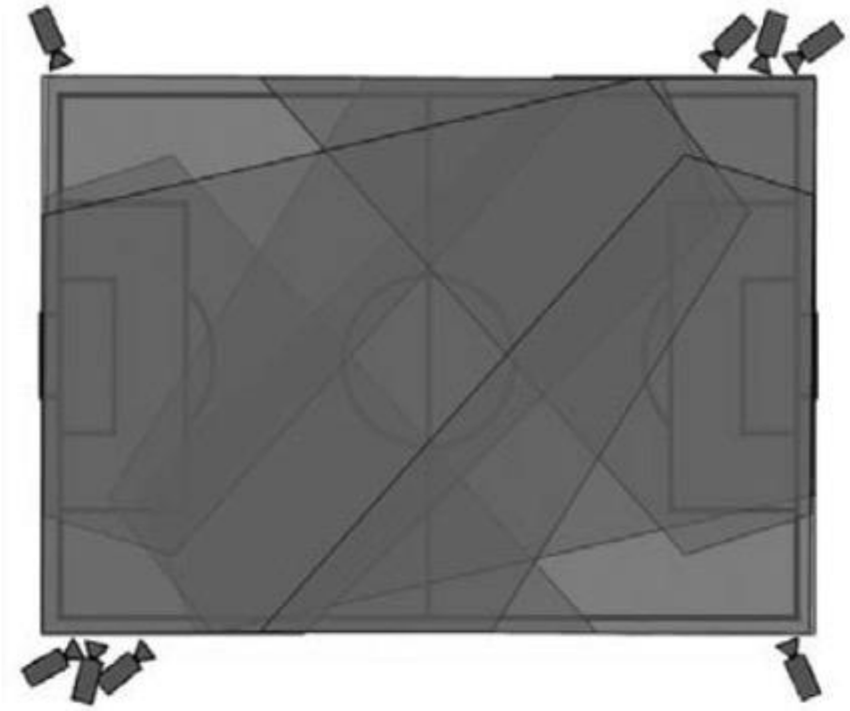


Figure 2.3. Schematic representation of PROZONE's camera placement and coverage.

Both the AMISCO and PROZONE® systems were suggested to provide accurate measures for average speed during straight line running and turning when validated using timing gates for comparison (r = 0.96-0.99) (119,120). However, these studies required participants to maintain a pre-determined constant speed during all straight line running courses, which is not typical among soccer-specific movements. Whilst these systems provide an intuitive and efficient solution to the tracking of player's movement and match activities without the requirement of wearing a device, these systems are expensive to install and their use appear to be limited to professional male football clubs. Despite being predominately automated in their tracking, these techniques still require some manual input from operators, particularly during instances in the game where a number of players may crowd together and cause occlusions (e.g. during corner kicks) (23).

Non-commercial vision-based motion-analysis systems have also been developed and used to quantify activity profiles of players. One such system, ASPOGAMO (Automated SPOrt Game Analysis MOdel), provides player positional information based on a live television broadcasting feed (15,16). ASPOGAMO detects and monitors the coordinates and trajectories of players based on views provided by the main overview cameras used in game broadcasts. The system processes the video-stream by initially predicting the camera parameters for the current frame, and then detects players by identifying "blobs" on the pitch that are not field green and meet pre-determined size constraints. Player positions are then calculated, reportedly within 50 cm, based on the known camera parameters and players are tracked by combining individual positions over time. Whilst the system can operate in real-time the process of player identification does involve a manual component. Furthermore, as the system relies on television broadcasting feed, the tracking process can be interrupted during close-ups and replays and can only provide positional information on players in camera view.

Speed Thresholds

Movement analyses of players during matches and training sessions are often summarised according to the intensity at which the movements are executed (9,10,54). Previously, common intensity categories have been described as standing, walking, jogging, running and sprinting, with a pre-defined speed range allocated to each (9,54,102). These intensity categories have further been grouped according to low, moderate and high-intensity movements. It has been suggested that distance run at velocities classified as "high-intensity" are the most valid measure of physical performance (79), as it has been shown that elite level players cover more distance in high-intensity running and sprinting than moderate level players (9,101). As such, in more recent studies distances covered in the higher speed thresholds have tended to be reported more than lower speed thresholds (26,131,134).

The common use of high-intensity running to quantify physical performance emphasises the importance of ensuring the operational definitions for Speed thresholds are accurate. A number of studies that have summarised match performance of players have not provided physiological justification for their use of intensity thresholds (9,54,79,101). The first study to suggest individualised speed thresholds for male soccer players used an incremental treadmill test to exhaustion to determine an appropriate high-speed running threshold (1). The running speed at which players reached the second ventilatory threshold ($VT_{2speed)}$ was considered the lower threshold for high-speed running. The mean VT_{2speed} was 15.3 $km{\cdot}h^{-1}$ and it was therefore recommended that 15 $km{\cdot}h^{-1}$ (4.16 $m{\cdot}s^{-1}$) can be used as an appropriate threshold for high-speed running. A similar study of elite female rugby sevens players (36) showed that players' VT_{2speed} was 3.5 $m·s^{-1}$ and is considerably lower than previously used thresholds for female soccer players.

Another novel study that aimed to develop and justify new operational definitions for field sport athletes investigated the speed distribution to generate speed ranges that could be adopted consistently by a number of different sports (46). Global positioning data were collected from five games each of men's and women's hockey (senior state league teams), men's (professional A-League team) and women's (a senior state league team) soccer, and Australian Rules Football (an AFL team). Five players from each sport were analysed, contributing to a total of 125 data sets (25 data sets each sport). Computer software (Fortran 90, IBM, Armonk, NY, USA) was used to determine the optimal fit for four Gaussian curves (normal distribution) to the averaged speed distribution for each sport. The points at which the curves intersected each other were used to determine the speed ranges for walking, jogging, running and sprinting. The subsequent recommended speed thresholds for high-speed running and sprinting in women's soccer were 3.4 $m·s^{-1}$ and 5.4 $m·s^{-1}$, respectively, which are similar to thresholds recommended for women's rugby sevens (36). It should be acknowledged that this study used 1Hz GPS which has been shown to be considerately less accurate than the newer 10Hz models (74). Based on the above evidence, it can be seen that informed consideration is required prior to choosing appropriate speed thresholds. The use of standardised thresholds can be used to compare and contrast results from other studies with more ease, however this method limits the specificity and individualisation of players that needs to be taken into account to obtain valid results. On the other hand, using individualised speed thresholds may be difficult in an elite sport setting as this method requires regular physical testing of athletes.

Interchangeability of using multiple systems

Motion-analysis systems are continually developing to ensure they meet the scientific criteria for quality control (23). The validity and reliability of systems need to be considered not only during the data collection and analysis of match activity, but also when interpreting results. Additionally, the level of interchangeability of using multiple systems must be taken into account. For example, until recently FIFA regulations did not permit the use of tracking devices in a number of competitions. Therefore it was common practice for professional sporting teams to use GPS devices during training sessions and video-based motion analysis systems (such as PROZONE® and AMISCO) during competitive games (59). However, if data is analysed collectively, this process can be problematic if both the level of agreement and bias between the systems are not considered when interpreting the results (23). A recent technical report showed that when used simultaneously in a match, GPS technology reported higher values for total distance covered than PROZONE®. Alternatively, PROZONE® reported higher sprinting and high-intensity running distance when compared with GPS (59). As such, the error of measurement of the systems needs to be taken into account and for quality control it is recommended different systems should not be used interchangeably without consideration.

2.7 Conclusion

This review discussed: 1) the physical and physiological characteristics of female soccer players, 2) the activity profiles and associated energy expenditure of female soccer matches and small-sided training games, and 3) the methods and systems used to measure soccer matches and training.

Elite female soccer players analysed in previous research have typically been described as 19.3-25.8 years of age, 1.67-1.70 m tall, weigh 62.9-65.0 kg and have 14.6-18.5 % body fat. Mean YYIR1 performance was observed to be 1,213-1,774 m while 20 m sprint performance and CMJ were reported to be 3.17 s and 29.8-31.6 cm, respectively. Maximal oxygen uptake was 49.4 – 55.4 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ and has been correlated with the amount of high-intensity running in matches.

Elite female soccer players tend to cover 8.9-11.3 km in total distance and 1.3-2.8 km at high-intensity, with variations between positions and levels of competition. The distance covered in female matches is well documented in the literature, however information related to acceleration and deceleration profiles have not yet been reported. Acceleration and deceleration are important attributes that contribute to soccer specific actions such as changes of direction and contesting for the ball over short distances. Further, to accelerate is more energetically demanding than constant speed running and studies that have not considered acceleration may be underestimating player load. Future research should aim to investigate the acceleration and deceleration profiles of female soccer players to provide a more comprehensive and accurate quantification of match activities.

Matches contribute ~20 % of total weekly load with the majority of load (~80 %) imposed on players during training sessions. Despite this, research has tended to focus on the activity profiles of matches, and there is a lack of emphasis on evidence-based training strategies among female soccer. Small-sided training games have been shown to be a useful conditioning stimulus and the physical, physiological and perceptual responses can be manipulated by changing the number of players and pitch size in male training sessions. Unfortunately, this is yet to be thoroughly investigated in female players and coaches are often structuring sessions based on anecdotal evidence or research using male players. One study of a national women's team showed that 3v3 and 5v5 small-sided games simulated the overall movement patterns of competitive matches, however they did not simulate the high-intensity and repeated sprint demands. Further research of small-sided training games in female soccer is required to optimise training strategies and subsequently enhance on-field performance.

Despite the vast research of match activity profiles, to date only one study has reported on the energy expenditure of female soccer players. Exercise energy expenditure was estimated to be 3,439kJ during preseason and was shown to decline during the regular season. Monitoring energy expenditure assists in maintaining energy balance and avoid low energy availability, which contributes to metabolic, reproductive, and bone related changes.

High-speed running has been shown to be a valid indicator of the level of physical performance and female players tend to cover ~15 % of their total distance in matches at high-speeds. However, the large variation found in absolute high-speed distances may partly be the result of a lack of consistency of allocated high-speed running thresholds between previous studies. Further, evidence suggests that high-speed running and sprinting thresholds used previously are too high for female players and the high-intensity work-load may be underestimated. Speed thresholds should be adjusted accordingly, and future research should arguably consider using individualised thresholds.

3.0 STUDY OUTLINE

Study 1: The aim of this study was to investigate the variation in training demands, physical performance and player wellbeing across the course of a female soccer season. Players wore GPS tracking devices during every training session of one national league season. At the transition of each training phase players completed sprint and intermittent high speed running tests. Body composition was determined at the start of preseason and the finish of the playing season. In addition, subjective wellbeing measures were self-reported daily by players over the course of the season. Results showed that 5 m sprint time was lowest following preseason, while 15 and 25 m sprint performance peaked at midseason. Sprint performance across all three distances declined from the middle to the end of the playing season. Training demands varied between phases with total distance and high-speed distance greatest during preseason before decreasing during the early and late season phases. Endurance capacity, wellbeing measures and body composition did not change across training phases.

Study 2: This study assessed the total and exercise energy expenditure of female soccer players during one training week. Players wore SenseWear Mini Armband (SWA) devices for seven consecutive days during the preseason phase of a national league competition. In addition, players wore GPS devices during four training sessions and a friendly game. Total and exercise energy expenditure as well as training and game demands were collected. Mean total energy expenditure was 12,242 kJ for the game day, 11,692 kJ for the training days and 9,516 kJ for the rest days. In addition, it was observed that exercise energy expenditure for the game and training sessions were 2,695 kJ and 2,538 kJ, respectively. As total and exercise energy expenditure differs throughout the week in female soccer players, nutritional intake should be adjusted accordingly to avoid energy imbalances for optimal performance and recovery.

Study 3: The purpose of this study was to investigate the physical and physiological response to different formats of small-sided games in training sessions. Players wore GPS devices and heart rate monitors during different formats (small, medium and large) of small-sided games. Information related to work-rate, heart rate and acceleration profiles were collected. Players covered more relative sprinting distance during large sized games when compared with small and medium games. Accordingly, there were increases in the mean and maximum distance of acceleration efforts as the training game size increased. In addition, a greater proportion of acceleration efforts that had a commencement speed <1 $m{\cdot}s^{-1}$ were shown in small games when compared to large games. This was accompanied by a greater proportion of acceleration efforts, with a final speed equivalent to the sprint threshold, in large games than small games. Percent time spent in heart rate zone > 85 % HR_{max} was greatest during small sized games compared to larger formats. The results from this study demonstrate that coaches can manipulate sprinting, heart rate and acceleration profiles by concurrently modifying the number of players and field dimensions in elite female soccer training games.

Study 4: This study assessed the accuracy and reliability of displacement estimates derived from a new Optical Player Tracking System. Participants completed a soccer-specific running protocol while being filmed by a multi-camera system. The participants x,y field positions were determined by the Optical Player Tracking System and displacement was estimated by applying Euclidean distance calculations and compared with actual distance. The difference between actual distance and estimated displacement was 1.39 % and strong correlations (r = 0.986 – 0.988) were observed. Collectively, the typical error (0.25 – 0.36), typical error as a coefficient of variation (1.06 – 1.75) and intraclass correlation coefficient (0.88 – 0.93) showed high levels of intra-operator reliability. The results from this study showed that the Optical Player Tracking system provides accurate and reliable estimates of displacement of players on a soccer field. This system provides the opportunity to collect activity data non-invasively on players during matches.

Study 5: This study determined the activity profiles of elite female players during competitive matches using a new Optical Player Tracking System. Eight high-definition video cameras were positioned at vantage points surrounding the soccer field so that when each camera view was combined the entire field could be viewed at once. Following each match the video footage was imported into an Optical Player Tracking System that detected the x,y coordinates of each player for every frame of video. Formulas applied to the Euclidean distance equation were used to determine activity variables for twelve elite female players across seven competitive matches. Players covered 9,220–10,581 m of total distance, 1,772–2,917 m of high-speed running distance and 417–850 m of sprinting distance, with variations between positional units. Similarly, the number of high-speed runs differed between positional units and a large proportion of both high-speed runs (81–84 %) and sprints (71–78 %) were performed over distances less than 10m. Mean time between high-speed runs (13.9 s ± 4.4) and sprints (86.5 s ± 38.0) varied according to playing position and time period of the match. The results of this study can be used to design match-specific conditioning drills, and also shows that coaches should take an individualised approach to training load monitoring according to positional unit.

Study 6: This study followed on from study 5 by determining the acceleration and deceleration profiles of elite female soccer players during competitive matches. Eight high-definition stationary video cameras were positioned at vantage points surrounding the soccer field so that when each camera view was combined the entire field could be viewed at once. Following each match the video footage was imported into an Optical Player Tracking System that detected the x,y coordinates of each player for every frame of video. Formulas applied to the Euclidean distance equation were used to determine acceleration (≥ 2 m·s^2) and deceleration (≤ -2 m·s^2) variables for twelve elite female players across seven competitive matches. In total, players performed 423 (± 126) accelerations and 430 (± 125) decelerations per match. It was shown that the number of accelerations and decelerations at different intensities (based on the start and final speed) varied according to positional unit. The mean and maximum distance per effort was 1-4 m and 2-8 m, respectively, and differed between each intensity category. The mean time between efforts was 14 s for both accelerations (± 5 s) and decelerations (± 4

s) and fluctuated between 15 minute time periods. The results of this study can be used to design match-specific acceleration and deceleration drills to enhance change of speed ability.

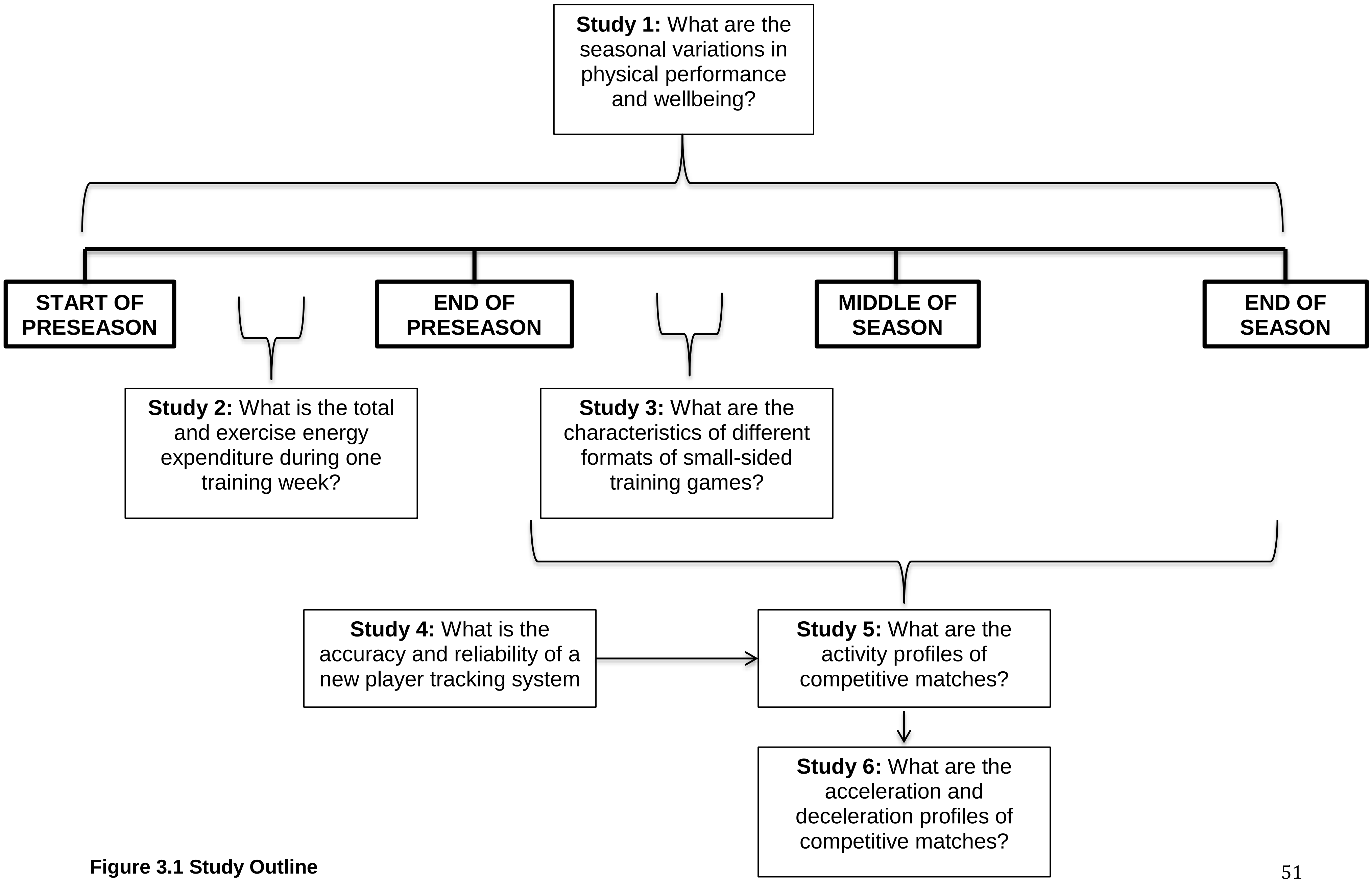


Figure 3.1 Study Outline

4.0 PERIODISATION AND PHYSICAL PERFORMANCE OF ELITE FEMALE SOCCER PLAYERS

4.i Form E: Declaration of co-authored publication chapter

Declaration by candidate

In the case of Chapter 4, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Study design, data collection and analysis, study write up	70 %

The following co-authors contributed to the work.

Name	Nature of contribution	Extent of contribution (%)	Contributor is also a student at UC Y/N
Kevin Thompson	Assistance with study design, proof reading and edits of draft	10	N
Kate Pumpa	Assistance with study design, proof reading and edits of draft	10	N
Nick Ball	Assistance with study design, proof reading and edits of draft	10	N

Candidate's Signature		Date
		19-10-15

Declaration by co-authors

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(4) there are no other authors of the publication according to these criteria;

(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	Research Institute for Sport and Exercise, University of Canberra

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

Signature 1		**Date** 19-10-2015
Signature 2		19-10-2015
Signature 3		19-10-2015

4.ii Preface

Chapter 4 discusses the first of six studies conducted to describe the physical and physiological characteristics of elite female soccer players. This chapter commences this research by first describing the variations in training demands, physical performance and player wellbeing across the course of one playing season. This study was published in the International Journal of Sports Physiology and Performance (Mara JK, Thompson KG, Pumpa KL, Ball NB, Periodisation and physical performance in elite female soccer players. International Journal of Sports Physiology and Performance, 2015, 10(5): 664-669).

4.1 ABSTRACT

Purpose: To investigate the variation in training demands, physical performance and player wellbeing across a female soccer season.

Methods: Seventeen elite female players wore GPS tracking devices during every training session (n = 90) throughout one national league season. Intermittent high-speed running capacity, 5, 15 and 25 m sprint testing were conducted at the beginning of preseason, end of preseason, midseason and end of season. In addition, subjective wellbeing measures were self-reported daily by players over the course of the season.

Results: Time over 5 m was lowest at the end of preseason (*mean* = 1.148 s, *SE* = 0.017 s), but then progressively deteriorated to the end of the season ($p < 0.001$). Sprint performance over 15 m improved by 2.8 % ($p = 0.013$) following preseason training; while 25 m sprint performance peaked at midseason, with a 3.1 % ($p = 0.05$) improvement from the start of preseason, before declining at the end of season ($p = 0.023$). Training demands varied between phases with total distance and high-speed distance greatest during preseason before decreasing ($p < 0.001$) during the early and late season phases. Endurance capacity and wellbeing measures did not change across training phases.

Conclusions: Monitoring training demands and subsequent physical performance in elite female soccer players allows coaches to ensure training periodisation goals are being met, and related positive training adaptations are being elicited.

4.2 INTRODUCTION

Periodisation is the systematic planning and variation of training demands, with the aim of optimising physical condition and minimising injury (52). A typical periodisation plan involves phases or cycles of varying training demands and goals (power, endurance) programmed across pre-season, early competition, late competition and transition phases. A purposeful change in training volume and intensity between training phases subsequently alters the physical condition of players, warranting the need for regular monitoring of both external (training prescribed by coaches) and internal (the physiological response elicited by training) training loads (136). The concept of periodising training into phases is widely accepted and implemented within elite female soccer, despite a lack of scientific evidence to support its application.

Training demands can be quantified objectively by player tracking systems (such as global and local positioning devices) and heart rate monitors, and subjectively through self-report scales such as rating of perceived exertion (RPE) and muscle soreness (103). Tracking devices provide comprehensive information related to physical performance such as distances covered, velocities, accelerations and decelerations. Coupled with match data, inferences can be made regarding the relative physical demand of training sessions, whether training stimulus targets were achieved and to avoid overtraining. In addition to objective measures of training demands, subjective questionnaires that encompass perceived muscle soreness, fatigue and sleep patterns are economical methods to monitor player wellbeing and thus provide a holistic approach to elite athlete monitoring (103).

Testing protocols have been designed to mimic and monitor the specific movements and qualities that are related to high performance in soccer games, such as acceleration, maximal speed and repeated high-speed running ability. Acceleration and maximal speed are considered independent characteristics of sprint performance in both male (86) and female (132) soccer players. As such, typical testing protocols include sprint tests of varying distance (e.g. 5 m and 20 m) to adequately measure both qualities (135), as well as to represent the typical distances of sprints observed in elite women's soccer matches (7). High-speed running performance, and more notably, the ability to recover from high-speed running bouts, are considered to be the most distinguishable physical characteristic between playing levels, and are directly related to training status (79,102). The Yo-Yo Intermittent Recovery (YYIR) tests (Level 1 and level 2) are commonly used in elite soccer to assess players' ability to repeat bouts of intense exercise. The distance achieved by players in the YYIR2 has been shown to reflect the amount of running performed during the peak five-minute period in elite men's matches (80).

The use of field tests to determine match-specific capabilities provide a practical alternative for laboratory tests and can be easily implemented within the training environment. It is commonplace for elite teams to undergo baseline testing at the beginning and end of preseason and then on a number of occasions during the season to determine if a high physical level is being maintained (76). Research that has investigated the seasonal variation in physical performance measures of elite and semi-elite male players have shown improvements in maximal aerobic capacity, multi-stage fitness test performance (MSFT), and sprint performance from the beginning of pre-season to mid-season (22,76,107). Following mid-season, MSFT performance tends to decline (22), while $\dot{V}O_{2max}$ and sprint have remained stable to the end of the season (22,76). On the other hand, acceleration and sprint characteristics in youth female players have been shown to decline across the course of the season (125). From these studies it would appear that there could be sex differences in seasonal variations for sprint performance, which highlights the need for sex-specific research.

Despite investigations into the seasonal changes in physical measures, changes in physical performance and wellbeing that occur from purposeful variation in training demands have yet to be thoroughly explored, particularly in female players across an entire season. As such, the main aim of the current study was to investigate the variation in training demands, physical performance and player wellbeing according to training phase in female soccer players. A secondary aim of this study was to examine the relationships between training demands, physical performance and player wellbeing.

4.3 METHODS

Subjects

Seventeen elite female soccer players (mean height = 172.9 cm ± 5.5 cm, mean body mass = 64.3 kg ± 5.9 kg) from the same national league team participated in this study. Goalkeepers were excluded from this study. Prior to commencing the study, institutional ethical approval was granted and subjects were thoroughly informed of the procedures of the study by verbal and written communication. All players that participated in the study provided written informed consent.

Methodology

This study was an observational study. Training periodisation was implemented by the club's coaching staff and the training season was divided into three training phases consisting six weeks each of pre-season, early season and late season (figure 4.1). Testing sessions occurred at the transition of each training phase:

1. At the start of pre-season training (START-PRE)
2. At the end of pre-season training and at the start of the competition (END-PRE)
3. At the midpoint of the season (MS)
4. At the end of the season (ES)

During the competition phases, fitness testing sessions were performed no sooner than 72 hours post-match to allow for adequate recovery from neuromuscular fatigue (8).

