

**PHYSIOLOGICAL CHARACTERISTICS OF ELITE FEMALE SOCCER PLAYERS:
INFLUENCE OF AGE, POSITION AND PLAYING STATUS**

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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made in the acknowledgements.

Chapters 3 and 4 of this thesis represent 2 separate papers that have either been published, or have been submitted to peer-reviewed journals for consideration for publication. My contribution and the contribution by the various co-authors to each of these papers are outlined within the candidate contribution to co-authored work section of this thesis. All co-authors have approved the inclusion of the joint work in this Masters' thesis.

A handwritten signature in black ink, reading "Sarah Manson", written in a cursive style.

Sarah Manson

December 1st 2013

LIST OF PUBLICATIONS FROM THESIS**Chapter 3.**

Manson, S, Brughelli, M, & Harris, N. Physiological Characteristics of International Female Soccer Players. *Journal of Strength and Conditioning Research (accepted)*.

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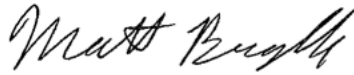
Manson, S, Brughelli, M, & Harris, N. Positional Differences and Determinants of Speed in Elite Female Soccer Players. *Journal of Strength and Conditioning Research (in review)*.

CANDIDATE CONTRIBUTIONS TO CO-AUTHORED WORK

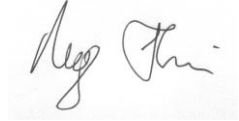
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Chapter 4. Manson, S., Brughelli, M., & Harris, N. Positional Differences and Determinants of Speed in Elite Female Soccer Players. In Review in <i>Journal of Strength and Conditioning Research</i> .	Manson 85% Brughelli 10% Harris 5%



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ETHICS APPROVAL

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC). The AUTEC reference was 12/95, with approval granted originally on 14 June 2012

ABSTRACT

Soccer is a highly dynamic and popular sport played by men, women and children of varying levels of expertise throughout the world. At the elite level it is imperative for strength and conditioning coaches to conduct a detailed analysis of the demands of the sport, in order to provide an evidence based evaluation of performance and further to inform specific goals and targets for athlete development. This thesis has sought to gain knowledge for the demands of female soccer at the elite and international level and to provide normative data regarding the physical characteristics associated with competition based on age, position and status as a starter or non-starter. On the basis of the literature review of the physiological demands and characteristics of elite female soccer it was established that performance outcomes are potentially linked to the physical capacity of the individual and could directly influence on-field technical performance and tactical choices. Elite female soccer players should strive to achieve the highest possible level of physical conditioning (aerobic and anaerobic) in conjunction with increased strength and power. There were no studies that focused on a link between physical characteristics and impactful performance outcomes (starters or non starters). The discrepancy in the literature between male and female demands of the game and the physical characteristics of elite female players made it difficult to distinguish what, if any physical characteristics are an asset for elite level competition. Age group data indicated that differences in physiological capacities are evident for the Under 17 players as compared to the Under 20 and Senior capped international players, suggesting a plateau in the development of physical qualities as players mature. Overall, starters tended to be faster ($ES = 0.55-1.0$, $p < 0.05$) and have a higher maximal aerobic velocity ($ES = 0.78-2.45$, $p < 0.05$), along with greater eccentric leg strength ($ES = 0.33-1.67$, $p < 0.05$) as compared to non-starters. When evaluating positional characteristics, isokinetic strength and maximal velocity were the only physiological measures of significant difference between playing position, mainly between strikers and central mid-fielders. In regards to sprint determinants, maximum sprint velocity was significantly correlated with isokinetic strength, sprint kinetics and kinematics, and leg power ($r = 0.36$ to 0.87 , $p < 0.05$), whereas acceleration was significantly correlated with isokinetic knee strength and horizontal jumping power ($r = 0.36$ and $r = 0.36$ respectively, $p < 0.05$). Practical

implications for future research as a result of this thesis include the need for coaches to emphasize the development of speed, maximal aerobic velocity and leg strength in developing female soccer players. It is suggested that improving unilateral leg strength and power may also be effective in enhancing maximal speed for elite players.

CHAPTER 1: INTRODUCTION AND RATIONALE

Background

Soccer is the worlds' most popular sport. Identification and development of talent from a young age is becoming increasingly important for national and international federations. Sport specific development academies and generalized training programs for developing players are being established to identify and develop both technical and tactical knowledge of the game (58). While there is an underlying theoretical framework for long-term athletic development in many countries (7) much of the detail regarding the influence of the demands of the game remains unclear, therefore physical training is becoming improvised by coaches.

To achieve success and reach the international level of any sport requires years of dedicated training and development across all impact areas of the sport, including technical skills, tactical knowledge, mental strength and physical ability aligned with the sports demands. To achieve this proficiency and ultimately reach the highest level of competition, training must begin at an early age and look to develop the physical qualities demanded of the sport. Soccer is a dynamic and intense multi directional intermittent sport, which requires a very high level of physical conditioning, strength and power to compete at the international level. It demands specific qualities or characteristics of an athlete, without which, success may only be short lived or unachievable.

Women's soccer has witnessed rapid growth over the last decade with over 29 million female players worldwide and a 32 % increase in participation (35). Despite this marked increase in participation, there is a disparity in the literature with the number of studies that characterize the physical performance characteristics of male players far outnumbering the studies on female players (47, 70, 88, 89). To date, there are only a handful of studies which outline the physical demands of the game and/or the physical characteristics needed at the elite or international level female soccer.