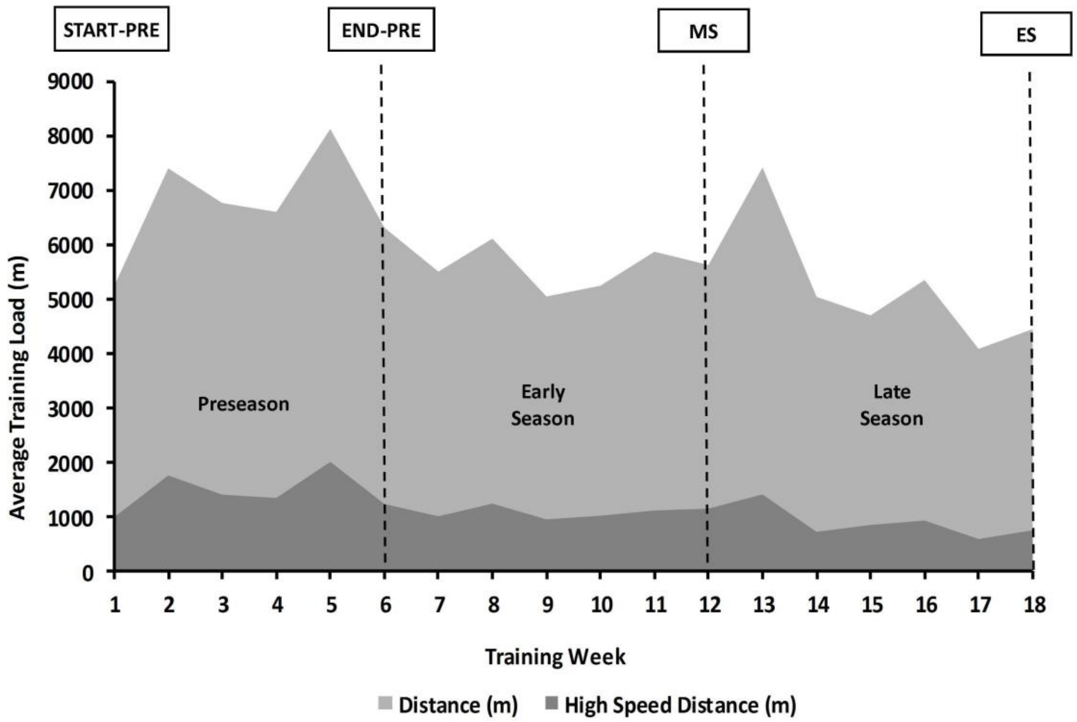


Figure 4.1: Training demands, periodisation and physical testing structure. *Note: Distance and high-speed distance are represented as mean training values per session for each week.*

Body Composition

Body composition testing was conducted at START-PRE and ES and was determined by a Dual X-Ray Absorptiometry (DXA) scan (2). All DXA scans were conducted in the morning between 7am and 9am, and participants were instructed not to eat or drink prior to being scanned. Total body mass, percent body fat, and percent lean muscle were collected.

Yo-Yo Intermittent Recovery Test

The YYIR2 is an intermittent running test, consisting 2x20 m shuttle runs separated by a 10 second active recovery interval. The test begins at an average running speed of 13 km·h^{-1} and progressively increases in speed until participants fail to reach the line by the required audio bleep (73).

Participants’ scores were recorded as the equivalent distance achieved, excluding the active recovery phase. To analyse the variation in YYIR2 performance throughout the season, participants were grouped into “high” and “low” YYIR2 scores by a median split of the equivalent distance achieved at START-PRE. The validity and reliability of the YYIR2 for measuring the intermittent high-speed running capacity of soccer players has been reported elsewhere (12,73).

Acceleration and Sprint Testing

Acceleration and sprint speed were assessed by individual 5 m, 15 m and 25 m sprint tests using electronic timing gates (Smartspeed, Fusion Sport, Cardiff, UK) accurate to 0.01 seconds. Participants were instructed to begin the sprint from a stand-still position half a meter behind the first timing gate to ensure the timing gate beam was not broken prematurely (22). Participants completed the test twice each, with adequate active recovery (approximately 5 minutes) between repetitions. The participants’ fastest times were included in the data analysis.

Player Wellbeing Questionnaire

Participants were asked to electronically record subjective scores related to their current wellbeing each morning during preseason, early season and late season using a cloud-based spreadsheet interface (Google Drive, Google, California, USA). Participants recorded perceived muscle soreness and fatigue on a scale of 1-10 adapted from the Borg CR-10, where 1 equals minimal muscle soreness and fatigue and 10 equals maximum muscle soreness and fatigue (103). The Borg CR-10 has been shown to be a valid method for the subjective assessment of muscle soreness and fatigue (40). Participants also recorded the number of hours they had slept the previous night.

Training Demands

Participants wore 15Hz global positioning devices (SPI HPU, GPSports Systems, Canberra, Australia) during all (n = 90) training sessions across the course of the season. Total distance (m), high-speed distance (> 3.4 $m \cdot s^{-1}$) (HSD) sprinting (> 5.4 $m \cdot s^{-1}$) high-intensity acceleration (> 2 $m \cdot s^{-2}$) and deceleration (< -2 $m \cdot s^{-2}$) counts were collected for all training sessions and were compared based on training phase (preseason, early season and late season). Speed thresholds were chosen based on recommendations for determining high-speed running thresholds in female soccer players (46) and were similar to recently used thresholds in previous research (97).

Match and Training Schedule

The team played a total of five friendly matches during the pre-season phase and 11 matches (10 round games and a semi-final game) in the competitive season. A typical weekly in-season training structure consisted of one game, followed by two recovery days, one conditioning, one skill and two tactical sessions.

Statistical Analysis

Statistical analysis was conducted using SPSS version 21.0 (SPSS Inc, Chicago, IL). A paired-samples t-test was used to determine any changes in body composition from START-PRE to ES. Repeated measures analysis of variance (ANOVA) tests were conducted to determine the variation in YYIR2 and sprint performance across the course of the season. A one-way ANOVA examined the differences in training variables between training phases. Where appropriate, Bonferroni post-hoc analyses were conducted to examine pairwise comparisons. Friedman's test assessed the difference in self-report wellbeing scores between training phases. Pearson's r and spearman's rho correlations were used to determine the relationship between training demands, player wellbeing and physical performance tests. In addition to acquiring statistical significance ($p < 0.05$), Cohen's d and r (small = 0.2; medium = 0.5, large = 0.8) effect size and partial eta-squared (η^2) (small = 0.01; medium = 0.06; large = 0.14) statistics were also used to measure the magnitude of difference (117).

4.3 RESULTS

Body Composition

Mean total body mass was 64.38 kg (*SD* = 5.94) at START-PRE and 65.16 kg (*SD* = 6.79) at ES (p = 0.432, d = 0.12). Percent body fat was 21.45 % (*SD* = 6.03) at START-PRE and 22.36 % (*SD* = 6.37) at ES (p = 0.300, d = 0.15), while percent lean muscle was 73.77 % (*SD* = 6.17) at START-PRE and 72.82 % (*SD* = 6.52, d = 0.15) at ES.

Yo-Yo Intermittent Recovery Test

The mean distance achieved during the YYIR2 was 425 m (*SD* = 122) at START-PRE, 400 m (*SD* = 95) at END-PRE, 420 m (*SD* = 122) at MS, and 450 m (*SD* = 118) at ES. However, there were no differences shown in YYIR2 performance between training phases (p = 0.195, partial η^2 = 0.197). The mean distance achieved by “high” YYIR2 performers was 600m (*SD* = 57m), 520 m (*SD* = 11), 580 m (*SD* = 85) and 560 m (*SD* = 57) for START-PRE, END-PRE, MS and ES, respectively. In addition, “low” YYIR2 performers achieved 392 m (*SD* = 18), 384 m (*SD* = 46), 392 m (*SD* = 52) and 440 m (*SD* = 102) for the respective training phases. There were no differences in YYIR2 performance between training phases for the “high” YYIR2 performers (p = 0.314, partial η^2 = 0.648) or “low” YYIR2 performers (p = 0.313, partial η^2 = 0.248).

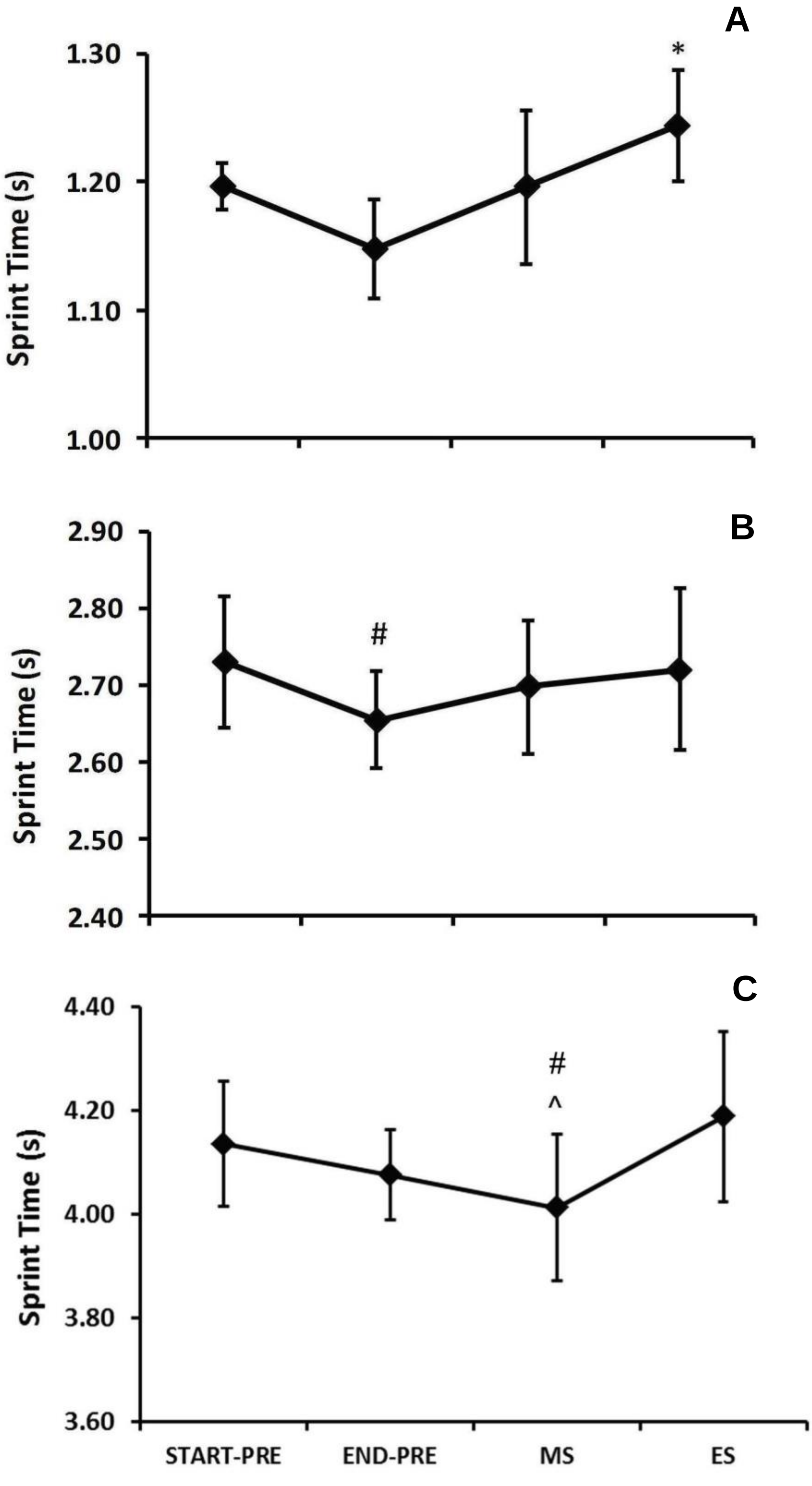


Figure 4.2: Sprint performance over a) 5 m; b) 15 m and c) 25 m. *Note: * Difference ($p < 0.05$) compared with END-PRE; # Difference ($p < 0.05$) compared to START-PRE; ^ Difference ($p < 0.05$) compared to ES*

Acceleration and Sprint Performance

There were differences in 5 m ($p = 0.001$, partial $\eta^2 = 0.711$), 15 m ($p = 0.002$, partial $\eta^2 = 0.700$) and 25 m ($p < 0.001$, partial $\eta^2 = 0.775$) sprint performance between training phases (Figures 4.2 a - 4.2 c).

Player Wellbeing

There were no differences ($p > 0.05$, $d = 0.00 – 0.14$) in mean hours of sleep between preseason (*mean* = 7.8, *SD* = 0.8), early season (*mean* = 7.8, *SD* = 0.5) and late season (*mean* = 7.7, *SD* = 0.6). Median fatigue scores were reported to be 3.5, 3.1 and 3.2 for preseason, early season and late season, respectively ($p = 0.056$, $r = 0.36$ - 0.56). Similarly, median muscle soreness scores were reported to be 3.8, 3.3 and 3.5 for the respective training phases ($p = 0.269$. $r = 0.31 – 0.41$).

Training Demands

The mean distance covered during training sessions were 6,646 m (*SD* = 111) during preseason, 5,437 m (*SD* = 106) during early season and 4604 m (*SD* = 110) during late season ($p < 0.001$, partial $\eta^2 = 0.38$). In addition, the mean high-speed running distance was 1,415 m (*SD* = 42) during preseason, 1,027 m (*SD*= 40) during early season and 742 m (*SD* = 41) during late season ($p < 0.001$, partial $\eta^2 = 0.32$). Similarly, there was a decline in sprint, acceleration and deceleration counts between training phases. It was observed that mean sprint counts during training sessions were 27 (*SD* = 15) for preseason, 24 (*SD* = 9) for early season and 15 (*SD* = 9) for late season. Acceleration counts were 56 (*SD* = 19) for preseason, 49 (*SD* = 14) for early season and 32 (*SD* = 18) for late season. Deceleration counts were 22 (*SD* = 10) during preseason, 20 (*SD* = 10) during early season and 12 (*SD* = 9) during late season. A multivariate ANOVA with Bonferroni post-hoc analyses showed differences in all counts ($p < 0.001$) between all phases, with the exception of sprint and deceleration counts between preseason and early season.

Relationship between Training Demands, Wellbeing and Physical Performance

Pearson's r correlations showed relationships between training variables and YYIR2 performance during the preseason and early season phases, but not the late season phase. YYIR2 performance at START-PRE was shown to have relationships with total distance ($r = 0.599$, $p = 0.03$) high-speed distance ($r = 0.708$, $p = 0.01$) and acceleration count ($r = 0.554$, $p = 0.05$) during training sessions in preseason. In addition, Spearman's rho tests revealed negative correlations between total distance covered in training and muscle soreness in the early season phase ($r = -0.571$, $p = 0.041$) and high speed distance covered in training and muscle soreness in the late season phase ($r = -0.577$, $p = 0.039$). However, there were no correlations between training and wellbeing variables in the preseason phase, or wellbeing and physical testing variables across the season.

4.4 DISCUSSION

This is the first study to examine the seasonal variations in physical performance, body composition and player wellbeing with respect to training demands. The main findings were: 1) Total distance, high-speed distance and acceleration counts during training sessions declined across all phases from preseason to late season, 2) 5 m acceleration peaked following preseason and then declined at the end of season, 15 m sprint performance improved from the start to the end of preseason and then remained stable throughout the season, and 25 m sprint performance improved from the start of preseason to midseason and then declined at the end of season, and 3) YYIR2 performance and player wellbeing remained stable across the course of the season. The secondary aim of this study was to examine the relationship between training demands, physical performance and player wellbeing. It was found that players that performed better in the YYIR2 at the start of preseason also covered greater total distances, high-speed distances and performed more acceleration counts during preseason.

Training demands fluctuated between preseason and early season, with observed declines in all training variables following preseason. These findings were expected as a traditional preseason phase aims to improve the physical condition of players following the transition period (i.e. the off-season) in which a detraining effect commonly occurs (22). Decreasing the training demands during the season can be explained by the increase in competitive match-play, and thus, an attempt by the coach to taper players in the training sessions preceding a match and provide adequate recovery in the days following. It can also be suggested that travelling for away games may have interfered with the regular training schedule, and may have also influenced the training demands during the early and late season phases.

Both 5 m and 15 m sprint performance peaked following the preseason training phase, with improvements identified between the start and end of preseason for 15 m. These results are in line with previous findings (22) however unlike the current study, 15 m sprint performance has been shown to improve until the middle of season, whilst the present findings showed decrements in 5 m and 15 m performance following preseason. Despite this, 25 m sprint performance improved and peaked during the middle of season and the greatest decrements were shown at the end of season. This finding was in line with previous results in youth (under 13 and under 15 years) female soccer players (125). The varying degrees of improvement between the shorter (5 m and 15 m) and longer distance sprint tests (25 m) support the concept that acceleration and maximum speed are specific characteristics, and are relatively unrelated (86). In light of this, acceleration and maximum speed should be trained and tested accordingly.

In the current study YYIR2 performance did not improve following preseason training, which is in contrast to previous research reporting increases in male soccer players following preseason training before stabilising during the season phases (12). However, the seasonal changes in YYIR2 performance have not been previously established in female soccer players and as such comparisons are difficult to draw upon. One study has found that following the preseason training phase Yo-Yo Intermittent Endurance (YYIE2) test performance improved in elite female soccer players (19). Similarly, in elite male players multi-stage fitness test performance (22), YYIR1 performance (12) and $\dot{V}O_2$ max (76) have been shown to improve following preseason. However, it should be noted that the YYIE2 and YYIR1 tests begin at a lower intensity than the YYIR2 and the incremental progression in running intensity is different between tests. As such, this may be a potential reason for the conflicting findings between previous literature and the current findings. Future research should examine the training stimulus through heart rate measures to more thoroughly examine the cardiovascular demands experienced by players and the impact on performance outcomes. In addition, while 72 hours was allowed between a training session or game and a testing session, future research should also consider the optimal time to implement a testing session to ensure full recovery and training adaptations to occur.

Body composition (total body mass, percent body fat and percent lean muscle) did not change from the start of preseason to the end of the season. This finding is in contrast to a number of observations made by previous researchers in elite male soccer players which percent body fat decreased from the beginning to the end of the training season (22,58,76,107). However, there are no previously reported information regarding the seasonal changes in body composition using DXA scans in female soccer players. Future research in this area is warranted to determine any sex-specific differences in the way body composition changes as a result of a soccer season.

Subjective player wellbeing scores remained steady throughout the season, with the exception of a trend ($p = 0.056$, $r = 0.56$) showing that fatigue scores decreased from preseason to early season. A negative moderate relationship was found between total distance covered in training and muscle soreness during the early season phase and between high-speed distance and muscle soreness during the late season phase. These findings indicated that higher muscle soreness values were associated with lower total distance covered at training sessions earlier in the season, and as players were exposed to prolonged levels of muscle soreness, decrements were shown more so in high-speed distance.

4.5 CONCLUSIONS AND PRACTICAL APPLICATIONS

The physical demands of training sessions declined from preseason to the early competition phase. This coincided with a decrease in acceleration and sprint performance suggesting a decrease in power output throughout the season which has been shown previously. There was a lack of improvement in YYIR2 performance between the preseason and early season phase, which may indicate training was not providing the desired training stimulus, and modifying the preseason conditioning plan may be warranted. It is exceedingly important for coaches to approach athlete monitoring holistically, as these results demonstrate that declines in training demands following preseason are not always accompanied by a decrease in muscle soreness and fatigue levels in players. Monitoring training demands and subsequent physical performance in elite female soccer players allow coaches to ensure training periodisation goals are being met, and related positive training adaptations are being elicited.

5.0 ASSESSING THE ENERGY EXPENDITURE OF ELITE FEMALE SOCCER PLAYERS

5.i Form E: Declaration of co-authored publication chapter

Declaration for Thesis Chapter 5

Declaration by candidate

In the case of Chapter 5, the nature and extent of my contribution to the work was the following:

Nature of contribution	**Extent of contribution (%)**
Study design, data collection and analysis, study write up.	80%

The following co-authors contributed to the work.

Name	**Nature of contribution**	**Extent of contribution (%)**	**Contributor is also a student at UC Y/N**
Kevin Thompson	Assistance with study design, proof reading and editing of drafts.	10%	N
Kate Pumpa	Assistance with study design, proof reading and editing of drafts.	10%	N

Candidate's Signature		**Date** 19-10-15

Declaration by co-authors

The undersigned hereby certify that:

(7) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(8) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;

(9) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;

(10) there are no other authors of the publication according to these criteria;

(11) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and

(12) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	**Research Institute for Sport and Exercise, University of Canberra**

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

Signature 1		**Date** 19-10-15
Signature 2		19-10-15

5.ii Preface

The previous chapter discussed the variation in training demands, physical performance and player wellbeing across the course of one national league season. This chapter will describe the energetic demand associated with training in an elite female soccer team in one training week of preseason. This study was published in the Journal of Strength and Conditioning Research (Mara JK, Thompson KG, Pumpa KL. Assessing the energy expenditure of elite female soccer players: A preliminary study. Journal of Strength and Conditioning Research, 2015, 29(10): 2780-2786).

5.1 ABSTRACT

Purpose: To assess the total and exercise energy expenditure of elite female soccer players during a training week.

Methods: Eight elite female soccer players wore SenseWear Mini Armbands (SWA) for seven consecutive days during the preseason phase of a national league competition. In addition, players wore 15Hz GPSports tracking devices during four training sessions and a friendly game. Total energy expenditure, exercise energy expenditure and training and game demands were collected from the SWA and GPSports devices.

Results: Mean daily energy expenditure for the game day, training days and rest days were 12,242 kJ (*SD* = 603 kJ), 11,692 kJ (*SD* = 274 kJ) and 9,516 kJ (*SD* = 369 kJ), respectively**,** with significant differences shown between activities ($p < 0.001$, partial $\eta^2 = 0.357$), as well as between individual days ($p < 0.001$, partial $\eta^2 = 0.517$). Mean values for energy expenditure during the friendly game (*mean* = 2,695 kJ, *SD* = 301 kJ) and training sessions (*mean* = 2,538 kJ, *SD* = 316 kJ) were similar ($p = 0.278$, Cohen's $d = 0.5$). However, there were significant differences found between individual training sessions (p = 0.001-0.035).

Conclusion: Total and exercise energy expenditure differs throughout the week in female soccer players. Nutritional intake should be adjusted accordingly to avoid energy imbalances for optimal performance and recovery.

5.2 INTRODUCTION

It is typical for elite female soccer players to cover distances of 8-12 km interspersed with high-speed running efforts often totaling up to 1.7 km during a game (9,79). Sprinting actions are performed intermittently in bouts of 15 m, lasting 2.3 s with 2.5 minutes between each (134). In addition, it is common for female soccer players in an elite training environment to undergo several training sessions per week, covering distances of 6-7 km per session with high-speed distances matching those in games (unpublished findings). Analysing the movement patterns of competitive games and training sessions has provided valuable information for coaches to prescribe soccer-specific conditioning programs to maximise training and on-field performance. However, the related energetic cost of performing the movements required of elite female soccer players has not been well established in scientific literature.

It has been shown using the doubly labeled water (DLW) method that professional male soccer players can expend 14,834 kJ (± 1,714 kJ) per day, significantly more than their reported daily energy intake (13,074 kJ ± 2,440 kJ) (47). However, as the DLW method does not provide information on specific non-exercise activity thermogenesis and exercise energy expenditure (130) the energy expended during soccer matches and training was not determined. In another study, it was suggested that male elite soccer players expend up to 6,300kJ in a competitive match (14). However, over the last 20 years there has been a dearth of research in this area despite the scientific study of the game evolving. In addition to this, the DLW method is not suitable for continuous recordings or feasible during competitive matches.

In female players, it has been shown that training and game energy expenditure, measured by the equation suggested by Heyward (2010) (63) (EE = duration x [(MET's x 3.5 x weight) / 200)]) decreased over the course of a playing season. Exercise energy expenditure was reported to be 3,439 kJ (± 239), 2,696 kJ (± 109) and 668 kJ (± 117) during preseason, mid-season and post-season training sessions, respectively (114). Similar to the aforementioned study, it was also shown that energy expenditure was in excess of energy intake, increasing the risk of low energy availability and subsequent metabolic, reproductive and bone related changes, collectively referred to as the Female Athlete Triad (71,89). On the other hand, it has also been shown that lower percent body fat is related to better sprint performance (22,106) and therefore an excessively positive energy balance leading to increases in fat mass can also be detrimental to high-speed performance. This highlights the importance of players maintaining an energy balance that matches the energetic cost of training and games.

More recently, accelerometry-based monitors have become widely used for assessing resting and exercise energy expenditure. The SWA (SWA, BodyMedia, Pittsburgh, PA) combines tri-axial accelerometry with heat-related sensors that monitor galvanic skin response, heat flux, skin and near-body temperature (44), to accurately measure energy expenditure at rest (92) and during low to moderate intensity exercise (123). GPS tracking devices have recently integrated energy expenditure measures, calculated by algorithms incorporating a player's running speed, accelerations and decelerations (106). In an elite soccer environment, it is more common for teams to have access to GPS or other tracking devices more-so than energy expenditure monitors such as SWA. Therefore, the integration of energy expenditure measurements in GPS devices may be a useful tool if they are found to measure energy expenditure comparable to the SWA. However, to date there have been no comparisons made between measurements acquired from the SWA and GPS devices. Using accelerometry-based devices to monitor energy expenditure during rest and activity is a practical and non-invasive method, allowing the collection of data without causing discomfort for players. Quantifying the energy expenditure of players during training sessions and games will enable guidance to be made to ensure nutritional intake matches energy expenditure. This will assist players avoid low or excessive energy availability and subsequent metabolic, reproductive and bone-related changes. As such, maintaining a nutritional balance will promote optimal performance and recovery.

Therefore, the primary aim of this study was to assess the total and exercise energy expenditure of elite female soccer players during a training week. A secondary aim was to compare energy expenditure measured by the SenseWear Professional 8.0 to SenseWear Professional 7.0 and GPSports metabolic calculations.

5.3 METHODS

Subjects

Eight elite female soccer players of Caucasian ethnicity from the same national league team participated in the study. Only field players (two attackers, four defenders and two midfielders) were included in this study. Only eight players were selected to participate in this study due to SWA availability. Participants were selected after the team coaching staff indicated that these players would complete the entire friendly match and would not be substituted which allowed for a greater sample of data to be collected. Participant body composition as measured by Dual X-Ray Absorptiometry (DXA) scan according to methods previously described elsewhere (2) are displayed in table 5.1. Prior to the data collection week, institutional ethical approval was granted and subjects were thoroughly informed of the procedures of the study by verbal and written communication. All players that participated in the study provided written informed consent.

Table 5.1. Participant Anthropometric Characteristics

	Mean	***SD***
Height (cm)	172.9	5.5
Body Mass (kg)	65.1	5.9
Fat %	23.2	6.2
Fat Mass (kg)	14.5	4.7
Lean Mass (kg)	47.2	3.5
Fat Free Mass (kg)	50.3	3.7

Procedures

SenseWear Mini Armbands

Players (*n* = 8) wore SWA according to manufacturers' instructions on the left triceps muscles, for seven consecutive days during the preseason training phase. The data collection week consisted of training sessions (*n* = 4), a friendly game (*n* = 1) and recovery days (*n* = 2). Players were instructed to wear the armbands at all times, with the exception of instances when the armband could be at risk of submersion in water (i.e. in the shower or swimming). On average, players wore the armband for 97.3 % (± 0.6) of total time during the training week, allowing for an accurate measurement of daily energy expenditure. The SWA proprietary software (SenseWear Professional 8.0, BodyMedia, Pittsburgh, USA) was used and calculated energy expenditure based on a proprietary algorithm that incorporates subject information entered prior to data collection (height, weight, age and gender) as well as measurements collected by the armband (accelerometry, galvanic skin response, heat flux, skin and near-body temperature) (44). Information regarding total energy expenditure, exercise energy expenditure at various MET's and time spent lying down and sleeping were collected. The validity of the SWA for determining energy expenditure during physical activity has been reported elsewhere (44,92,123,137). In addition to SenseWear Professional 8.0 ($SWA_{8.0}$), the previous software version (SenseWear Professional 7.0) ($SWA_{7.0}$) was also used to compare measurements.