The ability to objectively assess physical performance has become a vital component for player development systems, player monitoring and youth player identification at the national and international level (19, 66, 74, 91). The literature reveals that elite players or selected players routinely achieve higher performance outcomes on sprint, strength and jump tests as compared to sub-elite (24, 40, 73, 85) or non-selected players (40, 47), further demonstrating the importance of evaluating the physical characteristics for soccer players. Since one sole characteristic or single performance measure cannot be isolated to determine the quality of a player (66, 74, 91) or their potential impact for team success, an understanding of the characteristics needed to be successful in the game can provide insight for an individual players potential for long-term success (58).

It is postulated that if key physical characteristics can be identified which reflect success at the elite or international level, young developing players may be trained in a way to develop these physical attributes so that a higher level of success and impact on the game may be achieved. This leads to the formulation of the central theme of this thesis, which was to identify the key physical characteristics in international female soccer players as a way to improve the understanding for the development of the next generation of international female soccer players.

Purpose Statement

The purpose of this thesis is to provide an overview of the knowledge regarding the physiological demands and the physical characteristics of elite female soccer players, including the influence of age, position and playing status. Firstly, literature examining the physiological demands of the game and the characteristics associated with performance for elite female soccer players will be reviewed. Secondly, the physiological characteristics of international female soccer players will be investigated, in terms of age, position and playing status. This thesis aims to fill in some of these gaps in the knowledge, to add context to the discussion and to make conclusions, which will guide best practice for developing impactful strategies for the physical development of elite female soccer players.

Study aims

The aims of this research were as follows:

1. To review the published literature for the physical demands of elite female soccer, including the physiological characteristics of players from an age, positional and playing experience perspective.
2. To research the physiological characteristics of international female soccer players, including anthropometrics, isokinetic strength, leg power, sprint kinetics and kinematics, aerobic and anaerobic running capacities, across FIFA international age brackets (Under 17, Under 20 and Senior), including the effect of position and status between starters and non starters.
3. To research the positional differences and determinants of speed (acceleration and maximal velocity) in FIFA international (Under 20 and Senior) female soccer players.
4. To use the data collected in the review and subsequent studies in context with the body of knowledge as a whole to provide best practice guidance to strength and conditioning coaches, technical coaches, soccer federations and players alike during assessment of physical performance during training, monitoring and youth player development at the national and international level.

Study Limitations

1. Data collected for chapters 3 and 4 took place during the final training phase for 3 International events, the FIFA U-17 Women's World Cup 2012, the FIFA U-20 Women's World Cup 2012 and the FIFA football tournament at the 2012 London Olympic Games. While the researcher was present for all training events throughout this period, on field and gym based sessions, accumulation of fatigue was present. Data collection was set for days in which the participants had a 24-hour rest period prior to testing. Participants were encouraged to provide truthful reports on any deviations from the set training schedule, hence full compliance was based on participant recall.
2. The length of the data collection extended over a 3-week period. While every attempt was made to collect data in their respective training groups, (Under 17, Under 20 and Senior), there was some cross over of participants. Thus a potential training adaptation for the participants tested in the final week of the

data collection period as compared to the participants in the first week of data collection may have occurred.

3. The reported $\text{VO}_{2\text{max}}_{30-15\text{IFT}}$ in Chapter 3 and 4 are based on prediction equations, which while validated, carry measurement errors and variability.

Study delimitations

1. Participation in the study was limited to participants who had represented New Zealand at the international level within the calendar year of 2012 for a pinnacle world event, including but not limited to the FIFA U-17 Women's World Cup 2012, the FIFA U-20 Women's World Cup 2012 and the FIFA football tournament at the 2012 London Olympic Games. This limitation was to insure participants were could be considered to be at an elite level.
2. To the best ability of the researchers, the data collection was standardized throughout the 3-week period of collection, working in conjunction with technical coaching staff of New Zealand Football; to ensure training loading was consistent throughout the collection period.

Structure of the thesis

This thesis consists of 5 chapters (see Figure 1) that culminate in an overall discussion. Some of the study chapters have been submitted for publication in research journals, which has allowed the author to gain international peer reviewed feedback on the content, which has improved the chapters. Each chapter is therefore presented in the wording of the journal for which they were written. Consequently, there is some repetition in the introduction and methods between the review and experimental chapters. References are not included at the end of each chapter; rather as required by AUT for thesis submission, an overall reference list from the entire thesis has been collated at the end of the final chapter. The reference format chosen is from the specific style required of submission to the Journal of Strength and Conditioning Research, based on the numerical style.