GPS Devices

In addition to the SWA, players (*n* = 8) wore 15Hz Global Positioning System (GPS) devices (SPI HPU, GPSports Systems, Canberra, Australia) during the friendly game and training sessions to quantify player movements. GPS devices were turned on 15 minutes before each session and were laid outdoors to ensure satellite connectivity. An atomic clock (Emerald Timestamp, Sequoia) was used to determine the start and end time of each session to accurately delineate the data (within .01 second). Total distance, high-speed distance (3.4-5.3 $m \cdot s^{-1}$) (HSD), sprint distance (>5.4 $m \cdot s^{-1}$), acceleration (> 2 $m \cdot s^{-2}$) and deceleration (< -2 $m \cdot s^{-2}$) counts were collected to quantify the physical demands of training sessions and the friendly game. Speed thresholds were chosen as they have been previously recommended for female soccer players (46). In addition, energy expenditure was derived from manufacturer software (Team AMS, GPSports Systems, Canberra, Australia) and was used to compare to $SWA_{8.0}$ and $SWA_{7.0}$ measurements.

Week Training Schedule

The week training schedule is outlined in table 5.2. The friendly game consisted 3x20 minute thirds against an under 16's boys club team, that compete in the state premier league. The friendly game commenced at 10am and all training sessions were conducted between 5.30 – 7.10pm. Players were instructed by the coach not to undergo intense physical activity during rest days to allow for adequate recovery.

Table 5.2: Preseason Weekly Training Schedule

Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
Game	*Rest Day*	*Training*	*Training*	*Rest Day*	*Training*	*Training*
3x20min Thirds		Warm Up Passing 6x2min 4v4 Cool Down	Warm Up Sprinting 4x6min 5v5 Cool Down		Warm Up 14min 4v4 2x14min 7v7 Cool Down	Warm Up Shooting 2x8min 7v7 Cool Down

Statistical Analyses

Statistical analysis was conducted using SPSS version 21.0 (SPSS Inc, Chicago, IL). A one-way analysis of variance (ANOVA) with Bonferroni post-hoc analysis was used to determine mean differences in daily energy expenditure between game, training and rest days. A repeated-measures ANOVA was used to determine differences in energy expenditure between individual days and training sessions. In addition to acquiring statistical significance ($p < 0.05$), Cohen's *d* (38) effect size (0.2 = small; 0.5 = moderate; 0.8 = large) and partial eta-squared (η^2) statistics were also used to measure the magnitude of difference (117).

5.4 RESULTS

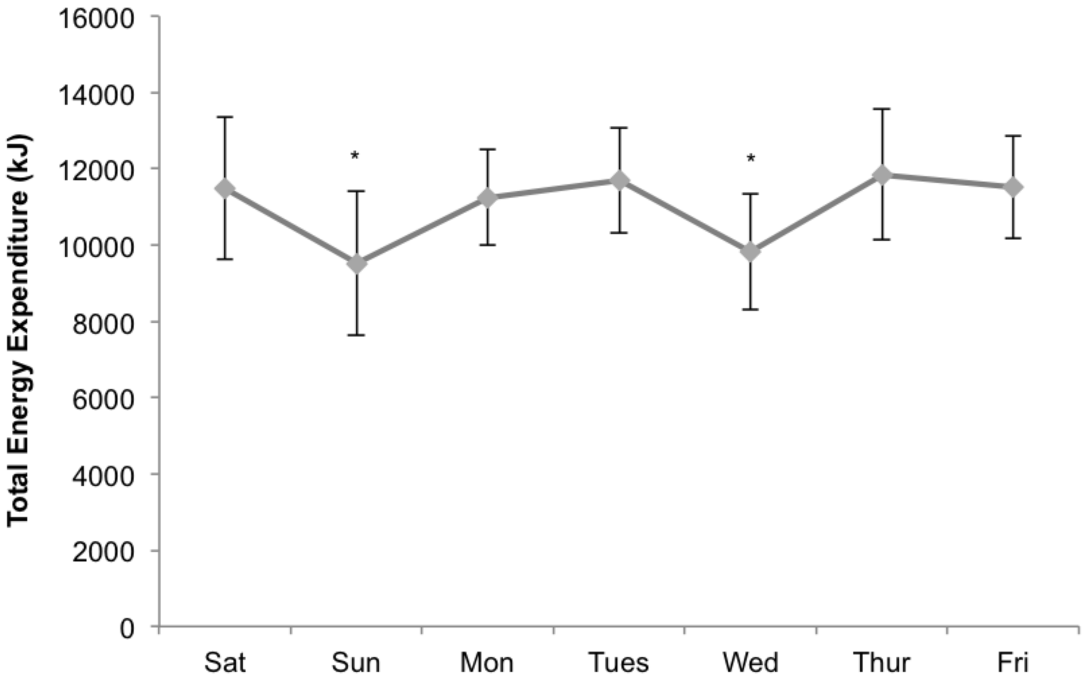


Figure 5.1: Mean Total Energy Expenditure For One Training Week During Preseason. *Note: * Indicates rest days.*

Total Energy Expenditure

Mean total energy expenditure for the game day, training days and rest days were 12,242kJ (*SD* = 603kJ), 11,692kJ (*SD* = 274kJ) and 9,516kJ (*SD* = 369kJ), respectively. A one-way ANOVA determined there was a significant difference in daily energy expenditure between activity codes ($p < 0.001$, partial $\eta^2 = 0.357$). Specifically, Bonferroni post-hoc analysis revealed differences in total energy expenditure between game day and rest days ($p = 0.001$), and training days and rest days ($p < 0.001$), but not game and training days ($p = 1.00$). In addition, a repeated-measures ANOVA showed that there were ($p < 0.001$, partial $\eta^2 = 0.517$) differences in daily energy expenditure between individual days of the week (figure 5.1). Figure 5.2 depicts total energy expenditure for individual players with reference to their playing position.

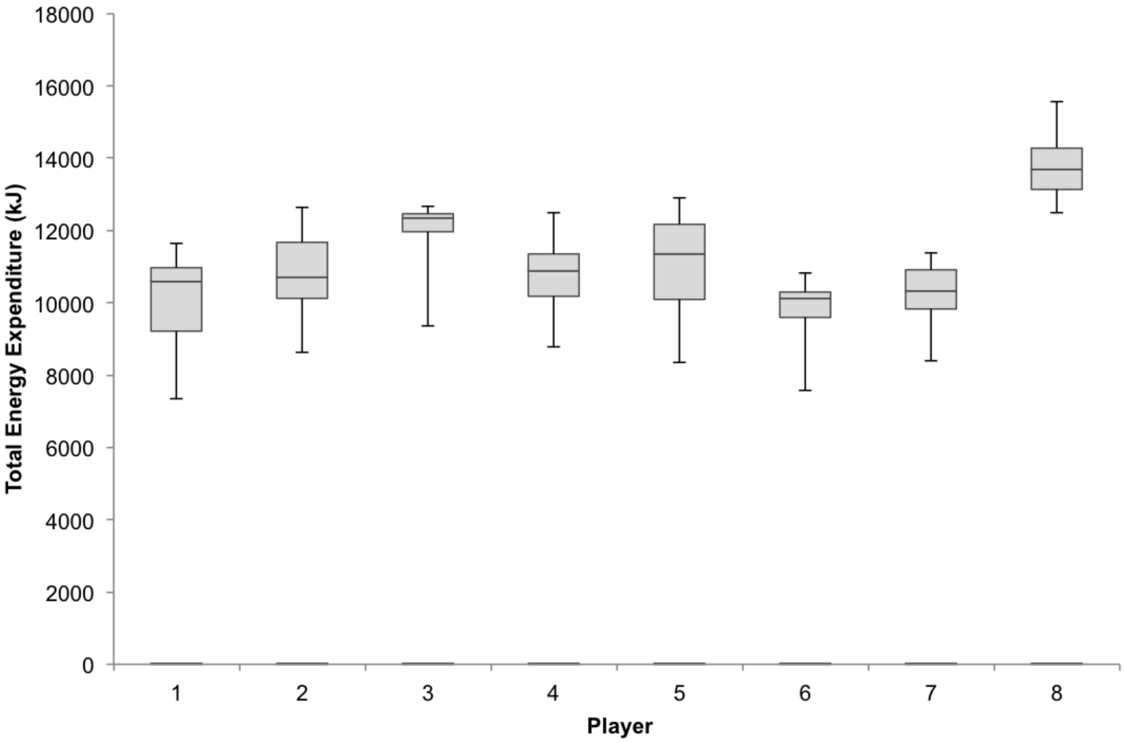


Figure 5.2: Total Energy Expenditure For Individual Players. *Note: Players 1 and 2 = attackers; players 3 – 6 = defenders; players 7 and 8 = midfielders.*

Exercise Energy Expenditure and Physical Demands

Mean exercise energy expenditure for the friendly game and training sessions were 2,695 kJ (*SD* = 301kJ) and 2,538 kJ (*SD* = 316kJ), respectively. An independent samples t-test revealed that the mean difference of 157 kJ was not significant (p = 0.278). Mean total running distance, high-speed running distance and sprinting distance covered during the friendly game were 7,962 m (*SD* = 412 m), 1,905m (*SD* = 185m) and 301 m (*SD* = 126m), respectively. In addition, mean total distance, high-speed running distance and sprinting distance covered during training sessions were 6,581 m (*SD* = 847m), 880 m (*SD* = 244 m) and 333 m (*SD* = 107 m), respectively. Acceleration and deceleration counts were 49 (*SD* = 20) and 21 (*SD* = 9) for the friendly game, and 49 (*SD* = 13) and 18 (*SD* = 9) for training sessions. Independent samples t-tests showed significant differences with large effect sizes between the friendly game and training sessions for total distance ($p = 0.001$, $d = 2.07$) and high-speed distance ($p < 0.001$, $d = 4.74$), but not sprinting distance ($p = 0.515$), acceleration count ($p = 0.980$) or deceleration count ($p = 0.407$).

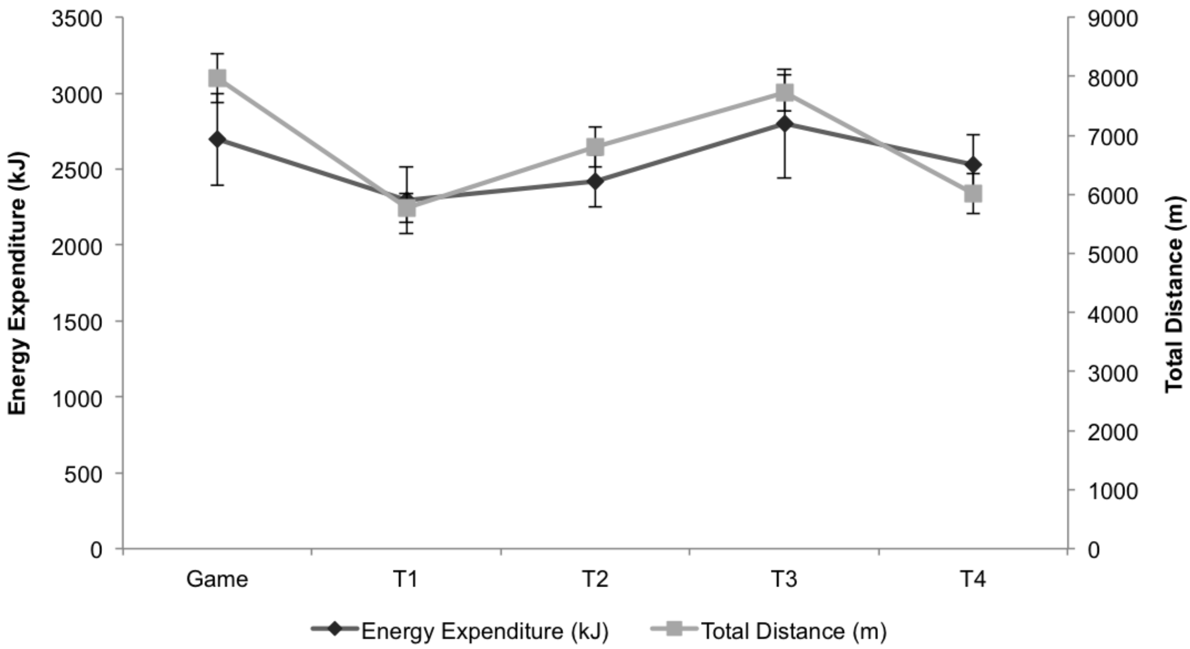


Figure 5.3: Exercise Energy Expenditure and Total Running Distance for One Training Week During Preseason. *Note: T1 = Training 1; T2 = Training 2; T3 = Training 3; T4 = Training 4.*

Further, a repeated-measures ANOVA revealed significant differences with a large effect size ($p < 0.001$, partial $\eta^2 = 0.968$) in energy expenditure between individual training sessions. Post-hoc analysis showed significant pairwise comparisons between all training sessions ($p = 0.001 – 0.035$) (figure 5.3).

Accordingly, total running distance ($p < 0.001$, partial $\eta^2 = 0.839$) high-speed running distance ($p < 0.001$, partial $\eta^2 = 0.932$), sprinting distance ($p = 0.001$, partial $\eta^2 = 0.506$), acceleration ($p = 0.005$, partial $\eta^2 = 0.414$), and deceleration counts ($p < 0.001$, partial $\eta^2 = 0.619$) were all shown to be significantly different between individual training sessions. In addition, figure 5.4 depicts exercise energy expenditure for individual players with reference to their playing position.

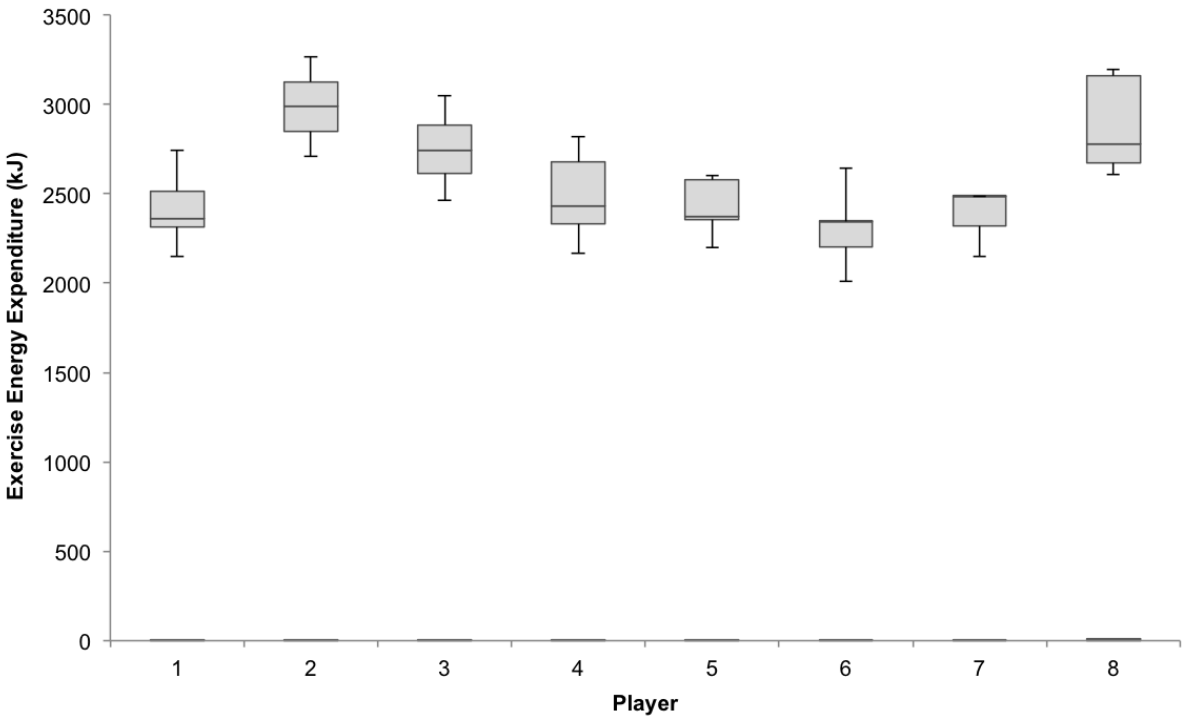


Figure 5.4: Exercise Energy Expenditure for Individual Players. *Note: Players 1-2 = attackers; players 3-6 = defenders; players 7-8 = midfielders.*

Table 5.3: Comparison of Measured Energy Expenditure using the $SWA_{8.0}$, $SWA_{7.0}$ and GPS.

Session	$SWA_{8.0}$ (kJ) Mean	SD	$SWA_{7.0}$ (kJ) Mean	SD	GPS (kJ) Mean	SD	Sig.	Partial η^2
Game	2695	301	2456*	279	2398*	221	0.002	0.719
Training 1	2260	222	2120*	182	1734*	154	0.001	0.951
Training 2	2411	185	2246*	185	2123*	179	0.001	0.912
Training 3	2892	261	2814	320	2548*	463	0.033	0.529
Training 4	2499	199	2368	304	1860*	166	0.001	0.916

**Indicates $p < 0.05$ when compared to $SWA_{8.0}$.*

Comparison of Exercise Energy Expenditure measured by $SWA_{8.0}$, $SWA_{7.0}$ and GPS

A repeated-measures ANOVA showed that the energy expenditure measured during the game using $SWA_{8.0}$ (*mean* = 2695 kJ, *SD* = 301 kJ) was significantly higher ($p = 0.002$, partial $\eta^2 = 0.719$) than measurements made by $SWA_{7.0}$ (*mean* = 2456 kJ, *SD* = 279 kJ) and GPS calculations (*mean* = 2398 kJ, *SD* = 221 kJ). Specifically, Bonferroni post-hoc analysis showed that pairwise comparisons were significant between $SWA_{8.0}$ and $SWA_{7.0}$ (p = 0.006) and $SWA_{8.0}$ and GPS (p = 0.015). However, no significant differences were found between $SWA_{7.0}$ and GPS (p = 1.00). A repeated-measures ANOVA revealed significant differences ($p < 0.001$, partial $\eta^2 = 0.741$) in energy expenditure during training sessions using $SWA_{8.0}$ (*mean* = 2538 kJ, *SD* = 316 kJ), $SWA_{7.0}$ (*mean* = 2403 kJ, *SD* = 364 kJ) and GPS (*mean* = 2077kJ, *SD* = 417kJ). Bonferroni post-hoc analysis showed that pairwise comparisons were significant between all devices ($p < 0.001$). Further analysis showed there were significant differences in measured exercise energy expenditure between $SWA_{8.0}$, $SWA_{7.0}$ and GPS for all individual training sessions (table 5.3).

5.5 DISCUSSION

The primary aim of this research was to assess the total and exercise energy expenditure of elite female soccer players during a typical training week. This is the first study to assess both total and exercise energy expenditure in elite female soccer players using the SenseWear Mini Armbands. The main findings of this study were: 1) total energy expenditure was 12,242 kJ for the game day, 11,692 kJ for the training days and 9,516 kJ for the rest days, 2) mean exercise energy expenditure was 2,695 kJ for the friendly game and 2,538 kJ for the training sessions, and 3) daily and exercise energy expenditure varied between individual days of the week and training sessions.

Total energy expenditure ranged from 9,516-12,242 kJ and declined during the rest days when compared with the training days and the game day. While there were expected differences between days of activity and rest days, no differences existed in daily energy expenditure between the game day and training days. While there are no previous reports on daily energy expenditure in female soccer players, dietary energy intake has been shown to be 11,735 kJ, 9,274 kJ and 9,076 kJ during preseason, mid-season and post-season phases, respectively (114). Based on the previous results and given that the current study collected data during the preseason phase it can be speculated that the energy availability for female soccer players is comparable for a training day during preseason (11,692 kJ vs 11,735 kJ). Future research should also aim to assess the dietary intake as well as energy expenditure in order to more accurately determine daily energy availability.

Exercise energy expenditure measured by the SWA was found to be 2,695 kJ and 2,538 kJ for the friendly game and training sessions, respectively. These findings are comparable to previously reported exercise energy expenditure in female soccer players (2,696 kJ) during the mid-competition phase of the season (114). However, data collection in the current study occurred in the preseason training phase, and appear to be substantially lower than previously reported preseason exercise energy expenditure (3,439 kJ) (114). The disparity in these results may be attributed to the different methods used to obtain energy expenditure measurements, training loads and sample of players used for data collection. Further, there were no significant variations in exercise energy expenditure between the friendly game and training sessions, despite players covering significantly more distance and high-speed distance during the friendly game. These findings could be a result of the modified structure of the game and shortened length of time (3x20 minute thirds vs. 2x45 minute halves). A better insight into the energetic demands of matches would be gained by collecting data from a full-length friendly match. Regardless, this is the first study to assess the exercise energy expenditure of soccer players using the SenseWear Mini Armbands. These devices have been validated for exercise at low to moderate intensities (70,123) and it has been previously shown that a large proportion of soccer matches (85-90 %) are played at an equivalent intensity (13). However, it has also been shown that the SWA tends to underestimate exercise energy expenditure when actions are performed at higher speeds (70) and this should be considered when interpreting the energy expenditure of the friendly game and training sessions.

Daily and exercise energy expenditure varied between individual days of the week and training sessions, indicating that the energy requirements of elite female soccer players should be adjusted accordingly. It should be noted that this study was limited by the sample size of players (n = 8), as well as the timeframe in which data was collected (one week). Due to FIFA regulations, players are not permitted to wear any type of device during official matches. As such, the preseason phase was chosen to provide a snapshot of energy expenditure, as the players would not be competing in any competitive matches during this time. However, previous research has shown that exercise energy expenditure in female soccer players is greatest during the preseason training phase and declines significantly during the mid-season and post-season phases (114). Nonetheless, this study provides preliminary findings of energy expenditure in elite female soccer players, and future research will endeavour to build upon the current findings by increasing the sample size and the timeframe of data collection. In this way, future research will aim to develop normative profiles of energy expenditure in elite female soccer players.

A secondary aim of the study was to compare exercise energy expenditure measured by the latest version of SWA software (SenseWear Professional 8.0), to the previous version of SWA software (SenseWear Professional 7.0) and GPSports measurements. It was shown that $SWA_{7.0}$ and GPS repeatedly underestimated exercise energy expenditure when compared with $SWA_{8.0}$ and GPS consistently measured exercise energy expenditure as being significantly lower than both $SWA_{8.0}$ and $SWA_{7.0}$. It should be noted that the current study does not aim to validate, but rather compare these devices, and further research that aims to validate the GPSports devices for measuring energy expenditure is warranted.

5.6 CONCLUSIONS AND PRACTICAL APPLICATIONS

This is the first study to assess the daily and exercise energy expenditure of female soccer players using the SWA. Daily energy expenditure ranged from 9,516-12,242 kJ and varied between training/game days and rest days. Average training and game energy expenditure were similar, however like daily energy expenditure there were variations between individual sessions. As such, elite female soccer players should adjust their dietary intake accordingly to avoid energy imbalance and ensure optimal performance and recovery. GPSports devices underreported exercise energy expenditure when compared to the $SWA_{8.0}$ and $SWA_{7.0}$. These findings provide initial insight into the energetic demands of daily and exercise energy expenditure during one training week. The SWA provides a practical and unobtrusive method for quantifying energy expenditure in a field-based setting.

6.0 THE PHYSICAL AND PHYSIOLOGICAL CHARACTERISTICS OF VARIOUS-SIDED GAMES IN FEMALE SOCCER TRAINING

6.i Form E: Declaration of co-authored publication chapter

Declaration for Thesis Chapter 5

Declaration by candidate

In the case of Chapter 6, the nature and extent of my contribution to the work was the following:

Nature of contribution	**Extent of contribution (%)**
Study design, data collection and analysis, study write up.	80%

The following co-authors contributed to the work.

Name	**Nature of contribution**	**Extent of contribution (%)**	**Contributor is also a student at UC Y/N**
Kevin Thompson	Assistance with study design, proof reading and editing of drafts.	10%	N
Kate Pumpa	Assistance with study design, proof reading and editing of drafts.	10%	N

Candidate's Signature		**Date** 15-02-16

Declaration by co-authors

The undersigned hereby certify that:

(13) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.

(14) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;

(15) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(16) there are no other authors of the publication according to these criteria;

(17) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(18) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	**Research Institute for Sport and Exercise, University of Canberra**

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

Signature 1		**Date** 15-02-16
Signature 2		15-02-16

6.ii Preface

The previous chapter assessed the total and exercise energy expenditure of players during one training week in preseason. This chapter becomes more specific to training and describes the physical response to small-sided games, which are a frequently used drill to develop soccer-specific fitness. This study has been accepted for publication in the International Journal of Sports Physiology and Performance (Mara, JK, Thompson, KG, & Pumpa, KL. The physical and physiological characteristics of various-sided games in elite female soccer. International Journal of Sports Physiology, 2016, In press. An oral presentation of this research was presented at the World Congress on Science and Football conference in Denmark in May, 2015.

6.1 ABSTRACT

Purpose: To investigate the physical and physiological response to different formats of various-sided games.

Methods: Eighteen elite female soccer players wore 15Hz global positioning system (GPS) devices and heart-rate monitors during various-sided games (small: 4v4 and 5v5, medium: 6v6 and 7v7, large: 8v8 and 9v9).

Results: Players covered more relative sprinting distance during large-sided games when compared with small- ($p < 0.001$, $d = 0.69$) and medium- ($p < 0.001$, $d = 0.54$) sided games. In addition, a greater proportion of total acceleration efforts that had a commencement speed < 1 m/s were observed in small-sided games (44.7% ± 5.5) when compared to large-sided games (36.7% ± 10.6) ($p = 0.018$, $d = 0.94$). This was accompanied by a greater proportion of acceleration efforts with a final speed equivalent to the sprint threshold in large-sided games (15.4% ± 7.7), than small-sided games (5.2% ± 2.5) ($p < 0.001$, $d = 1.78$). The proportion of time spent in heart rate zone 4 (> 85% HR_{max}) was greatest during small-sided games (69.8% ± 2.5) compared with medium- (62.1% ± 2.8, $d = 2.90$) and large- sided games (54.9% ± 3.1) ($p < 0.001$, $d = 5.29$).

Conclusion: The results from this study demonstrate that coaches can use small-sided games as an aerobic conditioning stimulus and to develop players' explosiveness and repeat sprint ability over short durations. Large-sided games can be used to maintain aerobic capacity and develop maximum speed over longer distances.

6.2 INTRODUCTION

Small-sided games are modified soccer games, commonly used during training sessions to develop soccer-specific physical, tactical and technical performance, without exposing players to the full physical load of a match (67). It has also been shown that small-sided games are as equally effective as generic interval training for developing and maintaining aerobic and anaerobic fitness in male youth players (72,116). In order to maximise the effectiveness of small-sided games as a conditioning stimulus, previous research has focused on the influence of modifying small-sided games conditions such as the number of players per team and the field dimensions (41,65,66,122).

The vast majority of research on small-sided games has been conducted using men's elite soccer teams and only one study has quantified the physical demands of Small-sided games in elite female soccer training, and compared these to competitive matches (54). It was found that work to rest ratios during small-sided games (1:13) were less than national level matches (1:16), but were similar to international level matches (1:12). This study concluded that small-sided games were similar to the overall movement demands of matches, but did not offer an appropriate training stimulus for simulating the high-intensity and sprinting patterns of international level matches. While this study is novel in its findings, the manual tracking approach for acquiring movement data from players is now outdated with recent advancements in GPS technology.