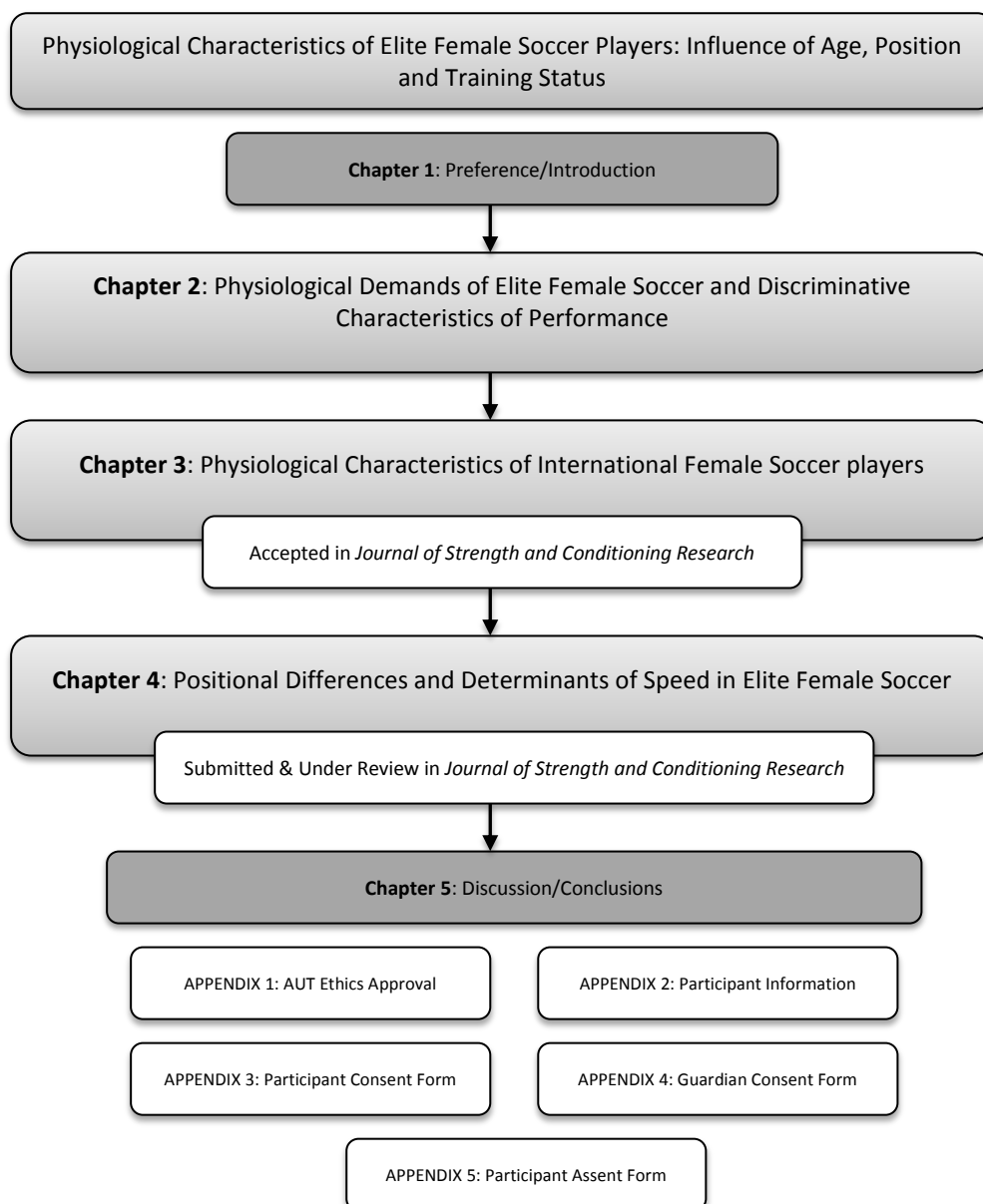


Figure 1: Overview of master's thesis chapter flow.

Chapter 2 contains a review of the literature relating to the physiological demands of international female soccer, with reference to the characteristics needed for competition at the elite level with respect to age, position and level played. This review looks to highlight the disparity in the literature pertaining to female soccer players and to provide recommendations relative to player physical development at the international and elite level.

As chapter 2 demonstrated a lack of normative data pertaining of international female soccer players, the third chapter of this thesis examined the physiological

characteristics of FIFA eligible elite female soccer players ranging from 14 to 36 years of age on sprinting kinetics and kinematics, isokinetic strength, unilateral jumping and maximal aerobic velocity, in an effort to distinguish age related and playing-time related differences. The main body of chapter 3 includes the accepted paper from the *Journal of Strength and Conditioning Research*, where normative data of the physiological characteristics for this cohort of athletes was presented and key findings from the analysis suggest there is little difference in sprint kinetics and kinematics post maturation, but there may be a window of accelerated adaptation to training for increased development of these characteristics, before the completion of sexual maturation.

As a result of the findings from chapter 3 regarding the maturational differences in speed and strength development at the international level, chapter 4 utilized data from the Under 20 and Senior level age groups, 18 to 36 years of age. This analysis was to identify the position specific physiological characteristics of FIFA eligible female soccer players, and to identify the relationship of strength, power, sprinting kinetics and kinematics with measures of acceleration (10-m time) and maximal velocity. It was established that positional related differences are present in the variables assessed and that the relationship for acceleration and maximal velocity are different between strength, power and sprinting kinetics and kinematics.

Chapter 5 consists of a general discussion of the findings from the presented research projects, comments on limitations to the research studies, provides areas for future research, and provides some concluding statements on the key finding from the thesis.

CHAPTER 2: PHYSIOLOGICAL DEMANDS OF ELITE FEMALE SOCCER AND DISCRIMINATIVE CHARACTERISTICS OF PERFORMANCE

Introduction

Soccer is the most popular sport in the world (8), played by men, women, children and adolescents at varying levels of expertise. Most noticeable, the popularity of women's soccer has witnessed rapid growth in the past ten years as evidenced by 29 million female players worldwide and a 32 % increase in participation (35). While soccer may be played for fun, fitness or pure enjoyment, soccer at the elite level is highly competitive and underpinned by science (8). Successful performance outcomes in soccer are heavily reliant on an integrated approach, incorporating technical proficiency, tactical knowledge and an exceptionally high level of physical conditioning at the elite level. By understanding the physical demands of the game at the elite level, specific activity profiles may be developed regarding age, position and training status to better inform assessment and conditioning practice.

Physical Demands of the Game

Previous research has identified that on an average pitch (105 meters x 68 meters) senior elite female field players will cover upwards of 10.4 km of field space and goalkeepers roughly 4km (38, 39, 56, 67). Current research reports that midfield players run the longest distances and that elite and international players run longer distances than non-professionals (30, 67). Intensity of exercise is shown to reduce throughout the match and the distance covered is 5-10% less in the second half compared to the first (9, 68). During a match, a sprint bout can occur up to every 90 seconds, with each sprint lasting upwards of 2 to 6 seconds (9). Elite female players will perform over 1300 different activities, with a change in the type or level of activity every 4 seconds (38, 39, 56, 67). While low intensity activities including standing, walking and jogging have been identified as the predominant movement patterns (upwards of 90 % of the 90 minute game), the distance covered, as well as the rate of fatigue during the high intensity and sprinting activity is the main determinant between higher and lower standards of play (3, 49, 67, 68). Elite female players complete 1.68 ± 0.09 km at high intensity and 0.46 ± 0.02 km sprinting throughout a game, which is 28 % and 24 % greater than non-elite level respectively (67). Furthermore, explosive actions such as

sprints, jumps, tackling, duels, kicking and changing pace help to determine the outcome of a match and add to the overall demands on the athlete (73).

Game Intensity

Throughout a 90-minute match, soccer players rely mainly on aerobic metabolism to sustain activity(82). The intensity of work throughout this 90-minute period is measured as a percentage of maximal heart rate (HRmax) and remains close to anaerobic threshold (i.e. the highest intensity possible where the production and removal of lactate is equal; normally between 80-90% of HRmax in soccer players (82)) throughout the match duration. (see Table 2.). As soccer is an intermittent sport, there are periods of very intense activity (> 90% HRmax) and periods of relatively low-intensity activity which aids in the removal of lactate from the working muscles. When reviewing the literature, there is no difference in exercise intensity between professional and non professional soccer, although absolute intensity is higher in professionals (30). Stroyer et al.(83) identified that HRs during matches of younger elite players were elevated above those of their non-elite counterparts. For young elite boys, average HRs during games were similar during early puberty and at the end of puberty, although early pubescent boys had a higher VO₂ relative to body mass than non-elite players. Furthermore, time motion analysis revealed that the main difference between elite and non-elite players was match activity, and the quantity of time-spent standing was significantly higher for non-elite players throughout a match. While this data refers to elite youth male players, it may be postulated that with further investigation into the female game, intensity may be relative between male and female, and that the same findings may be present for the female game.

It has been shown that there is a large variation in distances covered at different intensities in male soccer, with extreme differences between level, league and playing divisions within countries (82). While the data is not as extensive for elite female soccer, the variability of distance covered at high intensity between playing levels (see Table I) demonstrates that international level female players cover more distance at high intensity and perform a greater number of high intensity runs as compared to top domestic elite leagues while covering similar absolute distances within a match. This difference leads to the acknowledgement that the intensity of an international match

may be elevated over a top domestic league with greater time spent above 90% HRmax, thus requiring a higher aerobic capacity than their domestic counterparts.

Anaerobic Utilization in Soccer

While aerobic metabolism is the dominant system for energy delivery during a soccer game, it is the anaerobic based actions such as short sprints, jumps, decelerations, tackles, shots and duels which lead to successful performance outcomes (73). While data is very limited for female players, male data suggests that elite players tax the anaerobic system to a larger degree than non-elite players and to a higher degree in the first half of play than the second half. Brewer and Davis (1994) reported that female players dropped their blood lactate levels from 5.1 ± 2.1 to 4.6 ± 2.1 mmol/L between the first and second half of a Swedish elite league match. It is important to note that the actions leading to anaerobic energy use are variable within a match, and are dependent on the activity patterns of players prior to sampling.

Physiological Profile of Elite Female Soccer Players

Previous research indicates that both male and female soccer players tax the anaerobic and aerobic systems to a similar level (44), although female soccer players appear to cover less distance within a match, perform fewer high intensity efforts and have a reduction in sprints compared to male players. There are relatively few studies which profile the physical demands of the female game or provide a physiological profile of female players. There is a reported VO₂max of 46.0-57.6 ml/kg/min for female players (table 2). The VO₂max reported for out-field players varies to that of goalkeepers. Large differences have been observed between levels of play, with international players demonstrating superior levels of aerobic capacity as compared to domestic league players or NCAA/CIS counterparts. As the information published regarding the aerobic abilities of elite female soccer players is limited, it is difficult to establish an age related effect for aerobic capacity. All players within the current literature have been of the same maturation

Table 1. Distance covered in different positions, and activity profile of distance covered at different speeds in elite female soccer