A greater heart rate response has been observed during small-sided (2v2 and 3v3) games when compared with larger-sided games (6v6 and 9v9) (66,109) and friendly matches (43) in elite (43,109) and youth (66) male players. Conversely, it has been shown that increasing the pitch size while maintaining the number of players (5v5) did not induce a change in heart rate response in professional male players (77). Higher ratings of perceived exertion (RPE) have been reported when the number of players and the playing area were increased concurrently in youth male players (30,66). In general, previous research has reported that decreasing the number of players in small-sided games tends to increase the overall workload, however there are mixed results which may be attributed to the lack of standardised methods used in terms of number of players and field dimensions.

The aim of the current study was to investigate the physical and physiological response to various-sided games in elite female soccer players. The findings from this study can be used to assist coaches make informed decisions regarding the format of training games to use in order to achieve specific training goals.

6.3 METHODS

Subjects

Eighteen elite female soccer players from the same national league team participated in this study (age: 24.3 ± 4.2 y, height: 171 ± 5 cm, mass: 65.3 ± 5.1 kg, body fat per cent: 23.0 ± 4.9 %, fat mass: 14.3 ± 3.6 kg, lean mass: 47.6 ± 3.6 kg, fat free mass: 50.7 ± 3.7 kg, bone mineral content: 3.1 ± 0.3 kg). Only field players (attackers = 4; midfielders = 7; central defenders = 4; wide defenders = 3) were included in this study. Participants' body composition was determined by a Dual X-ray Absorptiometry (DXA) scan, which has been previously described elsewhere (2), and are displayed in table 1. Prior to data collection, institutional ethical approval was granted and subjects were thoroughly informed of the procedures of the study by verbal and written communication. All players that participated in the study provided written informed consent.

Methodology

Various-Sided Games

This study used an observational design. Various-sided games (*n* = 18) were administered by the team coaching staff and were categorised according to number of players (excluding goalkeepers) on each team – Small-sided games (SSG): 4v4 and 5v5; medium-sided games (MSG): 6v6 and 7v7; large-sided games (LSG): 8v8 and 9v9. The details of each type of game are detailed in table 1 and are similar to that which have been used previously to distinguish small-, medium- and large-sided games (108). For games that required less than the eighteen players (all game formats apart from 9v9) players analysed were randomly selected by the coaching staff. All games consisted two full sized goals and a goalkeeper per team. All games were played in two sets, with two minutes of rest between each. Games were played as part of normal team training sessions following a standardised warm up of 20 min. Spare balls were kept in each team's goal in such a way that the goalkeeper could restart quickly when a goal was scored or the ball went out of play.

Table 6.1 Various-Sided Game Characteristics

No. of Players*	Time (mins)	Field Dimensions L x W (m)	Pitch Area Per Player (m^2)
SSG			
4 v 4	5	40 x 40	200
5 v 5	5	50 x 40	200
MSG			
6 v 6	7	60 x 40	200
7 v 7	7	70 x 40	200
LSG			
8 v 8	9	80 x 68	340
9 v 9	9	90 x 68	340

** Excludes goalkeepers*

GPS Analysis

Players wore 15Hz GPS tracking devices (GPSports, Canberra, Australia) during team training sessions of a national league season. These devices have reported interunit reliability expressed as a coefficient of variation as 1.9% for total distance, 7.6% for distance at speeds 3.8-5.5m/s and 12.1% for distance at speeds above 5.5m/s (74). These devices have also reported mean bias as 1.1% for total distance and < 1 % for measuring peak speed. While these particular devices have not been validated for measuring acceleration data, an earlier 5 Hz model (SPI Pro, GPSports, Australia) has been used previously to quantify the acceleration profiles of soccer players (128). Only data that was collected during various-sided games were included in this study. GPS devices were turned on 15 minutes before each session and were laid outdoors to ensure satellite connectivity. During all training sessions, 5 – 8 satellites were available for signal transmission, which is above the minimum required number of three for optimal position detection (48). An atomic clock (Emerald Timestamp, Sequoia) was used to determine the start and end time of each game to accurately delineate the data (within .01 second). Total running distance per minute (TD/min), low-speed (<3.4 m/s) running distance per minute (LSRD/min), high-speed (3.4 – 5.3 m/s) running distance per minute (HSRD/min) and sprinting (> 5.4 m/s) distance per minute (SD/min) were collected to quantify the physical demands of the games. Speed thresholds were chosen as have been recommended for female athletes (36,46) and are similar to that which has been used previously (62,93,94,97).

Acceleration efforts greater than or equal to 2m/s^2 were collected to determine the acceleration profiles of the different game formats. Acceleration profiles consisted mean acceleration interval (s), mean acceleration distance (m), maximum acceleration distance (m), peak speed (m/s), peak acceleration (m/s^2) and mean duration between accelerations (recovery duration) (s).

Accelerations were also classified according to their commencement and final velocities. Commencement velocities were categorised in 1m/s intervals and consisted < 1m/s, 1-2m/s, 2-3m/s and >3m/s (128). Final speed was defined as the peak speed achieved during the acceleration and was categorised according to the pre-defined speed thresholds for low-speed, high-speed and sprinting as outlined above. Repeated acceleration efforts were identified when two acceleration efforts were performed with less than 21 seconds between each. This definition of repeated acceleration efforts is similar to that which has been used previously to categorise repeated sprint activities (54,55).

Heart Rate Analysis

In addition to wearing GPS devices, players wore heart rate monitors (Polar Team Sport System, Polar Electro OY, Kempele, Finland) during all various-sided games. Heart rate variables measured comprised of mean (HR_{mean}) and peak heart rate (HR_{peak}), expressed as a percentage of each participant's maximum heart rate (HR_{max}). HR_{max} was determined as the maximum heart rate achieved during a level 1 Yo-Yo Intermittent Recovery test (YYIR1) (30,32,66). The procedures for the YYIR1 have been described elsewhere(12). Heart rate was categorised into four zones – HR zone 1: < 60% HR_{max}; HR zone 2: 60 – 74% HR_{max}; HR zone 3: 75 – 84% HR_{max}; HR zone 4: > 85% HR_{max}. The time spent in each heart rate zone was expressed as a percentage of total time of the various-sided games.

Statistical Analysis

Statistical analysis was conducted using SPSS version 21.0 (SPSS Inc, Chicago, IL). Proportional data (heart rate and accelerations expressed as a percentage) were transformed using arcsine transformation (37) . An analysis of variance (ANOVA) was conducted to determine differences in TD/min, LSRD/min, HSRD/min and SD/min and heart rate variables between game formats. An analysis of covariance (ANCOVA) was conducted to determine differences in acceleration variables (dependent variables) between game formats (independent variable), controlling for time of the games (co-variable). Where appropriate, Bonferroni post-hoc analyses were conducted to examine pairwise comparisons. A paired samples t-test was conducted to determine differences in GPS and heart rate variables between the first and second set of games. In addition to acquiring statistical significance ($p < 0.05$), Cohen's d (small = 0.2; medium = 0.5, large = 0.8) was used to measure paired effects.

6.4 RESULTS

Distances Covered

The relative LSRD/min, HSRD/min and SD/min varied between game formats (table 2). Players covered more LSRD/min in MSG, when compared with LSG ($p < 0.001$, $d = 0.49$) and SSG ($p = 0.034$, $d = 0.16$). Players covered more HSRD/min in LSG when compared to MSG ($p = 0.002$, $d = 0.26$), and more SD/min in LSG when compared with SSG ($p < 0.001$, $d = 0.69$) and MSG ($p < 0.001$, $d = 0.54$). There were no differences observed between game formats for TD/min ($p = 0.324$, $d = 0.01$- 0.17). It was also shown that players covered less TD/min ($p < 0.001$, $d = 0.99$) during the second set (mean = 117.3, $SD = 9.4$) when compared with the first set (mean = 128.9, $SD = 13.7$) in LSG.. This was accompanied with a decline in HSRD/min ($p = 0.031$, $d = 0.43$) in the second set (mean = 24.5, $SD = 7.0$) when compared with the first set (mean = 27.9, $SD = 8.6$). However, no differences in these parameters were observed between sets for SSG (p = 0.089-0.970, d = 0.01-0.40) or MSG (p = 0.168-0.846, d = 0.18-0.30).

Heart-rate Profiles

Table 6.2 shows the heart rate profiles of the various-sided games. HR_{mean} was lowest during LSG when compared with SSG ($p < 0.001$, $d = 0.60$) and MSG ($p = 0.031$, $d = 0.14$). The proportion of time in HR zone 4 (> 85% HR_{max}) was also lowest during LSG, when compared with SSG ($p = 0.006$, $d = 0.56$). The proportion of time in HR zone 2 (60 – 74% HR_{max}) was greatest during LSG when compared with SSG ($p = 0.021$, $d = 0.39$) and MSG (p =

0.024, d = 0.42). The proportion of time in HR zone 3 (75 – 84% HR_{max}) was greatest during LSG when compared with SSG (p = 0.001, d = 0.61), and was greater during MSG when compared with SSG (p = 0.008, d = 0.39). There were no differences shown for HR_{peak} (p = 0.110, d = 0.01-0.14) and proportion of time in HR zone 1 (< 60% HR_{max}) (p = 0.091, d = 0.00-0.04) between game formats. In addition, no differences were observed between the first and second set in heart rate profiles among all SSG formats (p = 0.173-0.846, d = 0.06-0.28).

Table 6.2 Physical and Heart Rate Response to Small-, Medium- and Large-Sided Games

Variable	SSG	MSG	LSG
TD/min	121.3 ± 12.5	123.3 ± 10.3	123.1 ± 13.1
LSRD/min	95.1 ± 11.5 ^{M}	98.7 ± 9.6 ^{SL}	91.7 ± 13.8 ^{M}
HSRD/min	24.9 ± 7.2	23.0 ± 6.5 ^{L}	26.2 ± 8.0 ^{M}
SD/min	1.3 ± 1.8 ^{L}	1.6 ± 2.5 ^{L}	4.6 ± 7.3 ^{SM}
HR_{peak} (% HR_{max})	94.8 ± 3.5	95.5 ± 5.7	94.9 ± 5.1
HR_{mean} (% HR_{max})	87.2 ± 5.7 ^{L}	86.3 ± 6.1 ^{L}	83.9 ± 4.9 ^{SM}
% time in HR zone 1	3.5 ± 6.6	3.5 ± 5.2	3.7 ± 3.8
% time in HR zone 2	9.5 ± 7.8 ^{L}	8.9 ± 9.1 ^{L}	13.0 ± 11.4 ^{SM}
% time in HR zone 3	17.3 ± 18.3 ^{ML}	25.5 ± 24.5 ^{S}	28.3± 18.6 ^{SM}
% time in HR zone 4	69.8 ± 25.9 ^{L}	62.1 ± 31.6	54.9 ± 27.9 ^{S}

Data are presented as means ± SD. S = p < 0.05 when compared to SSG, M = p < 0.05 when compared to MSG, L = p < 0.05 when compared to LSG.

Table 6.3 Acceleration Characteristics for Small-, Medium- and Large-Sided Games.

Variable	SSG	MSG	LSG
Interval (s)	2.7 ± 1.0^{L}	2.8 ± 1.2^{L}	3.3 ± 1.7^{SM}
Distance (m)	8.6 ± 4.5^{ML}	9.5 ± 5.5^{SL}	11.9 ± 8.3^{SM}
Max Distance (m)	24.3 ± 1.8^{L}	27.0 ± 1.7^{L}	38.5 ± 1.7^{SM}
Peak Speed (m/s)	6.2 ± 0.2^{L}	6.3 ± 0.2^{L}	7.0 ± 0.2^{SM}
Peak Acceleration (m/s^2)	3.7 ± 0.3	3.6 ± 0.3	3.7 ± 0.4
Recovery Interval (s)	28.4 ± 32.3^{ML}	32.7 ± 31.4^{SL}	43.2 ± 40.0^{SM}
Repeat acceleration (% of total accelerations)	51.1 ± 7.8^{ML}	40.1 ± 7.1^{SL}	30.7 ± 6.8^{SM}

Data are presented as means ± SD. S = $p < 0.05$ when compared to SSG, M = $p < 0.05$ when compared to MSG, L = $p < 0.05$ when compared to LSG.

Acceleration Profiles

Acceleration characteristics for the different game formats are displayed in table 6.3. Mean acceleration interval was greater during LSG when compared with both SSG ($p < 0.001$, $d = 0.47$) and MSG ($p < 0.001$, $d = 0.31$). The mean distance covered per acceleration increased as the game size increased. Differences were observed between SSG and MSG ($p = 0.006$, $d = 0.18$), SSG and LSG ($p < 0.001$, $d = 0.53$), and MSG and LSG ($p < 0.001$, $d = 0.37$). Peak speed increased as the game size increased, with differences shown between SSG and LSG ($p = 0.004$, $d = 0.43$), and MSG and LSG ($p = 0.010$, $d = 0.20$). Similarly, maximum distance increased as the game size increased, with differences also shown between SSG and LSG ($p < 0.001$, $d =$

1.54), and MSG and LSG ($p < 0.001$, $d = 6.76$). The recovery interval between accelerations increased as the game size increased, with differences shown between all game formats ($p < 0.001$, d = 0.20-0.41) The proportion of total acceleration efforts that were repeat efforts decreased as the game size increased ($p < 0.001$, d = 1.3-2.7) (table 6.3).

Table 6.4 Commencement and Final Speed of Accelerations (> 2m/s^2) for Small-, Medium- and Large-Sided Games.

	SSG (%) n = 1328	MSG (%) n = 1537	LSG (%) n = 1842
Commencement Speed			
< 1 m/s	44.7 ± 5.5^{L}	39.4 ± 6.8	36.7 ± 10.6^{S}
1-2 m/s	47.2 ± 5.8	50.8 ± 5.4	49.3 ± 8.3
2-3 m/s	6.9 ± 3.6^{L}	9.0 ± 3.0	12.7 ± 4.5^{S}
> 3 m/s	1.1 ± 1.9	0.7 ± 0.7	1.3 ± 1.7
Final Speed			
< 3.4 m/s	30.4 ± 6.1^{L}	25.1 ± 6.1	22.3 ± 10.2^{S}
3.4 – 5.4 m/s	64.3 ± 5.8	66.2 ± 6.3	62.3 ± 9.3
> 5.4 m/s	5.2 ± 2.5^{L}	8.7 ± 6.0^{L}	15.4 ± 7.7^{SM}

Data are expressed as the mean percentage (± SD) of total acceleration efforts. S = $p < 0.05$ when compared to SSG, M = $p < 0.05$ when compared to MSG, L = $p < 0.05$ when compared to LSG

Table 6.4 shows the proportion of acceleration efforts commencing and finishing in various speed thresholds for each game format. The proportion of accelerations with commencement velocities <1 m/s declined as the size of the game format increased ($p = 0.018$, $d = 0.94$), while the proportion of accelerations with commencement velocities 2-3m/s increased as the game format increased (p = 0.006, d = 1.42). In addition, the percentage of accelerations that were performed with a final speed < 3.4 m/s declined as the game format increased (p = 0.009, d = 0.96) while the percentage of accelerations performed with a final speed > 5.4 m/s increased as the game format increased (p < 0.001, d = 0.90-1.78) (table 6.4).

6.5 DISCUSSION

This is the first study to quantify the physical demands of various-sided games in female soccer training, with respect to acceleration and heart rate profiles. The key findings were 1) players covered more sprinting distance per minute during large-sided games compared with small- and medium-sided games; 2) players covered less total distance and high speed running per minute during the second set compared to the first set in large-sided games; 3) acceleration profiles differed in terms of distance, recovery duration, commencement and final velocities and repeated sprints between game formats; 4) players had a greater proportion of total time in HR zone 4 (> 85% HR_{max}) in small-sided games compared with larger formats.

Players covered more relative sprinting distance during large-sided games when compared with smaller formats. This is similar to previous research which showed a greater number of sprints were performed during friendly matches when compared with small-sided games in male soccer (29). However, previous reports of female soccer players observed no difference in time spent sprinting between small-sided games and international competition (54). The increase in relative distance in large-sided games in the current study is likely due to the increased displacement covered by players due to the greater pitch size, subsequently allowing players to achieve higher velocities during larger formats. This can also be explained by the increased proportion of accelerations that reached the sprinting threshold (> 5.4 m/s) during large-sided games when compared with smaller formats. However, due to the increased error of GPS devices at higher speeds (particularly > 5m/s) these results should be interpreted with caution.

When comparing the current findings to previously reported demands of female matches, sprinting distance per minute was found to be similar to large-sided games (~ 4 m/min in matches (62) vs 4.6 m/min in LSG) but not small- and medium-sided games (1.3-1.6 m/min). High-speed running distance per minute in matches was similar to values observed in all formats of various-sided games (25-27 m/min in matches (62,97) vs 23-26 m/min in various-sided games). Total distance per minute was greater during all formats of various-sided games (121-123 m/min) when compared to matches (103-107 m/min) (62,131). These comparisons show that various-sided games effectively replicate the total and high-speed distance of matches, however large-sided games should be employed to replicate the sprinting demands of matches.

The lack of differences found between formats in total distance covered per minute is consistent with previous research in male soccer (65,66,75). Despite this, it was shown that there was a reduction in total distance and high-speed running distance per minute from the first to the second set of large-sided games, but not small- and medium-sided games. This is in contrast to a previous study of elite male players which found reductions in total distance and high-speed running distance between the first and second set of 4v4 small-sided games (42). This was accompanied by an increase in blood lactate from 2.5-2.7 $mmol.l^{-1}$ and a decrease in technical performance (i.e.

decrease in successful passes). Future research should aim to collect blood-based markers and data related to technical aspects of various-sided games in female soccer to determine if there are any reductions in soccer-specific technical performance between sets.

The acceleration profiles of players differed between game formats. The mean acceleration interval and subsequent mean acceleration distance increased as the game format increased. Similar to the increase in relative sprinting distance in large-sided games, this may be attributed to the larger playing area and therefore the greater displacement required to be covered by players. In addition, the proportion of repeat acceleration efforts increased as the game format increased. This was accompanied by greater average recovery duration between acceleration efforts with larger formats compared with smaller formats. This may have been attributed to the lower number of players in smaller formats resulting in greater number of involvements and ball contacts per individual player, which has been shown previously in male soccer (109).

The percentage of acceleration efforts commencement speed < 1m/s decreased during large-sided games when compared with smaller-sided games. This was accompanied with an increase in the percentage of acceleration efforts with a commencement speed 2-3m/s. This indicates the larger format games consisted of more acceleration efforts beginning from higher velocities whereas there were a larger proportion of acceleration efforts that were explosive from nearly stationary starts during smaller format games.

The proportion of acceleration efforts with a final speed that was equivalent to a sprint threshold (> 5.4m/s) was greater during large-sided games, when compared with smaller formats. Accordingly, the proportion of acceleration efforts with a final speed that was equivalent to low-speed running (< 3.4m/s) declined in large-sided games compared with smaller formats.

The findings related to acceleration profiles collectively show that only small proportions (5.2 – 15.4 %) of all acceleration efforts > 2 m/s^2 ended in final velocities that were equivalent to the sprinting speed threshold. This supports previous research that only quantified the distances covered in speed thresholds without acknowledging acceleration profiles provide an underestimated representation of the physical demands of soccer training and matches. In the current study, players often performed acceleration efforts that ended in final velocities that were equivalent to the low-speed running threshold (~22-30% of all acceleration efforts > 2 m/s^2). These efforts have been previously shown to be physically taxing, as accelerating is more energetically demanding than constant speed running, even when accelerating at lower speed thresholds (106). Future research should also examine data relating to deceleration profiles due to the fatiguing nature of these actions (83).

The heart rate response of players differed between the various-sided games. The games induced an average heart rate between 84 – 87% HR_{max} and decreased during large-sided games when compared with small- and medium-sided games. These findings are similar to those reported previously

(75,113) in studies investigating the concurrent influence of number of players and pitch size in male players. In addition, the mean heart rate reported in the current study were similar to those reported previously for 5 v 5 (~ 89% HR_{max}), 6 v 6 (~ 87% HR_{max}) and 8 v 8 (~79% HR_{max}) formats in male soccer players (75,85,113). The average heart rate reported in the current study was also similar to that reported during competitive matches of elite female soccer players (87% HR_{max}) (79).

The proportion of time spent in HR zone 4 (> 85% HR_{max}) was less during large-sided games when compared with small- and medium-sided games, which is similar to previously reported research of male players (66,109). Accordingly, the proportion of time spent in HR zone 2 (60 – 74% HR_{max}) and HR zone 3 (75 – 84% HR_{max}) was greater during large-sided games compared with smaller formats. This is likely due to the greater time between acceleration efforts during large-sided games, which would enhance heart rate recovery. Collectively, these findings indicate smaller sided training games elicit a greater heart rate response and heavily tax the aerobic systems. While the greater frequency of accelerations from higher speeds and longer accelerations leading to higher peak speeds coupled with a reduction in high speed running and total distance per minute between sets in larger sided games is suggestive of a greater anaerobic energy demand. For a more thorough investigation of the physiological response of modified training games future research should aim to collect blood-based measures such as lactate values. However, this is difficult in practice due to the need to take multiple measurements from multiple players during sets to elicit meaningful data.

6.6 PRACTICAL APPLICATIONS AND CONCLUSIONS

The results from this study show that coaches can manipulate sprinting, high speed running, acceleration profiles, heart rate and metabolic demands by concurrently modifying the number of players and field dimensions in elite female soccer training games. Overall it was shown that smaller-sided games induced a greater heart rate response than larger-sided games and can be used for a predominately aerobic conditioning stimulus. In addition, smaller-sided games induced a greater proportion of acceleration efforts from near stationary starts while players performed longer acceleration efforts from leading starts during larger-sided games requiring a greater anaerobic energy contribution which might have led to fatigue being evident across repeated sets. Coaches can utilise smaller-sided games when aiming to develop players' explosiveness and repeat sprint ability over short durations while larger-sided games can be adopted to develop maximum speed. Future research should aim to collect information related to RPE and blood lactate values to provide a more holistic view of the perceptual and physiological response to different formats of training games.

7.0 THE ACCURACY AND RELIABILITY OF A NEW OPTICAL PLAYER TRACKING SYSTEM FOR MEASURING DISPLACEMENT OF SOCCER PLAYERS

7.i Preface

The first three studies (chapters 4-6) focused on the physical and physiological characteristics of elite female players during training. Chapter 4 examined broad variations across one season, and chapter 5 became more specific to investigate one training week in preseason, while chapter 6 narrowed the focus again to examine small-sided games in training sessions. The next three chapters (chapter 7-9) will focus on the physical characteristics of competitive matches. Prior to the data collection process of competitive matches, it was necessary to validate the player tracking system being used. Therefore, this chapter will describe the accuracy and reliability of a new Optical Player Tracking System for measuring displacement of players on a soccer field. This study is currently under review in the Journal of Strength and Conditioning Research.

7.1 ABSTRACT

Purpose: Recently, a novel Optical Player Tracking System has been developed to determine positional information of athletes in a non-invasive and inexpensive manner. The aim of this study was to measure the accuracy and reliability of displacement estimates derived from the system.

Methods: Eight high-definition video cameras were positioned around a soccer field such that when the vision was combined the entire field could be viewed at once. Two females and one male completed five soccer-specific running courses at three different speeds three times each while being filmed by the multi-camera system. The participants *x*,*y* field position were determined by the Optical Player Tracking System and displacement was estimated by applying Euclidean distance calculations and compared with actual distance.

Results: The difference between actual distance and estimated displacement was 1.39 % with the coefficient of variation becoming slightly larger during 90° turns (4.89 %) when compared with straight line running (4.09 %). In addition, there were strong correlations between actual distance and measured displacement (r = 0.986 – 0.988). Collectively, the typical error (0.25 – 0.36), typical error as a coefficient of variation (1.06 – 1.75 %) and intraclass correlation coefficient (0.88 – 0.93) showed high levels of intra-operator reliability.

Conclusion: The Optical Player Tracking System provides accurate and reliable estimates of displacement of players on a soccer field. This inexpensive system provides the opportunity to collect activity data non-invasively on players and opposition players during matches.

7.2 INTRODUCTION

Monitoring the physical performance of players in training and matches has become commonplace in elite soccer to ensure optimal physical preparation. Vision-based tracking technology, as well as global (GPS) and local (LPM) positioning systems are routinely used to quantify both the movement demands of matches and training. Vision tracking systems involve the installation of multiple cameras around the playing stadium in such a way that when all camera views are combined they provide coverage of the entire playing field (120). Automated tracking of player coordinates and trajectories are conducted by proprietary software, followed by a quality control process by an experienced operator. PROZONE®, which is commonly used by professional soccer teams, has been shown to be valid and reliable for measuring players' displacement (CV = 3.6 %) and speed (CV < 1.3 %) during matches (120). However, this system is relatively expensive which prohibits its use for most practitioners.

Global position systems are an alternate method for assessing the physical performance of soccer players, and utilise a network of earth-orbiting satellites to emit signals regarding the exact time and position to the receiver worn by a player. Using trigonometry, positional information and speed can be determined (91). Devices are commonly worn during training sessions of elite soccer teams, however until recently they were not permitted in official Fédération Internationale de Football Association (FIFA) matches and cannot be used to investigate indoor training sessions. Therefore, previous data obtained from GPS devices have often been limited to friendly matches.

Global positioning devices sampling at 10Hz are a valid measure of instantaneous and constant speed, however the level of accuracy tends to decline with an increase in running speed and decrease in displacement (CV = 1.9 – 6.0 %) (129).

Despite providing valuable physiological information to teams and researchers, the expensive nature of vision-based systems limits their use to professional male teams (and only a small proportion of elite female teams). Accordingly, the physical characteristics of elite female soccer matches have not yet been thoroughly examined, with previous research using manual tracking methods (9,54,101). Recently, a vision-based tracking system has been developed (Optical Player Tracking, Australian Institute of Sport, Canberra, Australia) to track the movements of individual and team sport athletes. This development has provided the opportunity for previously underreported information to be acquired during competitive matches. The Optical Player Tracking System samples noisy detections at 25 frames per second. Individual detections are aggregated into temporal sequences using the low and medium level hierarchical association methods described by Liu et al (88). This method generates short-term tracklets that encode the position of individual players over consecutive one-second epochs. A piece-wise cubic polynomial is fitted to the continuous player tracking using the midpoint for each one-second epoch. Coordinates (x,y) for players can then be estimated by solving the cubic polynomial at any time point. This method provides a compact representation of the large-scale tracking data, and also offers a smoothing function for noisy data. This system has been used previously to discover adversarial group behaviour in field hockey (90) but has not yet been used to track players on a soccer field.

The aim of this study was to measure the accuracy of displacement estimates derived from the Optical Player Tracking System for players on a soccer field. A secondary aim of the study was to assess the reliability of the manual quality control process of the Optical Player Tracking System.

7.3 METHODS

Subjects

One male (age: 23 years; mass: 80 kg; height: 180 cm) and two females (mean age: 25 years, mean mass: 65 kg; mean height: 164 cm) volunteered to participate in this study. Participants were regularly involved in competitive sport and free of injury. Institutional ethical committee approval was granted and all participants were informed of the procedures by verbal and written communication before informed consent forms were signed.