Study	Level (country)	Elite Playing Exp (y total)	Position	N	Age (y)	Distance Covered (km)	Distance Covered/ min (km/min)	HIT Running (km) (>18km)	HIT Running Efforts (#)	Sprint Distance (km) (>25km)	Sprint Effort (#)	Activity Changes (#)
Andersson et al. (3)	International (Denmark & Sweden)	+ 5 y	Defender	9		9.50 ± 0.90	0.11	1.30	149 ± 15	0.22 ± 0.03	21 ± 3	1641 ± 41
			Midfield	5	27±1	10.6 ± 0.30	0.12	1.90	239 ± 30	0.32 ± 0.05	27 ± 4	
			Forward	3		9.80 ± 0.20	0.11	1.65	208 ± 29	0.62 ± 0.05	25 ± 5	
Krustrup et al. (56)	Elite League (Denmark)	+ 3 y (+9y)	Defender	5	24±4	10.3 ± 1.10	0.11	1.31 ± 0.70	125 ± 61	0.16 ± 0.16	26 ± 24	1459 ± 137
			Midfield	5	23±5							
			Forward	4	25±4							
Mohr et al. (67)	International (Denmark & Sweden)	+ 5 y		19		10.3 ± 0.15	0.12	1.68 ± 0.10	154 ± 7	0.46 ± 0.02	30 ± 2	1379 ± 34
Mohr et al. (67)	Elite league (Denmark & Sweden)	+ 5 y		15		10.4 ± 0.15	0.12	1.30 ± 0.10	125 ± 7	0.38 ± 0.05	26 ± 1	1326 ± 24

HIT = High Intensity; Exp = Experience

Table 2. Physiological profile of elite female soccer players

Study	Level (country)	N	Anthropometry ($\pm$ SD)		VO ₂ max ($\pm$ SD)		% HRMax (average)
			Height	Weight	ml/kg/min	ml/kg0.75/min	
Andersson et al. (3)	International (Denmark & Sweden)	17					85 $\pm$ 3
Davis & Brewer (27)	International (England)	14	166.0 $\pm$ 6.1	60.8 $\pm$ 5.2	48.4 $\pm$ 4.7	135.2	
Evangelista et al. (32)	Elite League (Italian)	12			49.75 $\pm$ 8.3		
Gabbet et al. (68)	NCAA (American)	30			51.4 $\pm$ 5.4		
Helgerud et al. (45)	Elite League (Norway)	12	169.7 $\pm$ 7.1	62.5 $\pm$ 7.4	54.0 $\pm$ 3.54	151.5 $\pm$ 9.3	
Jensen & Larsson (52)	International (Denmark)	10	169.0	63.2	53.3	150.3	
Krustrup et al. (56)	Danish Elite League	23			52.3 $\pm$ 1.3		87 $\pm$ 8
Polman et al. (72)	Elite League (England)	36	164.0	65.2	46.0 $\pm$ 2.89	109.7	
Rhodes & Mosher (75)	CIS (Canada)	12	164.8	59.5	47.1 $\pm$ 6.4	130.8	
Tumilty & Darby (84)	International (Australia)	20	164.0 $\pm$ 6.1	58.5 $\pm$ 5.7	48.5 $\pm$ 4.8	134.1	

VO₂max = maximal oxygen uptake; HRMax = heart rate maximum; NCAA = National Collegiate Athletic Association; CIS = Canadian Interuniversity Sport

status. When reviewing the level of competition, it has been demonstrated that the Danish and Norwegian national teams (45, 52, 56) had a substantially higher maximal aerobic capacity than the least fit teams. These differences may be a result of the level of competition for the least fit teams.

The relationship between maximal strength and power has been recognized as a key contributor to performance. An increase in maximal strength is generally related to an increase in relative strength and further shown to impact power outputs. Hoff & Almasbakk (48) demonstrate a significant relationship between 1RM and acceleration and movement velocity in female team-sport athletes. The maximal strength/power relationship is further supported by jump test results and sprint performance (92). Through the increase of available force output during muscle contractions for the appropriate musculature, speed and acceleration in skills critical to soccer may improve, including change of direction; change of pace, sprinting, and decelerating. It has also been suggested that high levels of strength in both the upper and lower body may be beneficial for injury prevention and reduce acute injuries on the field (4). Strength training and injury prevention programs have been shown to help reduce the number of injuries and days lost due to injury significantly. Furthermore it could be postulated that an individual player's technical proficiency and team tactical ability would be strongly impacted throughout a 90-minute match by their endurance capacity and strength.

Strength Capacity

Currently there is no standardized strength evaluation for soccer players and therefore it is difficult to compare results among different studies. The results of previous studies involving female soccer players are summarized in table 3. A soccer player's absolute strength is critical for moving external objects, including the ball and oppositional players. Conversely, relative strength has been suggested as the most influential strength quality for controlling individual movement (11, 78, 90). It has been suggested that greater maximum lower body relative strength may improve an individual's ability to control his or her own body during acceleration and deceleration which would be advantageous for players to maintain high velocity actions including pivoting, turning, tackling and sprinting (93). In a previous study in our lab (63)

isokinetic strength was assessed at both the hip and knee for flexion and extension at $60^{\circ}\cdot s^{-1}$. It was revealed that relative peak torque during concentric knee flexion and extension was stable between groups (Under 17, Under 20 and Senior level New Zealand international players), while relative peak torque for both hip flexion and extension was significantly greater for the U20 group compared to both the U17 and Senior groups of players. These findings support those of Forbes et al., (37) that peak torque strength outputs do not necessarily increase as a product of age. Therefore, we speculate that the difference observed in our study and that of Forbes et al., (37) is limited to elite athletes, more specifically soccer players and in particular the impact of elite training pathways.

Leg Power

Throughout a match female elite soccer players perform over 1300 different activities (38, 39, 56, 67) including sharp turns, decelerations, short sprints, jumps and tackles, all utilizing a sustained forceful muscular contractions. As power is the ability to produce the highest amount of force in the shortest possible time (55), it is heavily reliant on muscular strength; therefore an increase in muscular strength will ultimately see an improvement in power output. The capacity of a player to produce multiple powerful actions during a 90-minute match is a distinguishing characteristic of soccer players and has been related to soccer performance (23). Table 3 represents the findings of previous studies investigating leg power development in elite female soccer players. Countermovement jump height, the most common form of assessment, displays a range of scores from 21.0 to 53.1 and 28.9 to 35 cm for with and without arm swing respectively (56, 57, 71, 72, 80, 89). The majority of these show a significantly lower score than male counterparts, which demonstrates a lack of power development in female players.

In a previous study (63) unilateral leg power was assessed through standing horizontal and lateral jumping of Under 17, Under 20 and Senior international female soccer players. Unilateral jumping was assessed in both the horizontal and lateral direction. The findings reflected that a robust relationship between maximal strength and maximal power exists. As the senior athletes had greater maximal strength, their ability to produce greater jump efforts was heightened above the younger athletes.

This relationship between maximal strength and power significantly greater values compared to non-starters for both isokinetic strength and leg power (i.e. horizontal and lateral jumping distance). These findings reflect that for an athlete to effect match performance, greater strength and power development are an essential component of their physical skill set.

Sprint Performance

The majority of sprint bouts in soccer are less than 30 meters in distance, and last between of 2 to 6 seconds in duration throughout a 90-minute match (56, 82). Sprint ability is critical in soccer for such actions as closing down opponents, attacking and breaking the line into the oppositions third, as well as defending. Research has identified that speed can also distinguish between elite (24, 40, 74) and selected players (40, 47) as compared to non-elite and non-selected players. Table (4) reveals the sprint times for elite level female soccer players. These numbers are much lower than those reported for male soccer players (82). Due to the lack of data with consistency in methodology it is difficult to compare across age and level played for female players. As a significant relationship has been observed between IRM and acceleration and maximal velocity (48), it may be the lower maximum leg strength of female soccer players, in both absolute and relative forms which may lead to these reduced speed values. Thus, increasing the potential for higher force outputs during muscular contractions, acceleration and maximal speed may potentially increase, for which performance may improve.

Sprint Kinetics and Kinematics

As sprinting is an essential component in soccer, the investigation of sprint kinetics and kinematics may provide valuable insight into the development of maximal velocity for female athletes. In a previous study (63) investigating the sprint kinetics and kinematics of international Under 17 (U17), Under 20 (U20) and Senior level players it was revealed that vertical force (F_v) increased in a linear fashion as the athlete matures, whereas horizontal forces (F_h), power (P_{max}) and maximal velocity were greatest for the younger U17 age bracket. Increased ground contact time and decreased step frequency with each foot strike was shown as the younger athletes covered greater distance (step length) and flight was also evident between starters of both the U17 and Senior group, where there were

Table 3. Strength and power characteristics of elite female soccer players

Study	Level (country)	N	Absolute 1RM (kg)	Relative 1RM (Kg·kg ⁻¹)	CMJ (cm)	Depth Jump (cm)	SL Lat (cm)	SL Hor (cm)
Haugen et al. (42)	International (Norway)	85			30.7±4.1 ^b			
Krustrup et al. (56)	Elite League (Denmark)	23			35.0±1.1 ^b			
Larson-Meyer et al. (57)	NCAA (American)	14	97.5±10.0	1.51	21.0±3.3 ^a			
Manson et al. (63)	International (New Zealand)	51					155±15.7	163±12.6
Nesser and Lee (71)	NCAA (American)	16	75.8±14.0	1.3±0.2	53.1±9.4 ^a			
Polman et al. (72)	International (England)	36			46.6±4.81 ^a			
Sedano Campa et al (80)	Elite players	20			28.9±0.9 ^b	29.4±1.1 ^b		
Vescovi et al. (88)	NCAA (American)	64			41.9±5.6 ^b			

^a arm swing ^b hands on hips

NCAA = National Collegiate Athletic Association; CMJ = countermovement jump; SL Hor – Single leg horizontal jump; SL Lat = Single leg lateral jump; 1RM = 1 Repetition Maximum

Table 4. Speed characteristics of elite female soccer players

Study	Level (country)	N	Split times (sec)							
			9.10 m	10.00m	18.28m	20.00m	25.00m	30.00m	36.56m	40.00m
Haugen et al. (42)	International (Norway)	85		1.67±0.07		3.05±0.07		4.35±0.06		5.64±0.06
Krustrup et al. (56)	Elite League (Danish)	23						5.06±0.06		
Nesser & Lee (71)	NCAA (American)	16								5.8±0.04
Polman et al. (72)	International (England)	36					4.12±0.13			
Tumilty & Darby (84)	International (Australian)	20				3.31±0.11				
Vescovi et al. (88)	NCAA (American)	64	1.98±0.11		3.34±0.17				5.9±0.31	

NCAA = National Collegiate Athletic Association

time with each step. As more time was spent in contact with the ground, they may have been able to produce more peak horizontal force and peak power, while generating speed throughout the sprint. The older and thus physically more mature athletes, while not generating top peak speeds were able to generate a higher step frequency which in turn could benefit them over longer distances. This is a key quality associated with performance; as they are able to withhold greater higher intensity running bouts (see Table 1) as compared to younger athletes.