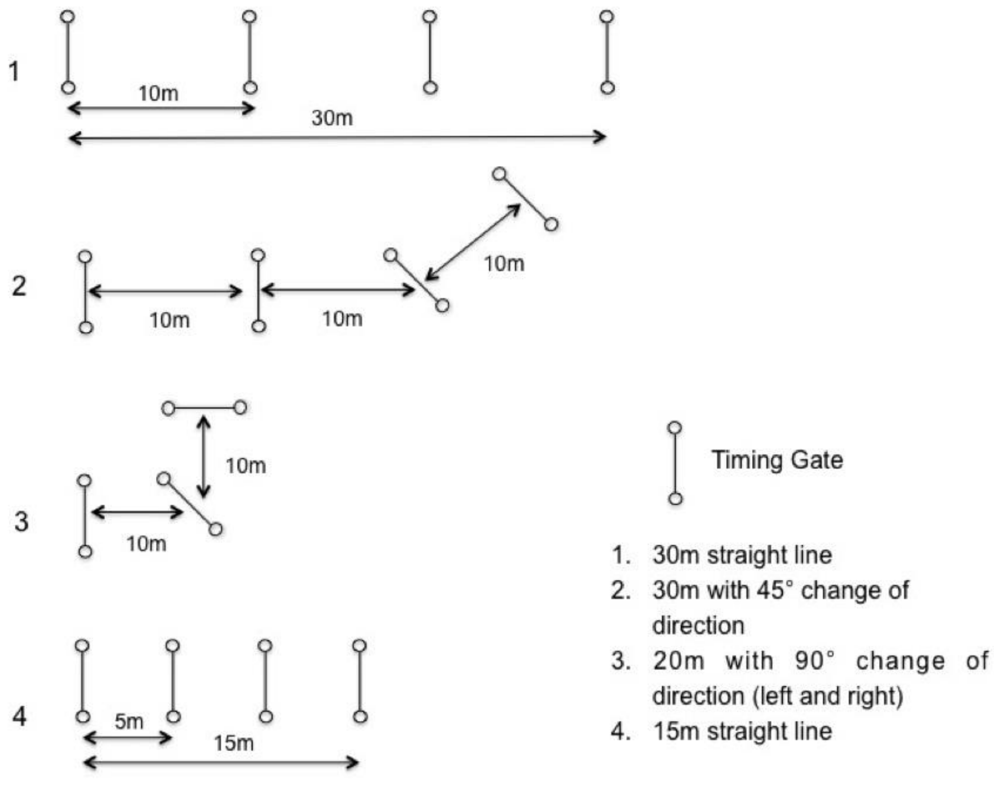


Figure 7.1 Schematic diagram of the soccer-specific running protocols

Procedures

Soccer-specific running protocol

The running protocol (figure 7.1) was designed based on common directional changes (17) and sprint lengths (134) in soccer and was similar to that which has been used previously to validate LPM (53) and vision-based tracking (120) systems. The distance of each running course was determined using a measuring tape. Running times were acquired by timing gates (Smartspeed, Fusion Sport, Cardiff, UK). Participants completed three trials of each running course at three varying self-paced speeds (jog, stride, sprint), providing 27 data points for each running course.

Optical Player Tracking System

Participants were recorded using eight stationary high-definition video cameras (Legria HF R38, Canon, Tokyo, Japan) at vantage points that collectively covered the entire 105 x 68 m playing area. Two video cameras were positioned 10 m behind each corner of the soccer field at a height of 20 m, which allowed for uninterrupted and unobscured capture for the duration of the running protocol. Following the running protocol, the video footage was imported onto a desktop computer (Apple iMac, California, USA) and split into separate video files for each individual trial. The start and end point of the video files were chosen as the frame at which the timing gate light was observed to have extinguished, indicating that the participant had crossed the gate. The video files were imported into the tracking software (Optical Player Tracking, Australian Institute of Sport, Canberra, Australia) and each camera's video image was calibrated to the markings of the soccer field so that a pixel represented a known unit of measurement. A state-of-the-art optical player detector (28) generated a set of player detection observations where each observation consisted of an x, y ground location and a timestamp t. Following the automatic tracking process, an operator verified that the trajectories identified for each participant remained constant to that participant to ensure quality control. To determine operator reliability, each video underwent the manual quality control process twice.

Data Treatment for Determining Displacement

The x,y coordinates of the participants for each frame of video were exported as text files before being imported into Excel spreadsheet software (Microsoft, Redmond, USA) for data treatment. The displacement covered by each participant per frame δ*(n)* was calculated using the Euclidean distance algorithm:

$$\delta(n) = \sqrt{[x(n) - x(n-1)]^2 + [y(n) - y(n-1)]^2}$$

where:

x(n) – x(n – 1) = change in x position between frame n and frame n – 1

y(n) – y(n – 1) = change in y position between frame n and frame n – 1 (106)

The displacement covered per frame was then summed to determine total distance.

Statistical Analysis

Statistical analysis was conducted using SPSS version 21.0 (SPSS Inc, Chicago, IL) and Microsoft Excel spreadsheet software (Microsoft, Redmond, USA). Descriptive statistics of the difference between actual distance (measured by a tape measure) and displacement measured by the Optical Player Tracking System (mean ± SD, range, % difference and 95 % confidence intervals) were calculated. Further, regression analysis determined the relationship between actual distance and measured displacement. Data were checked for heteroscedasticity by plotting the absolute difference against the mean and computing a correlation (11). To determine the reliability of the manual quality control process, absolute and relative (%) differences in displacement between the two measurements taken by the operator were determined. Typical error, total error, intraclass correlation coefficient (ICC) and typical error expressed as a coefficient of variation were calculated (68,69). A confidence interval of 95 % was used for all statistical analyses.

7.4 RESULTS

Table 7.1 Descriptive statistics of displacement measured by the Optical Player Tracking System compared to actual distance measured by a tape measure for all courses.

Course	Difference (Optical Player Tracking System minus actual distance)				SD as CV %
	Mean ± SD	Range (min-max)	% of actual distance	95 % CI	
30m Straight					
Overall	-0.31 ± 1.02	-1.84 – 1.82	-1.03	-0.69 – 0.07	3.43
Jogging	-0.59 ± 1.25	-2.16 – 1.82	-1.97	-1.41 – 0.23	4.27
Striding	-0.48 ± 0.61	-1.18 – 0.45	-1.61	-0.08 – -0.88	2.05
Sprinting	0.03 ± 1.24	-1.72 – 1.70	0.09	-0.78 – 0.84	4.11
30m 45° Turn					
Overall	-0.46 ± 0.89	-1.85 – 1.19	-1.53	-0.79 – -0.12	3.01
Jogging	-0.79 ± 0.74	-1.62 – 0.61	-2.62	-1.27 – -0.30	2.54
Striding	0.12 ± 0.65	-0.92 – 0.92	-0.40	-0.54 – 0.30	2.17
Sprinting	-0.47 ± 1.16	-1.85 – 1.19	-1.57	-1.23 – 0.29	3.94
20m 90° Right Turn					
Overall	0.16 ± 0.99	-1.57 – 2.41	0.82	-0.21 – 0.54	4.93
Jogging	0.52 ± 1.04	-1.21 – 2.04	2.58	-0.17 – 1.19	5.09
Striding	-0.11 ± 1.21	-1.57 – 2.41	-0.56	-0.90 – 0.68	6.08
Sprinting	0.09 ± 0.65	-1.01 – 1.14	0.43	-0.34 – 0.51	3.23
20m 90° Left Turn					
Overall	0.48 ± 0.99	-1.52 - 2.24	2.37	0.09 – 0.85	4.86
Jogging	0.01 ± 0.87	-1.52- 1.06	0.02	-0.56 – 0.57	4.34
Striding	1.04 ± 0.81	0.07 - 2.24	5.22	0.52 – 1.57	3.84
Sprinting	0.37 ± 1.09	-1.06 - 1.92	1.86	-0.34 – 1.08	5.34
15m Straight Line					
Overall	0.09 ± 0.71	-0.90 – 1.84	0.60	-0.18 – 0.36	4.73
Jogging	0.02 ± 0.71	-0.68 – 1.22	0.11	-0.45 – 0.48	4.75
Striding	0.25 ± 0.74	-0.61 – 1.80	1.64	-0.24 – 0.73	4.88
Sprinting	0.01 ± 0.74	-0.90 – 1.21	0.06	-0.48 – 0.49	4.94

Data are presented in m.

On average, the Optical Player Tracking System overestimated displacement by 0.25 % (table 7.1). The absolute mean difference for the estimates derived from the Optical Player Tracking System when compared with actual distance for all running courses was 1.39 %. The standard deviation of displacement measurements was greatest during sprinting trials (CV % = 4.31) when compared with striding (CV % = 3.80) and jogging trials (CV % = 4.19). A larger standard deviation was also observed with a greater turning angle (90° CV % = 4.89) when compared with straight line running (CV % = 4.08). Linear regression showed a strong correlation between displacement estimated from the Optical Player Tracking System and actual distance for jogging (n = 45, $r = 0.987$, $p < 0.001$), striding (n = 45, $r = 0.988$, $p < 0.001$) and sprinting (n = 45, $r = 0.986$, $p < 0.001$) trials. The data did not demonstrate heteroscedasticity. Further analysis revealed high levels of reliability for the manual quality control process for all running courses (table 7.2). Typical error was greatest during courses with a larger turning angle (90° TEM % = 1.74) when compared with straight line running trials (TEM % = 1.44).

Table 7.2 Reliability measures of the manual quality control process for each running course.

Course	Typical Error (m)	Total Error (m)	ICC	Typical Error as CV %
30m Straight	0.36	0.76	0.91	1.21
30m 45° Turn	0.31	0.67	0.93	1.06
20m 90° Right Turn	0.35	0.75	0.88	1.75
20m 90° Left Turn	0.35	0.75	0.89	1.73
15m Straight	0.25	0.53	0.89	1.67

ICC: Intraclass correlation coefficient.

7.5 DISCUSSION

The aim of this study was to measure the accuracy and reliability of displacement estimates derived from an Optical Player Tracking System while participants completed a soccer-specific running protocol. The key findings were: 1) the mean absolute percentage difference between estimated displacement and actual distance was 1.39 %, 2) the coefficient of variation was larger with a greater running speed and turning angle, and 3) the manual quality control process showed high levels of reliability.

On average, the Optical Player Tracking System overestimated displacement by only 0.25 % for all courses and running speeds. The absolute per cent difference was shown to be 1.39 %, which is less than the reported difference of a computer-based tracking system (5.8 % on average) (48) and GPS (4.7 % on average) (39,48), and is similar to a previously validated LPM system (<1.6% on average) (53). In addition, very high correlations ($r = 0.986 – 0.988$) were observed between displacement estimates and actual distance for jogging, striding and sprinting trials. The standard deviation expressed as a coefficient of variation increased with a greater running speed (sprinting compared to jogging) and turning angle (90° turn compared to straight line running). This finding is similar to observations made for LPM systems (53) and it can be suggested that this may be partly attributed to the running course design. Participants were instructed to follow the running course as closely as possible, however at higher running speeds and turning angles the corner may be cut or over-run because of an abrupt change of direction. The soccer-specific running protocol was based on courses used in studies that have previously validated vision-based tracking (120) and LPM systems (53), however future research may need to consider running courses that ensure participants do not deviate from the marked track for maximal accuracy of the criterion measure. Regardless, the coefficient of variation was well below 5 % on average and collectively these results show that the Optical Player Tracking System accurately estimates displacement on a soccer field.

The intraclass correlation coefficient values were similar for all running courses (ICC = 0.88 – 0.93) and showed high agreement between measures. The typical error expressed as a coefficient of variation was slightly greater for the 90° turns when compared with straight line running, however on average the typical error was only 1.48 %. In addition, this value is smaller than the reported coefficient of variation for the intra-model reliability of GPS (5.5 % on average) (39,48) and intra-operator reliability of a computer-based tracking system (2.76 % on average) (48). Collectively, data showed high levels of intra-operator reliability and therefore the human error associated with the manual component of the tracking process is minimal.

The present study determined the accuracy and reliability of displacement estimates derived from the Optical Player Tracking System. Speed and acceleration measures were not assessed as an accurate estimation of displacement subsequently results in an accurate estimation of speed and acceleration. This is because the Optical Player Tracking System generates an x,y ground location and timestamp t for each video frame. Therefore, the change in position between time points can be used to accurately determine speed by calculating displacement relative to known time. It should be acknowledged that the current study was limited to measuring forward running and turning movements. However, future research should include validating the Optical Tracking System to measure sideways and backwards movements to further replicate the soccer-specific movements involved in matches.

7.6 CONCLUSIONS AND PRACTICAL APPLICATIONS

The results of this study show that the Optical Player Tracking System offers an accurate and reliable method for determining displacement of players on a soccer field. Information related to activity profiles of soccer matches (particularly female soccer) are scarce due to tracking devices not being permitted in competitive matches until recently, and the expensive nature of commercially available vision-tracking systems. The non-invasive nature of this player tracking system offers an advantage over tracking devices as physical and tactical information of opposition teams can also be collected. In addition, this system allows data to be collected in indoor environments, offering an advantage over global positioning systems.

8.0 THE ACTIVITY PROFILES OF ELITE FEMALE SOCCER PLAYERS DURING COMPETITIVE MATCHES

8.i Preface

The previous chapter showed that the Optical Player Tracking System was both accurate and reliable for measuring displacement of players on a soccer field. This chapter will describe the activity profiles of elite female soccer players during competitive matches using the Optical Player Tracking System. This study is currently under review in the Journal of Sports Sciences.

8.1 ABSTRACT

Purpose: To determine the activity profile of elite female players during competitive matches using a new Optical Player Tracking System.

Methods: Eight high-definition video cameras were positioned at vantage points surrounding the soccer field so that when each camera view was combined the entire field could be viewed at once. Following each match the video footage was imported into an Optical Player Tracking System that detected the x,y coordinates of each player for every frame of video. Formulas applied to the Euclidean distance equation were used to determine activity variables for twelve elite female players across seven competitive matches.

Results: Players covered 9,220–10,581 m of total distance, 1,772–2,917 m of high-speed running distance and 417–850 m of sprinting distance, with variations between positional units ($p < 0.001$, partial $\eta^2 = 0.444$-0.488). Similarly, the number of high-speed runs differed between positional units ($p = 0.002$, partial $\eta^2 = 0.342$) and a large proportion of both high-speed runs (81–84 %) and sprints (71–78 %) were performed over distances less than 10 m. Mean time between high-speed runs (13.9 s ± 4.4) and sprints (86.5 s ± 38.0) varied according to playing position ($p < 0.001$, partial $\eta^2 = 0.409$) and time period of the match ($p < 0.001$, partial $\eta^2 = 0.113$ - 0.310).

Conclusion: The results of this study can be used to design match-specific conditioning drills, and also shows that coaches should take an individualised approach to training load monitoring according to positional unit.

8.2 INTRODUCTION

While it has been well established that during a match female soccer players cover a total of 8-11 km with up to 2.5 km at high-speeds (9,54,62,79,97,131), investigations that detail the specific high-speed running and sprint profiles of female soccer players are scarce. One study reported that the average distance per sprint effort above the sprint speed threshold was ~15 m, lasting 2.3 s with up to 2.8 minutes of lower intensity activity between efforts (134). It was also shown that the sprint characteristics varied between playing positions. Investigations of repeat sprint profiles reported that female players complete 4-6 repeat sprint bouts per game, with 3 sprints per bout and 4-7 s between each repeat sprint (54). This type of detailed activity profiling is useful for designing match-specific conditioning programs. However, to date only one study has reported the repeated high-speed and repeated sprint profiles of female soccer players (55) and a more thorough investigation of high-intensity activity profiles is warranted.

Until recently, player-tracking devices were not permitted in competitive soccer matches according to Fédération Internationale de Football Association (FIFA) regulations. As a result, the activity profiles of competitive matches have been predominantly quantified using vision-based tracking systems (e.g. PROZONE®). Unfortunately, because of their expensive nature, the use of these tracking systems are often limited to professional male soccer teams and research related to match activity profiles of females are scarce. In addition, the activity profiles of female players have predominately been quantified using manual time-motion analysis

(9,54,55,101). While these studies provide a useful foundation for the physical analysis of female players, the validity of manual time-motion analysis is questionable due the subjectivity of determining movement categories (e.g. jogging, running, sprinting).

Recently, the development of a novel, low cost Optical Player Tracking System has allowed for the non-invasive collection of competitive match data of soccer players. Therefore, the aim of this study was to determine the activity profile of elite female players across the course of a match using a new Optical Player Tracking System. A secondary aim was to determine the high-speed running and sprint profiles of female soccer players. The findings of this study can be used to develop match-specific conditioning protocols for elite female soccer players and optimise training load monitoring protocols.

8.3 METHODS

Subjects

Twelve elite female soccer players (age: 24.3 years ± 4.2, height: 171.9 cm ± 5.1, body mass: 65.3 kg ± 5.1, YYIR2 distance: 425 m ± 122, 25 m sprint time: 4.14 s ± 0.12) from the same Australian national league (W-League) team participated in this study. The team analysed was placed second to fourth in the overall league standings during the course of season analysed. All players analysed were considered free of injury by the team physiotherapist. The team played in a 4-3-3 formation for all matches analysed (n = 7) and players were categorised according to their playing position (central defenders = 3, wide defenders = 2, midfielders = 3, central attackers = 1, and wide attackers = 3). Only the activity profiles of players that played full matches were included in this study providing a total of 49 individual match files (central defender = 14, wide defender = 11, midfielder = 10, central attacker = 7, wide attacker = 7). The team trained four to five times per week and played one match per week. Prior to data collection, institutional ethical approval was granted and subjects were thoroughly informed of the procedures of the study by verbal and written communication. All players that participated in the study provided written informed consent.

Methodology

Player Tracking System

Matches were recorded using eight stationary high-definition video cameras (Legria HF R38, Canon, Tokyo, Japan) at vantage points that collectively provided a view of the entire 105 x 68 m playing area. Two video cameras were positioned 10 m behind each corner of the soccer field at a height of 20 m, which allowed for uninterrupted and unobscured capture for the duration of each match. Following each match, the video footage was imported into the tracking software (Optical Player Tracking, Australian Institute of Sport, Canberra, Australia) and each camera's video image was calibrated to the markings of the soccer field so that a pixel represented a known unit of measurement. A state-of-the-art optical player detector (28) generated a set of player detection observations where each observation consisted of an x, y ground location and a timestamp t. The Optical Player Tracking System samples noisy detections at 25 frames per second. Individual detections are aggregated into temporal sequences using the low and medium level hierarchical association methods described by Liu et al (88). This method generated short-term tracklets that encode the position of individual players over consecutive one-second epochs. A piece-wise cubic polynomial was fitted to the continuous player tracking using the midpoint for each one second epoch. Coordinates (x,y) for players can then be estimated by solving the cubic polynomial at any time point. This method provides a compact representation of the large-scale tracking data, and also offers a smoothing function for noisy data. Following the automatic tracking process, an operator verified that the trajectories identified for each player remained constant to that player throughout the duration of the match to ensure quality control. The Optical Player Tracking System has been shown to be accurate and reliable for measuring the displacement of players on a soccer field (chapter 7).

The x,y coordinates of the participants for each frame of video were exported as text files before being imported into SPSS statistical software (SPSS Inc. Chicago, IL) for data treatment. The distance covered by each player was calculated using the Euclidean distance algorithm which has been used previously to determine the activity profiles of soccer players (106):

$$\delta(n) = \sqrt{[x(n) - x(n-1)]^2 + [y(n) - y(n-1)]^2}$$

where:

$\delta(n)$ = the distance covered between frame n and frame n - 1

$x(n) - x(n - 1)$ = change in x position between frame n and frame $n - 1$

$y(n) - y(n - 1)$ = change in y position between frame n and frame $n - 1$

The distance covered per frame was summed to determine total distance.

The instantaneous speed $v(n)$ at time n/25 was then determined as:

$$v(n) = \frac{1}{t}[\delta(n) - \delta(n-1)]$$

where t = 1/25 s.

Match Activity Profiles

Total distance (TD), high-speed running distance (3.4 – 5.3 $m \cdot s^{-1}$) (HSRD) and sprint distance (>5.4 $m \cdot s^{-1}$) (SPRD) were reported for full matches, half matches and in 15 minutes time periods (P1: 0-15 mins, P2: 15-30 mins, P3: 30-45 mins, P4: 45-60 mins, P5: 60-75 mins, P6: 75-90 mins). Speed thresholds were chosen as they have been recommended for female soccer players (46) and are similar to recently used thresholds in previous research (62,97). Mean and maximum distance (m) per high-speed run and sprint were reported for each time period, as well as the mean and maximum time (s) between each run and sprint. High-speed runs and sprints were further analysed according to the distance of each individual run (< 10 m, 10-20 m, 20-30 m, > 30 m). In addition, high-speed runs and sprints were categorised according to whether they were repeat efforts (two or more high-speed runs or sprints with <20 seconds between each) and non-repeat (>20 seconds between each effort), which is similar to that which has been used previously to define repeat efforts (54,55). Only the first 45 minutes of each half were analysed to normalise the data (i.e. injury time was not included).

Statistical Analysis

Statistical analysis was conducted using SPSS version 21.0 (SPSS Inc, Chicago, IL). A Shapiro-Wilk test determined the data was normally distributed ($p > 0.05$). A one-way analysis of variance (ANOVA) with a Bonferroni post-hoc determined differences in variables between positional groups. A paired samples t-test and repeated-measures ANOVA determined variations in variables between 45 minute halves and 15 minute time periods, respectively. In addition to acquiring statistical significance ($p < 0.05$), partial eta-squared (η^2) (small = 0.01; medium = 0.06; large = 0.14) (117) and Cohen's d (small = 0.2; medium = 0.5, large = 0.8) (38) were used to measure the effect size. Data are presented as means ± standard deviations (SD) unless otherwise stated.

8.4 RESULTS

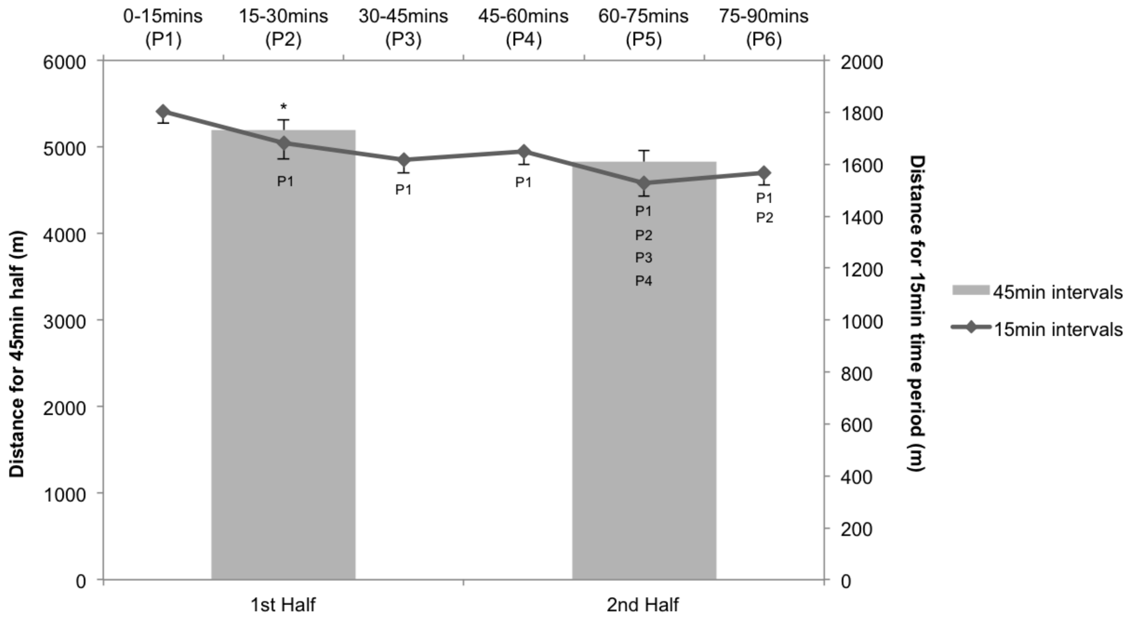
Table 8.1 Distances covered according to playing position.

Playing Position	Total Distance (TD) (m)	High-Speed Running Distance (HSRD) (m)	Sprinting Distance (SPRD) (m)
Central Attacker	9,661 ± 602	2420 ± 405	841 ± 238*#
Wide Attacker	10,472 ± 878*	2917 ± 545*	850 ± 178*#
Midfielder	10,581 ± 221*	2761 ± 417*	484 ± 169
Central Defender	9,220 ± 590	1772 ± 439	417 ± 116
Wide Defender	10,203 ± 568*	2569 ± 612*	680 ± 278*
All	10,025 ± 775	2452 ± 636	615 ± 258

*Data are presented as means ± SD. * $p < 0.05$ when compared to central defenders; # $p < 0.05$ when compared with midfielders.*

Total distance ($p < 0.001$, partial $\eta^2 = 0.488$), HSRD ($p < 0.001$, partial $\eta^2 = 0.444$) and SPRD ($p < 0.001$, partial $\eta^2 = 0.449$) varied according to playing position (table 8.1). Central defenders covered less TD ($p = 0.001$-0.003) and HSRD ($p = 0.001$-0.006) than wide attackers, midfielders and wide defenders, and less SPRD than central attackers ($p = 0.004$), wide attackers ($p = 0.001$) and wide defenders ($p = 0.039$). In addition, midfielders covered less SPRD than central attackers ($p = 0.025$) and wide attackers ($p = 0.007$). Players covered more TD ($p < 0.001$, $d = 0.896$), HSRD ($p < 0.001$, $d = 0.520$) and SPRD ($p = 0.001$, $d = 0.329$) in the first half when compared to the second half (figures 8.1a and 8.1b). In addition, fluctuations in TD ($p < 0.001$, partial $\eta^2 = 0.494$) and HSRD ($p < 0.001$, partial $\eta^2 = 0.378$) were found between 15 minute time periods (figures 8.1a and 8.1b), but not SPRD ($p = 0.078$). The mean SPRD per 15 minute time period ranged from 92-111 m. There were no time period x positional interactions found for 45 minute halves for TD, (p = 0.543) HSRD (p = 0.132) or SPRD (p = 0.293). Similarly, no time period x positional interactions were found for 15 minute periods for TD (p = 0.618), HSRD (p = 0.295) or SPRD (p = 0.090).

a)



b)

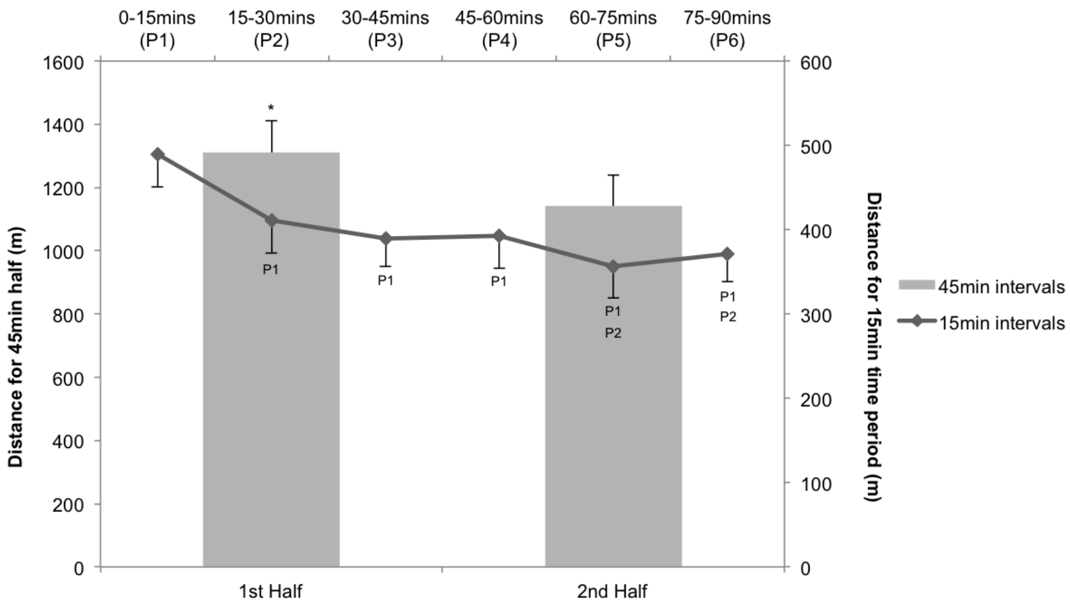


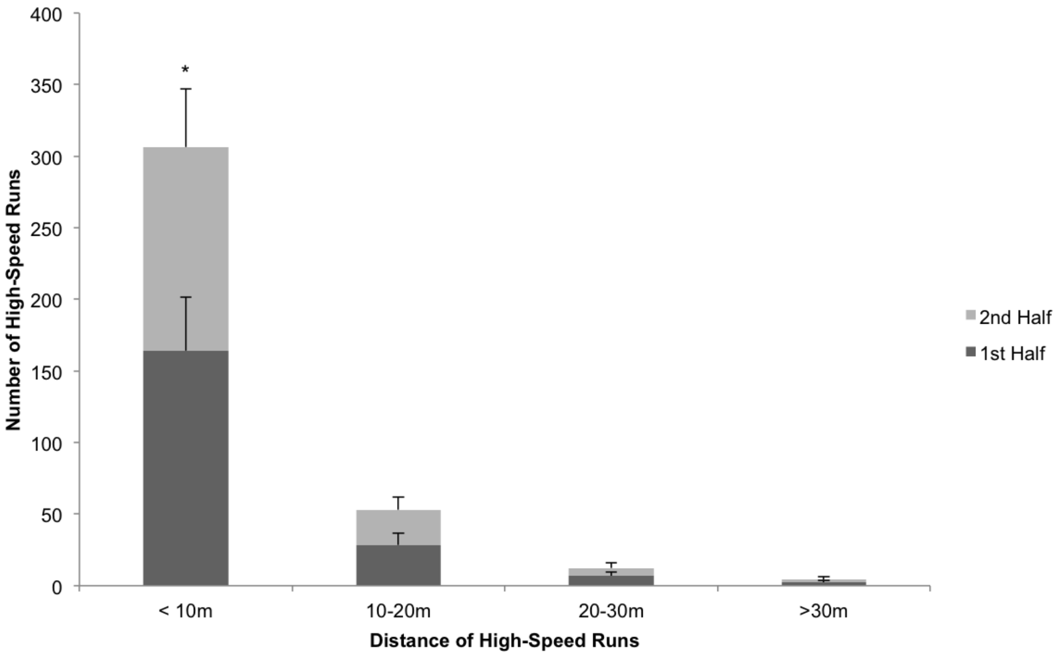
Figure 8.1 a) Total distance covered and b) high-speed running distance in 45min halves and 15min time periods. *Data are presented as means and 95 % Confidence Intervals. * indicates $p < 0.05$ when compared to 2nd half; $_{P1}$ (under error bar) indicates $p < 0.05$ compared to the P1 time period (0-15mins); $_{P2}$ (under error bar) indicates $p < 0.05$ when compared to the P2 time period (15-30mins); $_{P3}$ (under error bar) indicates $p < 0.05$ when compared to the P3 time period (30-45mins); $_{P4}$ (under error bar) indicates $p < 0.05$ when compared to the P4 time period (45-60mins).*

The number of high-speed runs (p = 0.001, d = 0.559) and sprints (p = 0.003, d = 0.366) that were < 10 m declined from the first half to the second half (figures 8.2 a and 8.2 b). In addition, the number of high-speed runs in each distance category varied according to playing position (p = 0.001 – 0.025, partial η^2 = 0.244 – 411) (table 8.2).

Table 8.2. Number of high-speed runs and sprints at different distances according to positional unit.

Position	Distance per effort			
	< 10 m (%)	10-20 m (%)	20-30 m (%)	> 30 m (%)
High-speed runs				
Central defender	243 ± 63 (84)	36 ± 12 (13)	8 ± 3 (3)	2 ± 1 (1)
Wide defender	310 ± 69 (81)	57 ± 16 (15)*	13 ± 4 (4)	5 ± 3 (1)
Midfielder	333±65 (81)*	59 ± 11 (14) *	15 ± 3 (4)*	6 ± 4 (2)*
Central Attacker	319 ± 75 (83)	53 ± 6 (14)	9 ± 3 (2)#	3 ± 1 (1)
Wide Attacker	350±55 (81)*	63 ± 13 (15)*	17 ± 5 (4)*	4 ± 2 (1)
Sprints				
Central defender	35 ± 20 (75)	7 ± 1 (15)	3 ± 1 (6)	2 ± 1 (4)
Wide defender	58 ± 27 (75)	11 ± 4 (14)	5 ± 2 (7)	3 ± 2 (4)
Midfielder	52 ± 22 (78)	10 ± 6 (15)	3 ± 2 (5)#	2 ± 1 (3)
Central Attacker	60 ± 24 (71)	13 ± 5 (15)	7 ± 2 (8)	5 ± 2 (6)*
Wide Attacker	63 ± 15 (71)	15 ± 5 (17)*	8 ± 2 (9)*	3 ± 1 (3)

*Data are presented as means ± SD of frequencies and per cent of total runs. * p < 0.05 when compared to central defender; # p < 0.05 when compared to wide attacker* a)



b)

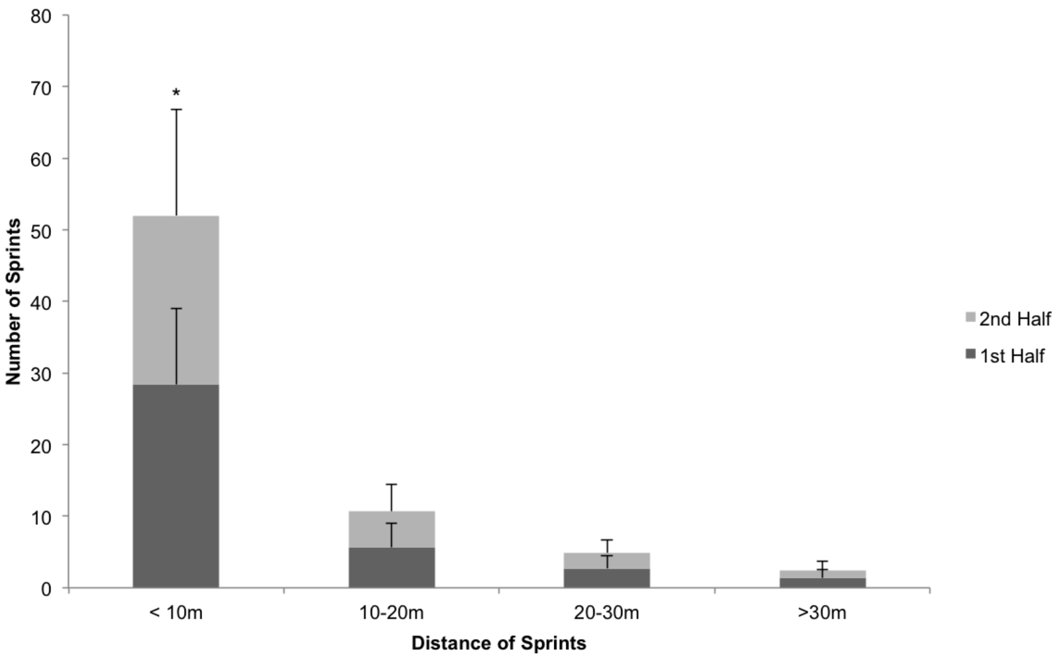


Figure 8.2 a) Number of high-speed runs and b) sprints at different distances. *Data are presented as means and SD of frequencies. * indicates $p < 0.05$ when compared to 2nd half*

The high-speed and sprint characteristics for repeat and non-repeat efforts are presented in table 8.3. The number of repeat high-speed runs differed between playing positions (p = 0.002, partial η^2 = 0.342), with central defenders performing the lowest number of repeat high-speed efforts (209 ± 71), compared to midfielders (334 ± 75, p = 0.009) and wide attackers (360 ± 75 p = 0.003). Similarly, the number of repeat (p = 0.014, partial η^2 = 0.270) and non-repeat (p = 0.006, partial η^2 = 0.305) sprints varied between playing positions. Central defenders performed the least number of repeat sprints (13 ± 9) compared to wide attackers (37 ± 11, p = 0.018). Likewise, central defenders performed the least number of non-repeat sprints (35 ± 13), compared to central attackers (57 ± 13, p = 0.012) and wide attackers (53 ± 7, p = 0.026).

There were no variations found between positional units for maximum and mean distance per high-speed runs (p = 0.265) or sprints (p = 0.234). However, the mean time between high-speed runs (p < 0.001, partial η^2 = 0.409) varied between positions, with central defenders reporting more time between runs (18.6 s ± 5.0) when compared to midfielders (11.9 s ± 2.2, p = 0.001), wide attackers (11.1 s ± 2.4, p = 0.001) and wide defenders (13.2 s ± 3.3, p = 0.011), but not central attackers (13.3 s ± 3.3, p = 0.088). Similarly, it was observed that central defenders also had a greater mean time between sprints (121.5 s ± 43.9, p = 0.002, partial η^2 = 0.340) when compared to central attackers (68.9 s ± 25.9, p = 0.047), wide attackers (59.1 s ± 13.8, p = 0.003) and wide defenders (77.5 s ± 27.6, p = 0.029), but not midfielders (85.9 ± 33.7, p = 0.162).

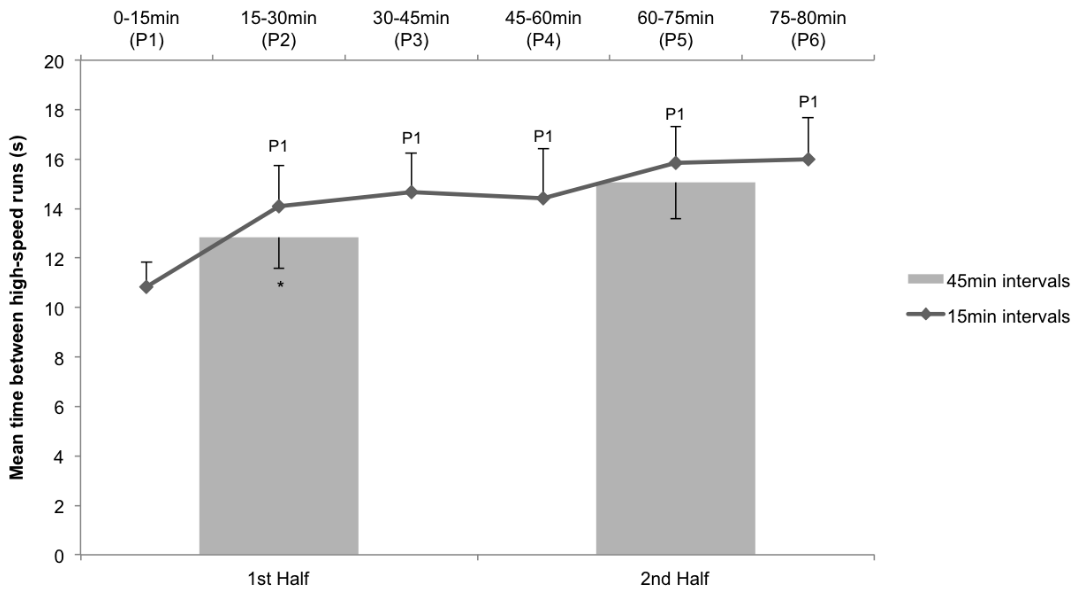
Table 8.3 High-speed and sprint characteristics for repeat, non-repeat and overall efforts during matches.

Variable	Repeat	Non-repeat	All
High-speed runs			
Count (n)	297 ± 93*	81 ± 6	376 ± 90
Max distance per run (m)	40.1 ± 9.9*	33.9 ± 9.5	42.4 ± 9.5
Mean distance per run (m)	6.3 ± 0.7*	6.9 ± 0.9	6.5 ± 0.7
Max time between runs (s)	19.4 ± 0.6	135.6 ± 41.4	135.6 ± 41.4
Mean time between runs (s)	4.9 ± 0.6	42.3 ± 5.8	13.9 ± 4.4
Sprints			
Count (n)	25 ± 17*	47 ± 13	70 ± 29
Max distance per run (m)	27.5 ± 12.6*	36.8 ± 10.0	39.1 ± 9.9
Mean distance per run (m)	7.7 ± 2.5*	8.8 ± 1.9	8.5 ± 1.8
Max time between runs (s)	16.8 ± 3.1	396.0 ± 144.5	396.0 ± 144.5
Mean time between runs (s)	5.2 ± 1.3	119.1 ± 40.5	86.5 ± 38.0

*Data are presented as means ± SD. * $p < 0.01$ when comparing repeat and non-repeat efforts.*

Further analysis revealed that the mean time between high-speed runs increased from the first to the second half ($p < 0.001$, $d = 0.493$) and varied between 15 minute time periods ($p < 0.001$, partial $\eta^2 = 0.310$) (figure 8.3a). In addition, maximum time between high-speed runs was lowest during P1 (70.7 s ± 20.2) when compared to all other 15 minute time periods ($p < 0.001$, partial $\eta^2 = 0.177$). Similarly, the mean time between sprints increased from the first half to the second half ($p = 0.005$, $d = 1.986$) and fluctuated between 15 minute time periods ($p < 0.001$, partial $\eta^2 = 0.113$) (figure 8.3b). The maximum time between sprints was lowest during P1 (212.4 s ± 91.2) when compared to P5 (294.3 s ± 124.9, $p < 0.001$, partial $\eta^2 = 0.107$).

a)



b)

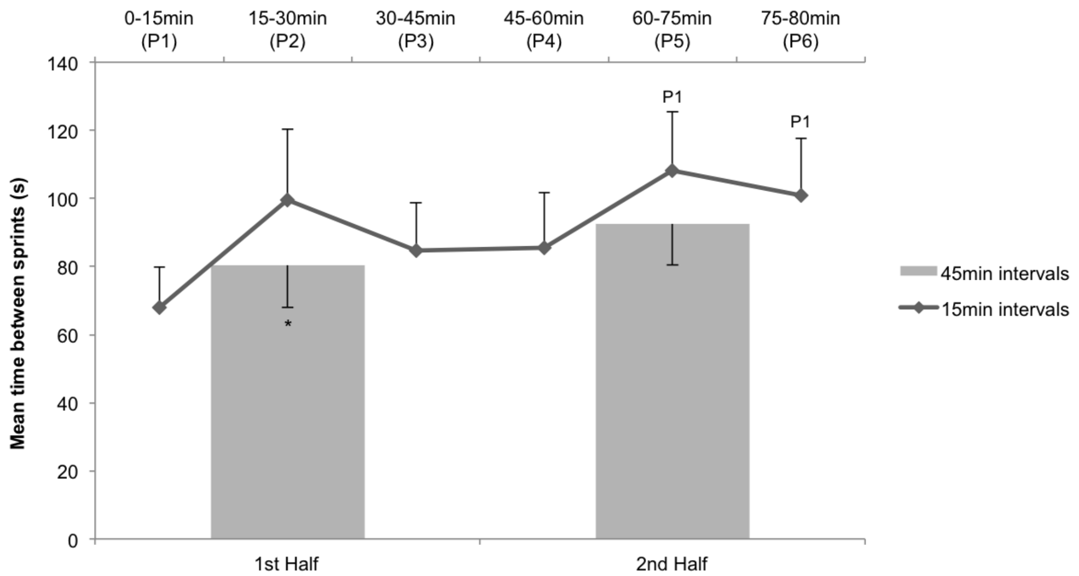


Figure 8.3. Mean time between a) high-speed runs and b) sprints in 45 min halves and 15 min time periods. *Data are presented as means and 95 % Confidence Intervals. * $p < 0.05$ when compared with 2nd half; $_{P1}$ indicates $p < 0.05$ when compared to P1 time period (0-15 mins).*

8.5 DISCUSSION

The aim of this study was to describe the activity profiles of elite female soccer players during competitive matches. To the authors' knowledge, this is the first study to quantify elite female players activity profiles during matches using an Optical Player Tracking System. The key findings were: 1) distances covered, high-speed running profiles and sprint profiles varied according to playing position, 2) the characteristics of high-speed runs and sprints differed for repeat and non-repeat efforts, and 3) distances covered and time between high-speed runs and sprints varied according to time period in the match.

Distance covered varied according to playing position with central defenders covering the least TD and HSRD when compared to midfielders, wide attackers and wide defenders. Central defenders also covered less SPRD than central attackers, wide attackers and wide defenders, while midfielders covered less SPRD than both the wide and central attackers. This is the first study of female soccer to categorise positional units based on wide and central positions and the results show clear differences in total distance, high-speed running distance and sprinting distance between central and wide defenders. Previous research in female soccer has tended to only categorise positional units according to defenders, midfielders and attackers (9,54,62,101,131), rather than considering the distinct tactical roles between the central and wide players. For example, wide defenders in a 4-3-3 formation will have attacking roles such as creating an overlap with midfielders or wide attackers to achieve a player advantage in their attacking third of the field, and will then be required to recover back to their own defensive third to perform defensive duties. The additional attacking role of a wide defender may attribute to the higher distance covered among all speed thresholds when compared to central defenders.

Similar to distances covered, the number of high-speed runs, the number of sprints and the time between each effort varied between playing positions. Central defenders performed the lowest number of high-speed runs when compared to midfielders and wide attackers for runs less than 10 m. Similarly, central defenders covered the least number of high-speed runs 10-20 m when compared to wide defenders, midfielders and wide attackers. This is the first study of female soccer to categorise the number of high-speed runs and sprints according to their distance and these findings have valuable implications for designing match-specific conditioning protocols. Overall, the majority of high-speed runs (81 – 84 %) and sprints (71 – 78 %) were less than 10 m in distance. These shorter distance efforts may be associated with one-on-one contests (duels) for the ball (128). The total number of high-speed runs (376 ± 90) and sprints (70 ± 29) reported in the present study are greater than earlier findings (number of high-speed runs = 125 – 239, number of sprints = 26 – 36) (79,101,134). This may be in part due to the different speed thresholds and tracking systems used to collect data, as well as the different levels of competition.

The mean time between high-speed runs ranged from 11-19 s with central defenders reporting the highest time between efforts compared to midfielders, wide attackers and wide defenders. Similarly, central defenders also had the greatest mean time between sprints (122 s ± 44) compared to central attackers, wide attackers and wide defenders (59–78 s). Earlier research has observed that the time between sprints was 126–168 s among professional domestic league players (134), and 94 s (± 44) among national level players (54). However, only one other study has reported on the time between high-speed running efforts during female matches (9–14 s) but this former research only investigated repeated high-intensity efforts and data from non-repeat efforts were not included (55). The findings from the current study can be used by coaches to monitor recovery times between training drills as well as ensure times between high-speed runs and sprints within small-sided games and conditioning drills are comparable to matches.

The characteristics of high-speed running and sprints differed between repeat and non-repeat efforts. It was observed that the majority (79 %) of all high-speed runs were repeat efforts while 35 % of all sprints were considered repeat sprints. Interestingly, the max distance per high-speed run was greater for repeat efforts (40 m ± 10) when compared to non-repeat efforts (34 m ± 10). On the other hand, the max distance per repeat sprint was lower (28 m ± 13) when compared to non-repeat sprints (37 m ± 10). In addition, the mean time between repeat high-speed runs and repeat sprints was 5 s, which is slightly less than previously reported findings of repeat high-speed runs (9-14 s) (55) and repeat sprints (6-8 s) (54). To date, this is the only study which has compared the characteristics between repeat and non-repeat efforts in matches and these findings have implications for designing specific repeat high-speed running and sprinting training drills.

Another key finding of this study was that the distances covered and time between high-speed runs and sprints varied according to time period in the match. On average, players covered 7 % more total distance, 13 % more high-speed running distance, and 14 % more sprinting distance in the first half compared to the second half. In comparison, a study of the female UEFA tournament showed a decrease of 4 % for total distance, 12 % for high-speed running distance, and 4 % for sprinting distance from the first half to the second half (21). In addition, players covered 8 % less total distance and 20 % less high-speed running distance in the first 15 minutes of the second half, compared to the first 15 minutes of the first half. Players also covered 13 % more total distance and 24 % more high-speed running distance in the first 15 minutes compared to the last 15 minutes of the match. These findings are comparable to another study that showed international and domestic level players decreased the amount of high-speed running distance by 24 % from the first 15 minutes to the last 15 minutes in a match (9), however one study of high-level players has also shown reductions of up to 40 % (101).

The mean time between high-speed runs and sprints increased from the first to the second half by 17 % and 15 %, respectively. These observations are similar to previous research which showed the recovery duration between repeat sprints was greater during the second half when compared to the first half (55). Likewise, the time between high-speed runs and sprints was lowest during the first 15 minutes compared to the final two 15 minute time periods. This is the first study to analyse time between high-speed runs and sprints according to 15 minute time periods, and these variations over the course of the match can be associated with the aforementioned reductions in total distance, high-speed running distance and sprinting distance. Collectively, these fluctuations in running performance and time between high-speed runs and sprints may be attributed to a combination of factors including physical and mental fatigue, game specific factors or strategies (i.e. players slowing the game down during the final minutes of play to avoid turning over possession) or the possibility of players adopting pacing strategies (111,126). However, the complexity of running performance variations in soccer makes it difficult to isolate specific factors and further research is required. Regardless, this information can be used by coaches to compare activity profiles in training to the distances covered in the most intense 15 minute time period of a match.

It should be acknowledged that this study was limited to seven games and twelve players from the same team. To create a more representative profile of elite female soccer players, data should be acquired from a greater number of games across several teams. However, due to the availability of the system, only home games for the analysed team were possible to collect. Further, the tracking system was not able to be used during severe weather conditions, limiting the number of games able to be analysed. Despite this, the current study provided 49 full match files in total, providing a sound representation of an elite female soccer team.

8.6 CONCLUSIONS

This was the first scientific paper to describe the activity profiles of elite Australian female soccer players during competitive matches using an Optical Player Tracking System. Players covered 9,220–10,581 m of total distance, 1,772–2,917 m of high-speed running distance and 417–50 m of sprinting distance. Players completed 376 high-speed runs and 70 sprints during a match, with a large proportion performed over distances less than 10 m with 14 s between high-speed runs and 87 s between sprints. The characteristics of high-speed runs and sprints differed between repeat and non-repeat efforts, and the activity profiles of players varied according to positional unit and time period of the match.

8.7 PRACTICAL APPLICATIONS

The findings from this study can be used to develop match-specific conditioning drills to optimise training and maximise on-field performance. Specifically, coaches should aim to increase players' speed over 10 m, which may be attributed to one-on-one contests for the ball. During repeat high-speed and sprint training, it is recommended that recovery time between efforts is 5 s and no more than 17 s. In addition, the maximal recovery time between training drills or efforts should not exceed 135 s. The findings from this study can also be used to develop activity profiles by which coaches can compare training demands to and optimise player load monitoring. For example, during training sessions coaches may aim to prescribe drills that match the high-speed running distance, number of high-speed runs and sprints, rather than the total distance of a full game. It is also recommended that coaches take an individualised approach to load monitoring and prescription of conditioning programs based on positional units.

9.0 THE ACCELERATION AND DECELERATION PROFILES OF ELITE FEMALE SOCCER PLAYERS DURING COMPETITIVE MATCHES

9.i Preface

Chapter 8 described the activity profiles of female soccer players in terms of constant speed runs and sprints. This chapter builds on chapter 8 by describing the acceleration and deceleration profiles of female soccer players during matches. This study is currently under review in the International Journal of Sports Physiology and Performance.

9.1 ABSTRACT

Purpose: The aim of this study was to determine the acceleration and deceleration profiles of elite female soccer players during competitive matches.

Methods: Eight high-definition stationary video cameras were positioned at vantage points surrounding the soccer field so that when each camera view was combined the entire field could be viewed at once. Following each match the video footage was imported into an Optical Player Tracking System that detected the x,y coordinates of each player for every frame of video. Formulas applied to the Euclidean distance equation were used to determine acceleration (≥ 2 m·s^2) and deceleration (≤ -2 m·s^2) variables for twelve elite female players across seven competitive matches.

Results: In total, players performed 423 (± 126) accelerations and 430 (± 125) decelerations per match. It was shown that the number of accelerations (p = 0.003-0.034, partial η^2 = 0.229-321) and decelerations (p = 0.012-0.031, partial η^2 = 0.233-275) at different intensities (based on the start and final speed) varied according to positional unit. Mean and maximum distance per effort was 1-4 m and 2-8 m, respectively, and differed between each intensity category ($p < 0.001$, partial η^2 = 0.753-0.908). The mean time between efforts was 14 s for both accelerations (± 5 s) and decelerations (± 4 s) and fluctuated between 15 minute time periods ($p < 0.001$, partial η^2 = 0.148–0.206).

Conclusions: The results of this study can be used to design match-specific acceleration and deceleration drills to enhance change of speed ability.

9.2 INTRODUCTION

The ability for a player to perform high-intensity actions over short distances can be linked with critical match events (50) and common soccer-specific requirements such as contesting for the ball in one-on-one situations (119). Because a number of these actions occur at distances less than 10 m (134) the capacity to accelerate can be an important factor for successfully taking on players when in possession of the ball, tackling players when in defense and getting to the ball first in a one-on-one contest. It has been theorised that accelerating on flat terrain is energetically equivalent to running on an uphill terrain (106) and is therefore more energetically demanding than constant speed running, even when accelerating from lower speeds. In addition, the capacity to decelerate can be linked to change of direction ability (33), which is important for regaining the ball after a loss of possession and performing cutting maneuvers to evade opposition tackles. It has been suggested that repeated deceleration might increase fatigue due to the rapid eccentric contractions required and therefore hinder performance (83). Further, a deceleration combined with a change of direction or cutting maneuver has been identified as a common movement that precludes non-contact playing injuries such as anterior cruciate ligament (ACL) injury (4). Therefore, match-specific training of acceleration and deceleration ability may help to optimise on-field performance and prevent injury. Research that details the acceleration and deceleration profiles of male players are scarce, and there are currently no reports of acceleration and deceleration profiles of female players during matches.

Two studies of male players have observed that the total distance covered was 1,022-1,767 m accelerating (> 1 $m \cdot s^2$) and 899-1,775 m decelerating (< -1 $m \cdot s^2$) (3,106). In addition, 178-180 m and 162-188 m were performed at high acceleration (> 3 $m \cdot s^2$) and deceleration (< -3 $m \cdot s^2$) thresholds, respectively. Acceleration profiles have also been quantified according to the start and final velocities of maximal accelerations (> 2.78 $m \cdot s^2$) to provide context to the intensity of the movement (128). It was observed that the majority of maximal accelerations (78 %) were undertaken from a starting speed < 2 $m \cdot s^{-1}$, and only 4 % of efforts reached a speed that was equivalent to the sprint threshold, despite being a maximal acceleration effort. Collectively, these findings demonstrate that examining distances covered in constant speed thresholds, without acknowledging acceleration and decelerations, may underestimate the physical demands of soccer matches. Further, it can be suggested that speed thresholds previously used to define sprinting may be too high as only a small proportion of maximal acceleration efforts even reach this threshold, despite being energetically demanding movements.