Conclusions and Recommendations

The quality of data pertaining to elite female soccer players is disproportionately low, with the number of published reports on male soccer players far outnumbering those of female players. What is clear is that the physical capacity of elite female soccer players directly influences their on-field technical performance and tactical choices, leading to either positive or negative performance outcomes. As illustrated in the presented material, ensuring that female soccer players strive to achieve the highest possible level of physical conditioning (aerobic and anaerobic) in conjunction with increase strength and power will ultimately impact a successful career at the elite level.

CHAPTER 3: PHYSIOLOGICAL CHARACTERISTICS OF INTERNATIONAL FEMALE SOCCER PLAYERS

Abstract

The purpose of this study was to investigate the physiological characteristics of FIFA eligible international female soccer players aged 14 to 36 yrs, and to determine if measures were significantly different for players selected (i.e. starters) to the starting line up for a FIFA tournament as compared to those not selected (i.e. non-starters). Fifty-one (N=18 Under 17; N=18 Under 20; N=15 Senior) international female soccer players participated in this study. Subjects underwent measurements of anthropometry (height and body mass), lower body strength (isokinetic testing), sprint kinetics and kinematics (non-motorized treadmill), leg power (unilateral jumping) and maximal aerobic velocity (30:15 intermittent fitness test) during the final preparatory stage for a FIFA event. Outcomes of the age group data indicate that differences in physiological capacities are evident for the Under 17 players as compared to the Under 20 and Senior capped international players, suggesting a plateau in the acquisition of physical qualities as players mature. Starters tended to be faster (ES = 0.55-1.0, $p<0.05$) and have a higher maximal aerobic velocity (ES = 0.78-2.45, $p<0.05$), along with greater eccentric leg strength (ES = 0.33-1.67, $p<0.05$). Significant differences were detected between starters and non-starters for isokinetic leg strength (ES = 0.54-1.24, $p<0.05$) and maximal aerobic velocity (ES = 0.87, $p<0.05$) for Under 17 players, where maximal aerobic velocity was the primary difference between starters and non-starters (ES = 0.83-2.45, $p<0.05$) for the Under 20 and Senior players. Coaches should emphasize the development of speed, maximal aerobic velocity and leg strength in developing female soccer players.

Key Words: physical profile, standard of play, athlete development, football

Introduction

Soccer is an intense multi-directional and intermittent field sport that demands technical ability, tactical awareness and an exceptionally high level of physical conditioning to compete at the international level. The ability to objectively assess physical performance has become a vital component for player development systems, player monitoring and youth player identification at the national and international level (19, 66, 74, 91). As evidenced in the literature, elite players or selected players routinely achieve higher performance outcomes on sprint, strength and jump tests as compared to sub-elite (24, 40, 73, 85) or non-selected players (40, 47), further demonstrating the importance of physical characteristics for soccer. While a single performance measure cannot be isolated to determine the quality of a player (66, 74, 91) or their potential impact, an understanding of the strength and speed characteristics needed to be successful in the game can provide insight for individual players potential for long-term success (58).

The popularity of women's soccer has witnessed rapid growth in the past ten years as evidenced by 29 million female players worldwide and a 32 % increase in participation (35). Previous research has identified that on an average pitch (105 meters x 68 meters) senior elite female players will cover upwards of 10.4 km of field space, and perform over 1300 different activities, with a change in the type or level of activity every 4 seconds (38, 39, 56, 67). While low intensity activities including standing, walking and jogging have been identified as the predominant movement patterns (upwards of 90 % of the 90 minute game), the distance covered, as well as the rate of fatigue during the high intensity and sprinting activity is the main determinant between higher and lower standards of play (3, 49, 67, 68). With elite female players completing 1.68 ± 0.09 km at high intensity and 0.46 ± 0.02 km sprinting throughout a game, which is 28 % and 24 % greater than non-elite level respectively (30). Furthermore it is the explosive actions such as sprints, jumps, tackling, duels, kicking and changing pace which when determine the outcome of a match and add to the overall demands on the athlete (73). These explosive actions are dependent on strength and speed characteristics of the individual player and should be developed from a young age.