Therefore, the aim of this study was to determine the acceleration and deceleration profiles of elite female soccer players during competitive matches. The findings from this research can be used to design match-specific acceleration and deceleration conditioning programs to optimise training and prevent deceleration related injuries.

9.3 METHODS

Subjects

Twelve elite female soccer players (age: 24.3 years ± 4.2, height: 171.9 cm ± 5.1, body mass: 65.3 kg ± 5.1) from the same Australian national league (W-League) team participated in this study. The team played in a 4-3-3 formation for all matches analysed (n = 7) and players were categorised according to their playing position (central defenders = 3, wide defenders = 2, midfielders = 3, central attackers = 1, and wide attackers = 3). Only the acceleration and deceleration profiles of players that played full matches were included in this study. The team trained four to five times per week and played one match per week. Prior to data collection, institutional ethical approval was granted and subjects were thoroughly informed of the procedures of the study by verbal and written communication. All players that participated in the study provided written informed consent.

Procedure

Player Tracking System

Matches were recorded using eight stationary high-definition video cameras (Legria HF R38, Canon, Tokyo, Japan) at vantage points that collectively provided a view of the entire 105 x 68 m playing area. Two video cameras were positioned 10 m behind each corner of the soccer field at a height of 20 m, which allowed for uninterrupted and unobscured capture for the duration of each match. Following each match, the video footage was imported into the tracking software (Optical Player Tracking, Australian Institute of Sport, Canberra, Australia) and each camera's video image was calibrated to the markings of the soccer field so that a pixel represented a known unit of measurement. A state-of-the-art optical player detector (28) generated a set of player detection observations where each observation consisted of an x, y ground location and a timestamp t. The Optical Player Tracking System samples noisy detections at 25 frames per second. Individual detections are aggregated into temporal sequences using the low and medium level hierarchical association methods described by Liu et al (88). This method generated short-term tracklets that encode the position of individual players over consecutive one-second epochs. A piece-wise cubic polynomial was fitted to the continuous player tracking using the midpoint for each one-second epoch. Coordinates (x,y) for players can then be estimated by solving the cubic polynomial at any time point. This method provides a compact representation of the large-scale tracking data, and also offers a smoothing function for noisy data. Following the automatic tracking process, an operator verified that the trajectories identified for each player remained constant to that player throughout the duration of the match to ensure quality control. The Optical Player Tracking System has been shown to be accurate and reliable for measuring the displacement of players on a soccer field (chapter 7).

The x,y coordinates of the participants for each frame of video were exported as text files before being imported into SPSS statistical software (SPSS Inc. Chicago, IL) for data treatment. The distance covered by each player was calculated using the Euclidean distance algorithm which has been used previously to determine the activity profiles of soccer players (106):

$$\delta(n) = \sqrt{[x(n) - x(n-1)]^2 + [y(n) - y(n-1)]^2}$$

where:

$\delta(n)$ = the distance covered between frame n and frame n - 1

$x(n) - x(n - 1)$ = change in x position between frame n and frame $n - 1$

$y(n) - y(n - 1)$ = change in y position between frame n and frame $n - 1$

The distance covered per frame was summed to determine total distance.
The instantaneous speed $v(n)$ and instantaneous acceleration $a(n)$ at time n/25 was then determined as:

$$v(n) = \frac{1}{t}[\delta(n) - \delta(n-1)]$$

$$a(n) = \frac{1}{t}[v(n) - v(n-1)]$$

where t = 1/25 s.

Match Acceleration and Deceleration Profiles

Moderate to high-intensity acceleration (≥ 2 $m{\cdot}s^2$) and deceleration (≤ -2 $m{\cdot}s^2$) efforts were analysed. Thresholds were chosen as they have been defined as moderate intensity in previous research (3,106) and are similar to thresholds used to define max acceleration (128). Accelerations and decelerations were categorised by the starting and final speed of each effort to provide context to the intensity of the movement (table 9.1). Speed thresholds were chosen as they have been recommended to define high-speed running (3.4 – 5.4 $m{\cdot}s^{-1}$) (36,46) and sprinting (> 5.4 $m{\cdot}s^{-1}$) (46). Mean and maximum distance (m) per acceleration and deceleration effort, and mean and maximum time between efforts (s) were reported for full matches, half matches and 15 minute time periods (P1: 0-15 mins, P2: 15-30 mins, P3: 30-45 mins, P4: 45-60 mins, P5: 60-75 mins, P6: 75-90 mins). Only the first 45 minutes of each half were analysed to normalise the data (injury time was not included).

Table 9.1 Starting and final speed thresholds used to define acceleration and deceleration intensity

	Starting Speed ($m \cdot s^{-1}$)	Final Speed ($m \cdot s^{-1}$)
Acceleration		
A1	< 3.4 (low)	< 3.4 (low)
A2	< 3.4 (low)	3.4 – 5.4 (high)
A3	3.4 – 5.4 (high)	3.4 – 5.4 (high)
A4	3.4 – 5.4 (high)	> 5.4 (sprint)
A5	> 5.4 (sprint)	> 5.4 (sprint)
A6	< 3.4 (low)	> 5.4 (sprint)
Deceleration		
D1	< 3.4 (low)	< 3.4 (low)
D2	3.4 – 5.4 (high)	< 3.4 (low)
D3	3.4 – 5.4 (high)	3.4 – 5.4 (high)
D4	> 5.4 (sprint)	3.4 – 5.4 (high)
D5	> 5.4 (sprint)	> 5.4 (sprint)
D6	> 5.4 (sprint)	< 3.4 (low)

Statistical Analysis

Statistical analysis was conducted using SPSS version 21.0 (SPSS Inc, Chicago, IL). A Shapiro-Wilk test determined the data was normally distributed ($p > 0.05$). A one-way analysis of variance (ANOVA) with a Bonferonni post-hoc determined the differences in acceleration and deceleration variables between positional units. A paired samples t-test and repeated-measures ANOVA determined variations in variables between 45 minute halves and 15 minute time periods, respectively. In addition to acquiring statistical significance ($p < 0.05$), partial eta-squared (η^2) (small = 0.01; medium = 0.06; large = 0.14) (117) and Cohen's d (small = 0.2; medium = 0.5, large = 0.8) (38) were used to measure the effect size. Data are presented as means ± standard deviations (SD) unless otherwise stated.

9.4 RESULTS

Number of acceleration and deceleration efforts

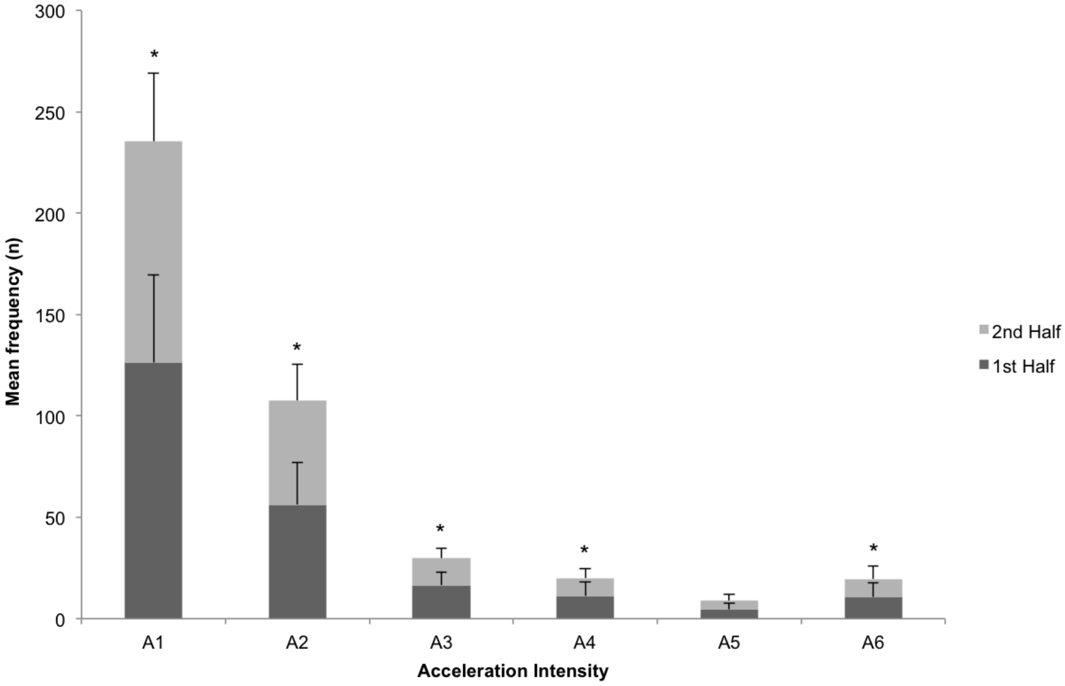
In total, players performed 423 (± 126) accelerations and 430 (± 125) decelerations per match. The number of acceleration (p = 0.003-0.034, partial η^2 = 0.229-321) and deceleration (p = 0.012-0.031, partial η^2 = 0.233-275) efforts per intensity category varied between positional unit (table 9.2), however there were no positional differences found for the total number of accelerations (p = 0.145) and decelerations (p = 0.183). The number of accelerations (p < 0.001, d = 0.471) and decelerations (p < 0.001, d = 0.468) declined from the first half to the second half. In addition, the number of accelerations and decelerations for each intensity category also declined from the first half to the second half, with the exception of A5 (figures 9.1a and 9.1b).

Table 9.2. The number of acceleration and deceleration efforts at different intensities for each position.

Intensity	Central Attacker	Central Defender	Midfielder	Wide Attacker	Wide Defender
Acceleration					
A1	198 ± 59	213 ± 79	266 ± 72	252 ± 64	237 ± 73
A2	116 ± 44	79 ± 30	123 ± 44	124 ± 23	108 ± 27
A3	35 ± 9*	20 ± 9	32 ± 8*	34 ± 9*	32 ± 9*
A4	26 ± 14*	11 ± 6	21 ± 9	27 ± 7*	21 ± 10
A5	14 ± 3*	7 ± 4	5 ± 3#	12 ± 3	10 ± 7
A6	24 ± 14	12 ± 7	18 ± 9	26 ± 11	23 ± 18
Deceleration					
D1	204 ± 54	225 ± 84	280 ± 72	254 ± 56	254 ± 74
D2	113 ± 41	83 ± 30	122 ± 43	129 ± 22	107 ± 32
D3	30 ± 12	17 ± 7	28 ± 8	29 ± 8	28 ± 14
D4	19 ± 10*	11 ± 5	14 ± 8	22 ± 7	19 ± 9
D5	9 ± 5	4 ± 3	5 ± 3	11 ± 6*	6 ± 6
D6	34 ± 15*	16 ± 8	24 ± 10	29 ± 9	29 ± 11

*Data are presented as means ± SD of frequencies. * $p < 0.05$ when compared to central defenders, # $p < 0.05$ when compared to central attacker*

A



B

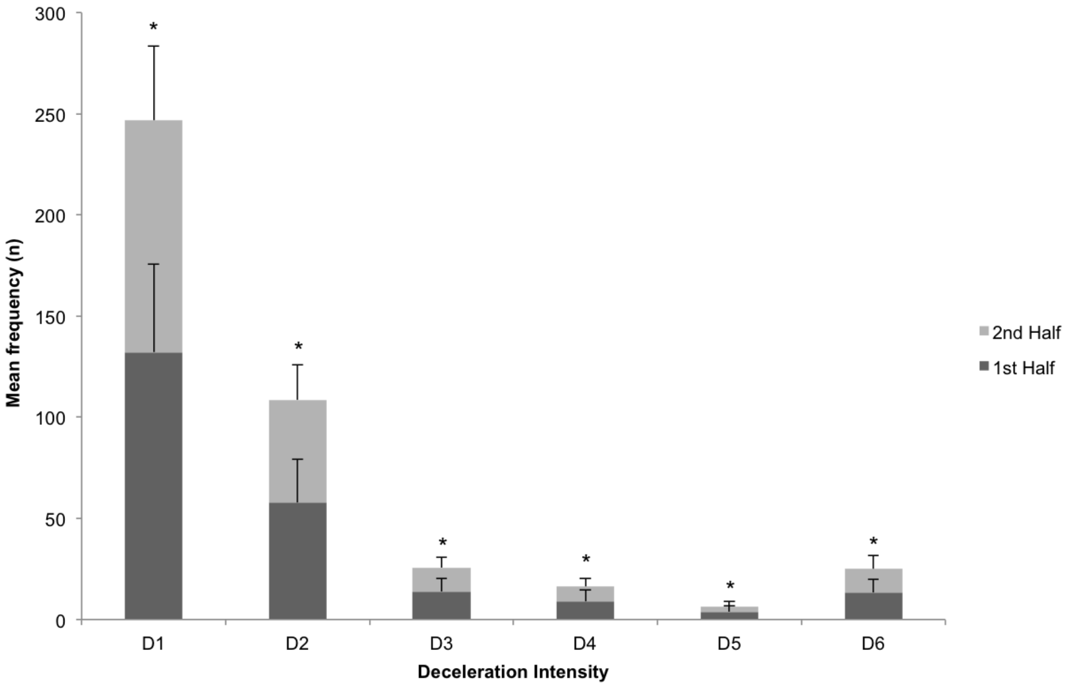


Figure 9.1 The frequency of efforts at different a) acceleration and b) deceleration intensities. *Data are presented as means ± SD of frequencies. * $p < 0.05$ when comparing the 1st and 2nd half.*

Distance per acceleration and deceleration effort

The maximum distance per acceleration (p = 0.017, partial η^2 = 0.260) and deceleration effort (p = 0.002, partial η^2 = 0.347) also differed between positional units. The maximum distance achieved while accelerating for wide defenders was 8.4 m (± 1.3), which was higher compared to central defenders (6.6 m ± 0.99) (p = 0.009). In addition, the maximum distance achieved when decelerating for central attackers was 10.5 m (± 1.3), which was higher when compared to central defenders (7.5 m ± 1.5, p = 0.008) and midfielders (7.1 m ± 1.4, p = 0.003). The mean distance per effort was 1.4 m for both accelerations (± 0.15) and decelerations (± 0.14), however there were no positional differences observed (p = 0.104–0.175).

Further analysis showed that the mean and maximum distance per effort varied according to acceleration and deceleration intensity (table 9.3). Pairwise differences were found among all acceleration and deceleration intensities, with the exception of A2 and A5 (p = 1.000), and D2 and D5 (p = 0.356). There were no variations in distance per acceleration and deceleration observed between 45 minute halves (p = 0.077-0.958) or 15 minute time periods (p = 0.149-0.989).

Table 9.3 Maximum and mean distance for each acceleration and deceleration effort at different intensities.

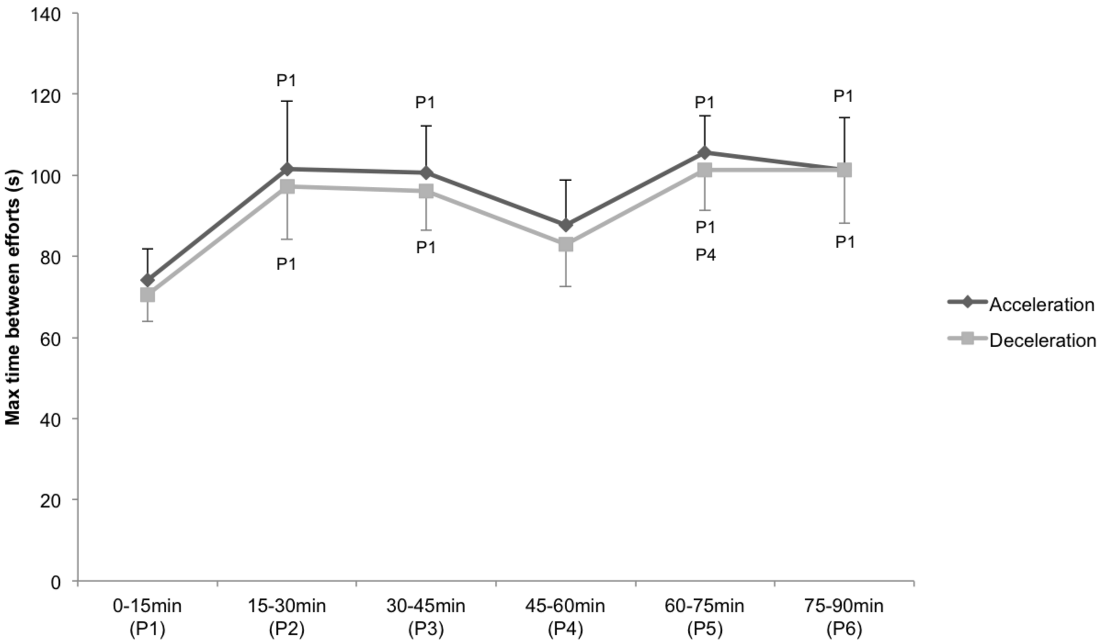
Intensity	Maximum Distance (m)	Mean Distance (m)
Acceleration		
A1	2.2 ± 0.2*	0.7 ± 0.0*
A2	4.7 ± 0.6#	2.1 ± 0.1#
A3	2.7 ± 0.4*	1.1 ± 0.2*
A4	6.2 ± 1.4*	3.1 ± 0.4*
A5	4.2 ± 1.6	2.0 ± 0.8
A6	7.4 ± 1.3*	4.3 ± 0.5*
Deceleration		
D1	2.1 ± 0.3*	0.7 ± 0.1*
D2	4.7 ± 1.1#	2.0 ± 0.1#
D3	2.7 ± 0.4*	1.2 ± 0.1*
D4	6.0 ± 1.4*	3.2 ± 0.5*
D5	3.9 ± 1.8	2.0 ± 0.7
D6	8.0 ± 1.9*	4.0 ± 0.4*

*Data are presented as means ± SD. * $p < 0.05$ when compared to all other intensities; # $p < 0.05$ when compared to all other intensities with the exception of A5.*

Time between acceleration and deceleration efforts

The mean time between efforts was 14 s for both accelerations (± 5 s) and decelerations (± 4 s). In addition, the maximum time between efforts was 136 s (± 48) for accelerations and 131 s (± 41) for decelerations. Further analysis showed that the mean time between accelerations ($p < 0.001$, $d = 0.360$) and decelerations ($p < 0.001$, $d = 0.431$) increased from the first half to the second half, and the mean and maximum time between efforts fluctuated between 15 minute time periods ($p < 0.001$, partial $\eta^2 = 0.148$–0.206) (figures 9.2a and 9.2b). There were no differences ($p = 0.090$-0.218) between positional units for mean and maximum time between accelerations and decelerations.

A



B

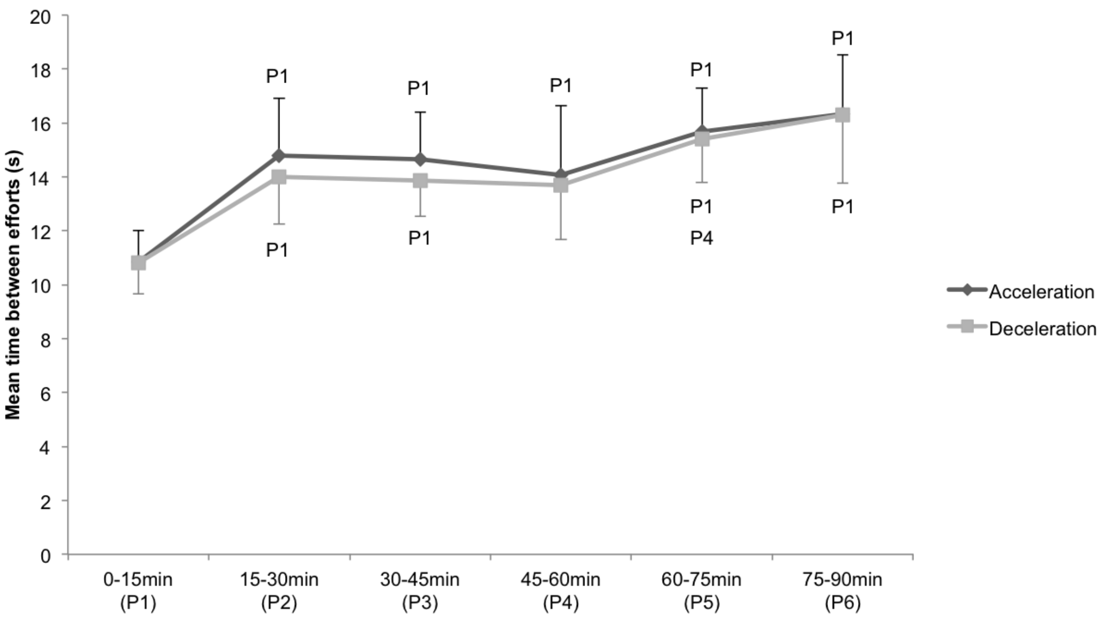


Figure 9.2a) Maximum and b) mean time between acceleration and deceleration efforts across 15min time periods. *Data are presented as means and 95 % confidence intervals.* $_{P1}$ *indicates* $p < 0.05$ *when compared to P1;* $_{P4}$ *indicates* $p < 0.05$ *when compared to P4.*

9.5 DISCUSSION

This is the first study to investigate the acceleration and deceleration profiles of elite female soccer players during competitive matches. The key findings of this research were: 1) The number of accelerations and decelerations at different intensities varied according to positional unit, 2) The distance covered while accelerating and decelerating differed according to the intensity of the effort and, 3) The time between acceleration and deceleration efforts fluctuated between time periods of the match.

In total, players performed 423 (± 126) accelerations (≥ 2 $m\cdot s^2$) and 430 (± 125) decelerations (≤ -2 $m\cdot s^2$) per match. Positional differences were observed in the number of accelerations at intensity A3 (started and finished at high-speed), A4 (started high and finished at sprint speed) and A5 (started and finished at sprint speed). Central defenders performed less A3 accelerations (20 ± 9) compared to all other positions (N= 32-35). Similarly, central defenders performed less A4 accelerations (11 ± 6) than central attackers (26 ± 14) and wide attackers (27 ± 7). Midfielders (5 ± 3) and central defenders (7 ± 4) performed less A5 accelerations than central attackers (14 ± 3). Collectively, these observations indicate that central defenders performed less “leading” accelerations, whereby players were already running before making a change in speed to a higher threshold. This is supported by research in men’s soccer where central defenders performed less leading sprints (13 ± 6) than other positions (17-27) (118).

Similarly, positional differences were also observed for the number of decelerations at intensities D4 (started at sprint speed and finished at high-speed), D5 (started and finished at sprint speed) and D6 (started at sprint speed and finished at low speed). Central defenders performed less D4 (11 ± 5) and D6 decelerations (16 ± 8) than central attackers (19 ± 10 and 34 ± 15), and less D5 decelerations (4 ± 3) than wide attackers (11 ± 6). Collectively, these findings showed that central defenders performed less deceleration efforts where they decelerated but continued to run at a high-speed, as well as fewer efforts where they decelerated from a sprint speed to a low speed. Overall, the number of decelerations reported in the current study (430 ± 125) was distinctly higher than a previous report of male players (n = 54) (18). This may be due to the previous study using a manual time-motion analysis system, which relies on a more subjective classification of decelerations. Further, the present study is the first to define deceleration by the starting and final speed and provides valuable insight into how coaches can train deceleration ability for each positional unit.

The maximum and mean distance for each acceleration and deceleration effort was different between all intensities, except for when comparing between A2 (start low and finish high) and A5 (start and finish at sprint speed), and D2 (start high and finish low) and D5 (start and finish at sprint speed). Players tended to cover the most distance when accelerating from low speed (< 3.3 $m \cdot s^{-1}$) to sprint speed (> 5.4 $m \cdot s^{-1}$) (A6), and when decelerating from sprint speed to low speed (D6), compared to all other intensities. On average, when players accelerated from low speed to sprint speed they covered 4.3 m (± 0.5) while changing speed. Likewise, players decelerated from sprint speed to low speed over 4.0 m (± 0.4). These explosive actions could be related to one-on-one contests for the ball. When accelerating from high speed (A4) to sprint speed, players covered 3.1 m (± 0.4) and similarly, players decelerated from sprint speed to high speed (D4) over 3.2 m (± 0.5). This is the first study to describe the distance covered per effort whilst accelerating and decelerating and this information can be used to effectively train leading and explosive accelerations and decelerations from different starting speeds. Future research should also consider the angle of any changes of direction that may accompany an acceleration and deceleration to effectively train change of direction ability.

Another key finding of the present research was that the mean time between acceleration and deceleration efforts increased from the first half to the second half by 14 % and 16 %, respectively. Previous research of female soccer has shown that the time between repeat sprints was greater during the second half compared to the first half (55), but no other research of female soccer has shown time between acceleration and deceleration efforts. In addition, both the mean and maximum time between accelerations and decelerations was lowest during the first 15 minutes compared to all other 15 minute time periods. Previous research has also shown reductions in acceleration and deceleration output across the course of a match (3), and collectively these findings may be attributed to a combination of factors including physical and mental fatigue, game specific factors or strategies (i.e.

players slowing the game down during the final minutes of play to avoid turning over possession) or the possibility of players adopting pacing strategies (111,126). Regardless, the mean time between efforts during the first 15 minutes was 11 s (± 4) for both accelerations and decelerations. The maximum time between efforts for the first 15 minutes was 74 s (± 25) for accelerations and 71 s (± 22) for decelerations. This information can be used by coaches to plan recovery duration between efforts by replicating the time between accelerations and decelerations during the first 15 minutes of matches.

It should be acknowledged that due to the availability of the system, only seven games and twelve players from the same team were able to be analysed. To create a more representative profile of elite female soccer players, data should be acquired from a greater number of games across several teams. Regardless, the current study provided 49 full match files in total, providing a sound representation of a female soccer team competing in an elite Australian national league.

9.6 CONCLUSION

This was the first study to describe the acceleration and deceleration profiles of elite female soccer players during competitive matches. In total, players performed 423 (± 126) accelerations and 430 (± 125) decelerations per match. The number of accelerations and decelerations at different intensities differed between positional units. The mean distance whilst accelerating and decelerating ranged from 1-4 m, and the maximum distance whilst accelerating and decelerating ranged from 2-8 m. The mean and maximum distance covered during acceleration and deceleration efforts varied according to the intensity of the movement. The mean time between efforts was 11-16 s for both accelerations and decelerations, and the maximum time between efforts was 74-105 s for accelerations and 70-101 s for decelerations. The time between efforts fluctuated throughout the course of the match.

9.7 PRACTICAL APPLICATIONS

The findings from this study can be used to develop match-specific acceleration and deceleration drills to optimise change of speed ability. Coaches can train leading accelerations by marking a 3-6 m zone whereby players need to accelerate from a high speed to a sprint. Coaches can also train explosive accelerations by marking a 4-7 m zone for players to accelerate from stationary or low-speed to a sprint. Similarly, coaches can mark a 3-6 m zone for players to decelerate from a high speed to a low speed and a 4-8 m zone to train deceleration from a sprint to a low speed. The distance of the acceleration or deceleration zone can be changed according to the starting and final speed wanting to be achieved. Further, it is recommended that the recovery time allocated between repetitions is 11 s, and the maximum recovery time allocated between drills is 71–74 s to replicate the mean and maximum time between efforts during the first 15 minutes of a match. It is also recommended that coaches take an individualised approach to monitoring the number of accelerations and decelerations during training sessions based on positional units.

10.0 DISCUSSION AND PRACTICAL APPLICATIONS

10.1 Chapter Reviews and Practical Applications

The aim of this thesis was to investigate the physical and physiological characteristics of elite female soccer players during training and competitive matches. The activity profiles of male soccer players during matches and training have been well documented in recent years. However limited research exists for female soccer players, despite the growing popularity and professionalism of the women's game. This thesis examined the characteristics of female soccer players across a playing season (chapter 4), during a week of preseason (chapter 5), during a sample of small-sided games in training (chapter 6) and during competitive matches (chapters 8 and 9). The research described in chapters 8 and 9 used a new and innovative player tracking system to quantify the activity profiles during matches. As such, prior to match data collection a validation study was conducted to determine the accuracy and reliability of this system for measuring displacement of players on a soccer field (chapter 7). This section will review the key findings of each chapter, provide practical applications of the results and identify future research directions.

10.1.1 Seasonal variations in training demands and physical performance

Chapter 4 described the variation in training demands, physical performance and player wellbeing across one playing season of an elite female soccer competition. The key findings were: 1) Total distance, high-speed distance and acceleration counts during training sessions declined across all phases from preseason to late season, 2) 5 m acceleration peaked following preseason and then declined at the end of season, 15 m sprint performance improved from the start to the end of preseason and then remained stable throughout the season, and 25 m sprint performance improved from the start of preseason to midseason and then declined at the end of season, and 3) YYIR2 performance and player wellbeing remained stable across the course of the season.

Figure 10.1 shows the variation in training demands and sprint performance across an Australian female team's national league season (W-League). The lower training demands during the competition phases, when compared to preseason, are likely due to the increased match load and therefore an attempt by the coach to taper players in the days prior to a match, and provide adequate recovery in the days following a match. In addition, acceleration performance (over 5 m and 15 m) is an independent characteristic to maximal speed (over 25 m) and improvements and decrements in performance are found at different stages of the season. That is, 15 m sprint performance peaked following the preseason phase, while 25 m sprint performance peaked following the early season phase (middle of competition). Coaches should also be aware that decrements in 5 m acceleration performance might be evident during the late season phase (figure 10.1).

Coaches should approach physical performance monitoring holistically, and incorporate objective measures of training load (e.g. from player tracking systems) as well as subjective measures of player wellbeing (e.g. muscle soreness and fatigue questionnaires). This will allow coaches to evaluate the physical performance of prescribed training and ensure that the session goals are being achieved. Further, coaches can also observe how players are responding to training through subjective measures of wellbeing. This form of monitoring has been implemented effectively at Canberra United Football Club, whereby every training session is monitored live using GPSports 15 Hz units and feedback is provided to coaches during sessions and a more comprehensive analysis is provided post session. Players also complete wellbeing diaries (recording subjective muscle soreness and fatigue) each day using a custom designed cloud-based spreadsheet interface (Google Drive, Google, California, USA). Adherence rates for completing the diaries have been high as players can access and complete the diaries quickly on their smartphones and this information is instantaneously shared with the coaching staff.

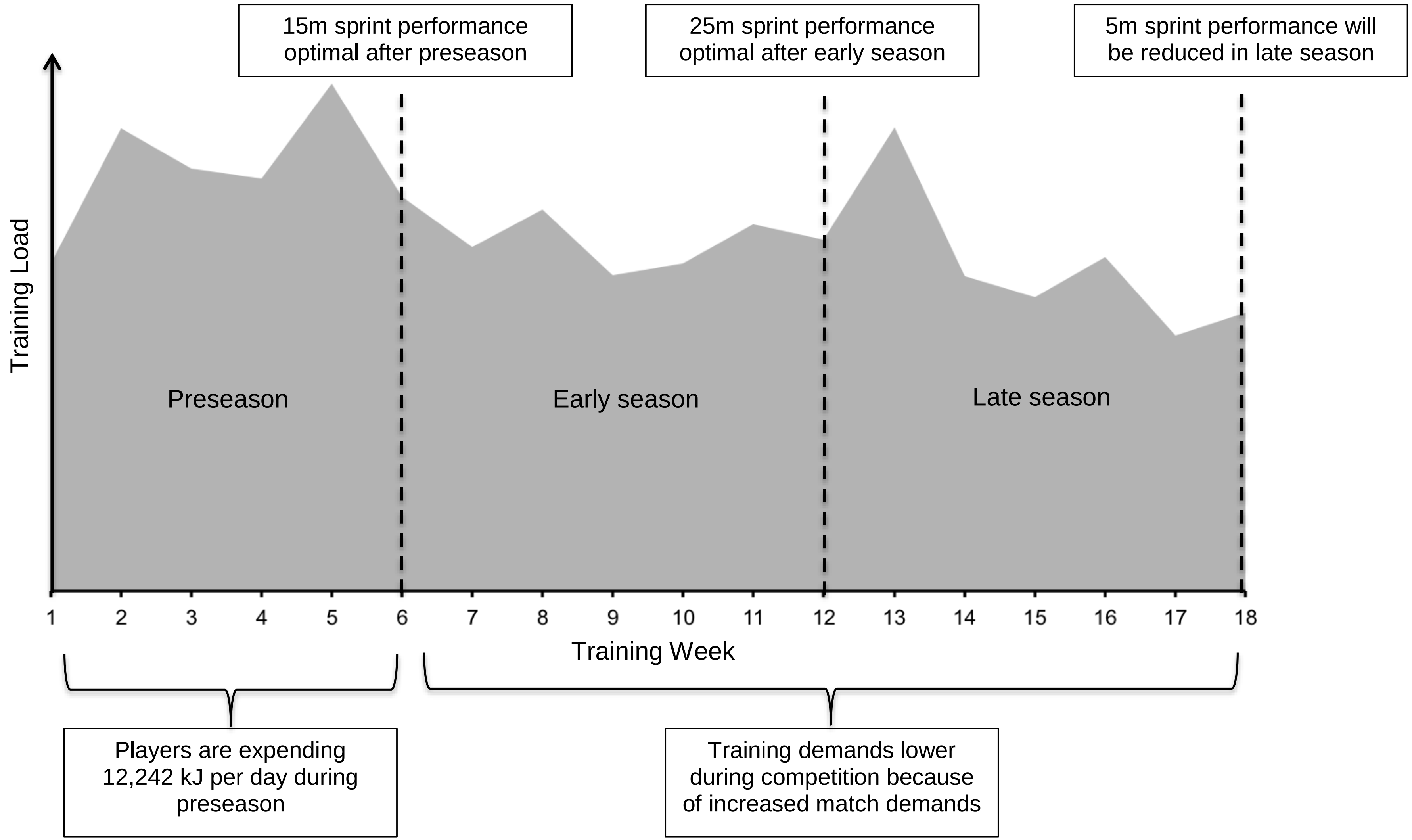


Figure 10.1 Performance and energy expenditure response to seasonal training load

10.1.2 Energy Expenditure

Chapter 5 assessed the total and exercise energy expenditure of elite female soccer players during one week of preseason. The key findings of this study were: 1) total energy expenditure was 12,242 kJ for the friendly game day, 11,692 kJ for the training days and 9,516 kJ for the rest days, 2) mean exercise energy expenditure was 2,695 kJ for the friendly game and 2,538 kJ for the training sessions, and 3) daily and exercise energy expenditure varied between individual days of the week and training sessions. It was also shown that GPS underestimated exercise energy expenditure when compared with the SenseWear Mini Armband. This was the first study to describe the total and exercise energy expenditure of elite female soccer players and the findings can be used as guidelines to advise players on adequate dietary intake during training days and rest days. Understanding the energy expenditure of elite female players is important for attaining optimal body composition traits that are advantageous for speed, and do not predispose players to Relative Energy Deficiency in Sport. Coaches should practice caution when using GPSports SPI HPU units to quantify energy expenditure and future research should aim to validate GPS units as a tool for measuring energy expenditure.

10.1.3 Small-sided training games

Chapter 6 investigated the physical and physiological response to different formats of small-sided training games. A review of the literature showed that only one study had previously described the physical characteristics of small-sided games for female soccer players, and no research had compared the response to different formats of small-sided games. This was also the first study to describe the acceleration profiles of female soccer players in training. The key findings were: 1) players covered more sprinting distance per minute during large sized games compared with smaller formats, 2) players covered less total distance and high speed running per minute during the second set compared to the first set in large sized games, 3) acceleration profiles differed in terms of distance, recovery duration, commencement and final velocities and repeated sprints between small-sided game formats, and 4) players spent more time in heart rate zones > 85 % HR_{max} in small sized games compared with larger formats.

Coaches can utilise smaller training games (40-50 m x 40 m) with less players per team (4v4 and 5v5) when aiming to develop players' explosiveness, repeat sprint ability over short durations, and to improve aerobic capacity, as shown in previous research of male soccer players (72) (table 10.1). Larger games (80-90 m x 68m) with a greater number of players per team (8v8 and 9v9) can be adopted to develop maximum speed and maintain aerobic capacity (table 10.1). Larger training games can also be used to develop the tactical elements of regular team play, because these games almost simulate the number of players and field dimensions of 11v11 conditions. Future research should compare small-sided games and generic interval training to determine the effectiveness of small-sided games as a conditioning stimulus among female soccer players. Future research should also aim to determine the technical and tactical implications of using different formats of training games.

Table 10.1. Characteristics of different formats of training games

Number of players*	Dimensions (m) L x W	Physical Goals	Physiological Goals
4v4 & 5v5	40-50 x 40	• Repeat acceleration ability • Less recovery time between accelerations • More 'explosive' accelerations from low speed thresholds	• Increase aerobic capacity
8v8 & 9v9	80-90 x 68	• Increase total sprint distance • Develop max speed • Longer distance per acceleration • Greater recovery between accelerations • More 'leading' accelerations	• Maintain aerobic capacity

** Excluding goalkeepers*

10.1.4 Player tracking system

The activity profiles of female soccer players during competitive matches (chapters 8 and 9) were quantified using a novel Optical Player Tracking System. This system had been used previously to discover adversarial group behaviour in field hockey (90), but had not been used to measure player movement on a soccer field. Therefore, chapter 7 aimed to determine the accuracy and reliability of this system for measuring displacement of soccer players. The difference between actual distance and estimated displacement was 1.39 % and collectively, typical error and intraclass correlation coefficient measures showed high levels of intra-operator reliability. It was concluded that the Optical Player Tracking System provided accurate and reliable estimates of displacement of players on a soccer field. The inexpensive and unobtrusive nature of the system allows data to be collected on all players simultaneously, including the opposition, providing an advantage over player tracking devices (e.g. GPS or LPS tracking). For the most accurate and reliable collection of data, cameras should be positioned in such a way that the entire field can be viewed at once when each video image is combined (figure 10.2). In addition, cameras should be positioned at a height which provides at least a 20° angle from the camera to the furthest point on the field in the camera image. This limits occlusions (i.e. if a player moves in front of another player in the image) and decreases the manual component of the tracking process (for quality control).

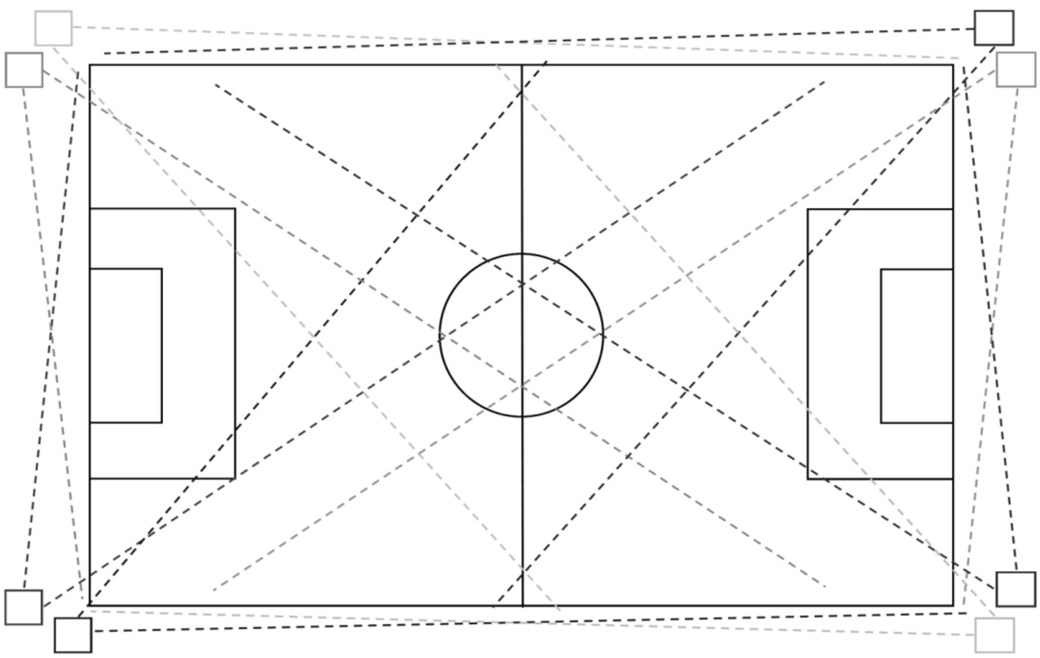


Figure 10.2 Multi-camera system positioning and field of view

This study validated the Optical Player Tracking System for forward running and turning movements. However, common soccer-specific movements such as sideways and backwards running were not included in the protocol and should be considered for future validation research.

10.1.5 Activity profiles in matches

Chapter 8 described the match activity profiles of elite female players. Specifically, the high-speed running and sprinting characteristics during matches were investigated. The key findings were: 1) players covered 9,220–10,581 m of total distance, 1,772–2,917 m of high-speed running distance and 417–850 m of sprinting distance, with variations between positional units, 2) the number of high-speed runs differed between positional units and a large proportion of both high-speed runs (81–84 %) and sprints (71–78 %) were performed over distances less than 10 m, and 3) mean time between high-speed runs (13.9 s ± 4.4) and sprints (86.5 s ± 38.0) varied according to playing position and time period of the match.

It should be acknowledged that this study was limited to seven games and twelve players from the same team. To create a more representative profile of elite female soccer players, data should be acquired from a greater number of games across several teams. However, due to the availability of the system, only home games for the analysed team were possible to collect. Despite this, the current study provided 49 full match files in total, providing a sound representation of an elite female soccer team.

A repeat sprint program has been developed from the findings from chapter 8 and is presented in table 10.2. This program is position-specific based on match demands, for example central defenders can perform less sprints than wide attackers, and receive more recovery time between sets than central attackers, wide attackers and wide defenders. It is recommended that recovery time between repetitions is 5 s (and no more than 17 s) and the distance of repeat sprints is 8 m. This program can be used to develop players' speed and repeat sprint ability over short distances, which are related to match specific actions such as one-on-one contests for the ball. Future research should investigate the activity profiles of substitutes and opposition players, and consider using individualised speed thresholds (e.g. based on a player's maximum sprint speed) to define high-speed running and sprinting.

Table 10.2 Position-specific repeat sprint training program

	Central Attacker	Central Defender	Midfielder	Wide Attacker	Wide Defender
Distance	8 m	8 m	8 m	8 m	8 m
Number	**29** (15-42)	**13**[a] (4-22)	**21** (12-31)	**38** (26-49)	**31** (22-40)
Recovery between repetitions	5 s	5 s	5 s	5 s	5 s
Recovery between sets	**69 s** (40-98)	**121 s**[b] (102-141)	**86 s** (65-107)	**59 s** (34-84)	**77 s** (58-97)

NB: Data are presented as means ± 95 % Confidence Intervals for number and recovery between sets. a = central defenders can perform less sprints than wide attackers. b = central defenders can receive more recovery time between sets than central attackers, wide attackers and wide defenders.

10.1.6 Accelerations and decelerations in matches

A review of the literature showed that no previous research had investigated the acceleration or deceleration profiles of elite female soccer players during matches. Further, quantifying the constant speed running of players without considering change of speed efforts may underestimate physical demands. Chapter 9 described the first study to determine the acceleration and deceleration profiles of elite female soccer players in competitive matches. In total, players performed 423 (± 126) accelerations and 430 (± 125) decelerations per match, with variations shown between positional units. The mean distance whilst accelerating and decelerating ranged from 1-4 m, and the maximum distance whilst accelerating and decelerating ranged from 2-8m. The mean and maximum distance covered during acceleration and deceleration efforts varied according to the intensity of the movement. The mean time between efforts was 11-16 s for both accelerations and decelerations, and the maximum time between efforts was 74-105 s for accelerations and 70-101 s for decelerations.

Tables 10.3 and 10.4 outline acceleration and deceleration training programs based on the findings from chapter 9. Coaches can train leading accelerations by marking a 3-6 m zone whereby players need to accelerate from a high speed to a sprint. Coaches can also train explosive accelerations by marking a 4-7 m zone for players to accelerate from stationary or low-speed to a sprint. Similarly, coaches can mark a 3-6 m zone for players to decelerate from a high speed to a low speed and a 4-8 m zone to train deceleration from a sprint to a low speed. It is recommended that the recovery time allocated between repetitions is 11-14 s, and the maximum recovery time allocated between sets is 70-105 s. The number of repetitions varies between playing positions based on match demands. That is, central defenders can perform less leading accelerations than central attackers and wide attackers, and less rapid decelerations than central attackers (tables 10.3-10.4).

Table 10.3 Leading and Explosive Acceleration Training

Acceleration	Leading (High → Sprint)	Explosive (Low → Sprint)
Distance	7 m high-speed lead* + 3-6 m acceleration to sprint speed	4-7m acceleration from stationary start to sprint speed
Number^	CA: 18-34 CD: 5-16[a] M: 15-27 WA: 20-34 WD: 16-27	CA: 12-35 CD: 5-20 M: 10-25 WA: 17-36 WD: 15-30
Recovery	11-14 s rest between repetitions, 70-105 s between sets	11-14 s rest between repetitions, 70-105 s between sets

*^ number of repetitions based on 95 % confidence intervals from matches (chapter 9), * based on findings from chapter 8, CA = central attacker, CD = central defender, M = midfielder, WA = wide attacker, WD = wide defender. a = CD can perform a lower number of leading accelerations than CA and WA.*

Table 10.4 Rapid and Moving Deceleration Training

Deceleration	Rapid Deceleration (Sprint → Low)	Moving Deceleration (Sprint → High)
Distance	9 m sprint lead* + 4-8 m deceleration to stop	9 m* sprint lead + 3-6 m deceleration to high-speed
Number^	CA: 24-43 CD: 9-22[b] M: 17-30 WA: 21-37 WD: 22-35	CA: 11-25 CD: 6-16 M: 9-19 WA: 16-28 WD: 14-23
Recovery	11-14 s rest between repetitions, 70-105 s between sets	11-14 s rest between repetitions, 70-105 s between sets

*^ number of repetitions based on 95 % confidence intervals from matches (chapter 9), * based on findings from chapter 8, CA = central attacker, CD = central defender, M = midfielder, WA = wide attacker, WD = wide defender. b = CD can perform a lower number of rapid decelerations than CA.*

10.2.7 Training Load Monitoring Tool (Chapters 8 and 9)

Tables 10.5-10.7 represent a Training Load Monitoring Tool that has been developed from the findings of chapters 8 and 9. The Training Load Monitoring Tool provides a guideline for a range of physical benchmarks whereby players can be monitored during conditioning training sessions according to their position. This monitoring tool is based on match activity profiles (chapters 8 and 9) and ensures players are not being overloaded or under-loaded. For example, central defenders covered less high-speed running distance and sprint distance combined in matches than all other positions. Therefore during training it is normal for these values to be lower than other positions because of their tactical roles. It is also recommended that the time between training drills (e.g. for players to have a drink break and for the coach to explain the next drill) should be no more than 135 s, as this is the maximum time between high-speed runs in matches.

Most tracking systems (e.g. GPSports) will have an alerting function which allows coaches to set benchmarks for each positional group, and if a player reaches the threshold the coach will be alerted by the software. The values presented in tables 10.5-10.7 can also be modified based on the session goals. For example, if the session goal is to condition players for match demands, these values should be reached by players in training. However, if the session has a tactical focus and the goal is for the session to be physically ‘moderate’ or ‘easy’ (e.g. the training session the day before a game), than the coach can ensure players reach only a predetermined percentage (e.g. 40-50 %) of these values. This system has been successfully implemented at

Canberra United Football Club (CUFC) training sessions for the 2015/2016 W-League season. Both the coaches and players have responded well to the objective evaluation of player load monitoring.

Table 10.5 Distances covered

Variable	Central Defenders	Central Attackers	Midfielders	Wide Defenders	Wide Attackers
HSRD (m)	**1771**[a] (1468-2075)	**2420** (1970-2871)	**2760** (2442-3079)	**2569** (2265-2872)	**2917** (2536-3298)
SPRD (m)	**417**[b] (294-540)	**840** (659-1023)	**483** (355–613)	**680** (558-803)	**850** (696-1003)
HSRD + SPRD (m)	**2188**[c] (1803-2574)	**3260** (2688-3833)	**3243** (2839-3649)	**3249** (2863-3635)	**3767** (3283-4250)

NB: Data are presented as means ± 95 % Confidence Intervals, a = central defenders cover less HSRD than all other positions, except central attackers. b = central defenders cover less SPRD than all other positions, except midfielders. c = central defenders cover less HSRD + SPRD than all other positions.

Table 10.6 Number of high-speed runs and sprints

Variable	Central Defenders	Central Attackers	Midfielders	Wide Defenders	Wide Attackers
High-Speed					
Repeat	**209**	**303**	**333**	**306**	**360**
	(160-257)	(231-375)	(282-384)	(258-355)	(299-421)
Not Repeat	**82**	**83**	**81**	**78**	**81**
	(78-85)	(78-89)	(77-85)	(73–83)	(77-85)
Sprint					
Repeat	**13**[a]	**29**	**21**	**31**	**38**
	(3-22)	(15-43)	(11-31)	(22-40)	(26-49)
Not Repeat	**35**[b]	**57**	**47**	**48**	**54**
	(29-43)	(47-68)	(39-54)	(40-55)	(45-63)

NB: Data are presented as means ± 95 % Confidence Intervals. Repeat = two consecutive runs with < 20 s recovery, non-repeat = two consecutive runs with > 20 s recovery. a = central defenders perform less repeat sprints than wide attackers, b = central defenders perform less non-repeat sprints than central attackers and wide attackers.

Table 10.7 Number of accelerations* and decelerations**

Intensity	Central Defender	Central Attacker	Midfielder	Wide Defender	Wide Attacker
Accelerations	**129**[a] (93-166)	**215** (160-269)	**199** (160-236)	**194** (158-231)	**223** (176-268)
Decelerations	**131**[b] (93-166)	**204** (150-258)	**192** (154-230)	**189** (152-225)	**220** (175-266)

*NB: Data are presented as means ± 95 % Confidence Intervals, * includes only accelerations that have a final speed > 3.4 $m.s^{-1}$, **includes only decelerations that have a start speed > 3.4 $m.s^{-1}$. a = central defenders perform less accelerations than wide attackers. b = central defenders perform less decelerations than wide attackers.*

10.2 Conclusions

This thesis aimed to investigate the physical and physiological characteristics of elite female soccer players during training and competitive matches. Firstly, the variations in training demands and subsequent physical performance were determined across a playing season. It was observed that training demands were highest during preseason and declined during the competition phases. In addition, 5 m, 15 m and 25 m sprint performance improved and declined at varying rates throughout the season, as sprint performance over 15 m and 25 m improved following preseason and early season, respectively, while 5 m acceleration performance declined following the late season phase. These findings support the concept that acceleration and maximal speed are independent characteristics and should be trained accordingly.

The second study assessed the total and exercise energy expenditure of elite female players during a week of preseason. Total energy expenditure was 11,692-12,242 kJ for training and a game day, and 9,516 kJ for rest days. In addition, mean exercise energy expenditure was 2,538-2,695 kJ. Understanding the energy expenditure of elite female players is important for attaining optimal body composition traits that are advantageous for speed, and do not predispose players to Relative Energy Deficiency in Sport. It was also concluded that coaches should practice caution when using GPSports metabolic calculations to determine energy expenditure. Future research should aim to determine the accuracy of GPSports metabolic calculations to assess exercise energy expenditure in soccer players.

The third objective of this thesis was to investigate the physical and physiological response to different formats of small-sided training games. The number of players and field dimensions were concurrently modified and it was shown that coaches can utilise smaller training games (40-50 m x 40 m) with less players per team (4v4 and 5v5) when aiming to develop players' explosiveness, repeat sprint ability over short durations, and to improve aerobic capacity. Larger games (80-90 m x 68m) with a greater number of players per team (8v8 and 9v9) can be adopted to develop maximum speed and maintain aerobic capacity. Future research should compare small-sided games and generic interval training to determine the effectiveness of small-sided games as a conditioning stimulus among female soccer players. Future research should also aim to determine the technical and tactical implications of using different formats of training games.

A novel Optical Player Tracking System was used to determine the activity profiles of elite female soccer players during competitive matches. This system had not been previously used to analyse the movements of players on a soccer field and therefore prior to match data collection a validation study was conducted. The difference between actual distance and estimated displacement was 1.39 % and collectively, typical error and intraclass correlation coefficient measures showed high levels of intra-operator reliability. It was concluded that the Optical Player Tracking System provided accurate and reliable estimates of displacement of players on a soccer field.

The final two studies of this thesis investigated the activity profiles and acceleration and deceleration profiles of elite female players during competitive matches. These were the first studies to use an Optical Player Tracking System to determine the movements of female soccer players. It was found that players covered 9,220–10,581 m of total distance, 1,772–2,917 m of high-speed running distance and 417–850 m of sprinting distance. A large proportion of high-speed runs (81–84 %) and sprints (71–78 %) were performed over distances less than 10 m and the mean time between high-speed runs and sprints were 14 s and 87 s, respectively. It was observed that central defenders covered less distance in all speed thresholds, performed fewer high-speed runs and sprints, and had a greater recovery time than other positions. This research only analysed players that completed a full 90 minute match and therefore future research should aim to determine the activity profiles of substitutes. In addition, future research should also consider the use of individual speed thresholds.

Chapter 9 discussed the first study that described the acceleration and deceleration profiles of female soccer players. It was shown that players performed 423 (± 126) accelerations and 430 (± 125) decelerations per match with variations observed between positional units. The mean distance whilst accelerating and decelerating ranged from 1-4 m, and the maximum distance whilst accelerating and decelerating ranged from 2-8 m. The mean time between efforts was 11-16 s for both accelerations and decelerations, and the maximum time between efforts was 74-105 s for accelerations and 70-101 s for decelerations. The findings from the final two studies have been used to develop match specific programs including a repeat sprint training program and acceleration and deceleration training programs. The findings from these studies have also been used to develop a Training Load Monitoring Tool that has been successfully implemented in an elite female soccer team. Collectively, the findings from this thesis can be used to provide objective information to coaches to optimise training and maximise on-field performance.

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