There is a disproportional gap in the literature with the number of studies that characterize the physical performance characteristics of male players, which far outnumbers the studies on female players (47, 70, 88, 89). Previous investigations designed to assess physiological or speed characteristics of soccer players have typically included athletes that span a small age range, with comparisons to sub elite athletes. Despite the paucity of research, it has been demonstrated that high intensity tasks lasting several seconds tend to plateau during early to mid teenage years for female athletes; where conversely gains in speed, agility and aerobic capacity show continual improvement into adulthood (60-62, 77, 89). In contrast Mujika et al. (33) reported that senior level female soccer players (first division, 20-26 years) performed better on countermovement jump and agility tests than junior players (second division, 16-19 years) suggesting a continual improvement in shorter duration anaerobic performance beyond teenage years for highly trained female soccer players. Current research highlights measures of high intensity ballistic assessment, but fails to report on measures of strength gains throughout this critical period of development.

To our knowledge no study has determined the physiological characteristics of female soccer players at the international level across a wide age range with specific attention paid to the identification of player suitability for the international game. Data extending across the Fédération Internationale de Football Association (FIFA) age brackets (U17 and U20) could have a profound impact for national team coaches and sports scientists who utilize performance measures to evaluate players within their national organizations through providing expected values for comparative chronological ages. Thus, the primary purpose of this study was to determine the physiological characteristics of FIFA eligible elite female soccer players ranging from 14 to 36 years of age on sprinting kinetics and kinematics, isokinetic strength, unilateral jumping and maximal aerobic velocity, in an effort to distinguish age related and playing-time related differences. A secondary aim was to establish normative data for this cohort of athletes.

Methods

Experimental Approach to the Problem

To study the discriminative physiological characteristics of elite female soccer players across all FIFA age brackets (U17, U20 and Senior), we performed a battery of laboratory and field based assessments during the final training period leading into a FIFA sanctioned international competition. In addition, we compared the findings of those players selected (starters) against those not selected (non-starters) at the featured international competition of each age bracket to determine both age related and playing-time related differences.

Subjects

Subjects included 51 elite female soccer players (19 ± 4.1 yr), all who represented New Zealand within the 2012 calendar year of competition, including but not limited to the U17 FIFA Women's World Cup in Azerbaijan, the U20 FIFA Women's World Cup in Japan and the FIFA Women's Football tournament at the London Olympics. At the time of testing, FIFA official rankings had the New Zealand Senior team ranked 23rd out of 125 (34) senior level international teams, where the U20 team was ranked 14th out of 30 (33) among FIFA U20 age group teams, and the U17 team was ranked 20th out of 27 (36) FIFA U17 age group teams. Testing was carried out during the training build up to the featured event for each training group and all players were tested within 4 weeks of each other. On average the U17 group (N=18, 14-17 yr) held 4 training sessions per week, where the U20 group (N=18, 17 – 19 yr) and Senior group (N=15, 19 – 36 yr) held 6 training sessions per week. All players also played a minimum of 1 game per week throughout the period of testing. Players had a minimum of 1, 2 and 3 yrs of experience training within the national program at the U17, U20 and Senior level, respectively. All players were free from any injury that would prevent maximal effort during performance testing. All procedures described in this study were approved by the Auckland University of Technology Ethics Committee (AUTC). All subjects and guardians, where appropriate were fully informed of all experimental procedures before giving their informed consent to participate.

Procedure

All subjects were required to avoid strenuous exercise 24 hours before testing and therefore testing was scheduled immediately following their prescribed rest day. All subjects performed a standardized warm-up consisting of 10-15 minutes that included

general exercises such as jogging, shuffling, sprinting, multi-directional movements, and dynamic stretching. Performance was assessed in a single session with the tests completed in the following order: anthropometrical assessment, sprint kinetics and kinematics unilateral jumping and isokinetic strength. Maximal aerobic velocity was further assessed during a group training session within the 4-week testing period.

Isokinetic Strength Assessment

Maximal torque generated by the knee extensors, knee flexors, hip flexors and hip extensors was obtained on an isokinetic dynamometer (Cybex Norm, Phoenix Healthcare, Nottingham, UK). The motor axis was visually aligned with the axis of the knee joint for knee flexion and extension, and at the axis of the hip joint for hip flexion and extension. The subject was either seated (trunk reclined to 15° from the vertical plane) or laying horizontal and stabilized so that only the knee or leg was moving with a single degree of freedom. The subject's dominant leg was assessed, as determined as the preferred kicking leg. All subjects performed testing in the following order: concentric knee flexion and extension, eccentric knee flexion and extension and concentric hip flexion and extension at the set experimental maximal velocity of 60°•s⁻¹, chosen to allow safe and reliable measurement of concentric and eccentric strength. After a standardized warm up consisting of 2 rounds of 3 to 5 submaximal (~50% and ~80%) contractions, 5 maximal repetitions were performed for the concentric measures, where as 3 maximal repetitions were performed for the eccentric measures. All subjects were encouraged to provide maximal effort during all tests performed. For all trials, peak torque (PT, N•m) was recorded and averaged for the 5 repetitions during concentric knee and hip flexion and extension, as well as the three repetitions during eccentric knee flexion and extension.

Sprinting Kinetics and Kinematics

Sprint kinetics and kinematics were assessed on a non-motorized treadmill (NMT) (Woodway, Force 3.0, Waukesha, WI, USA). The NMT sprint performance variables were measured after a warm-up on the NMT consisting of 3 minutes continuous jogging interspersed with 3 sprints at gradually increasing speeds (~60% of their perceived maximal speed). During the maximum effort sprints that followed, the subjects ran over the NMT with 4 embedded vertical load cells mounted under the

running surface and were connected to a mounted horizontal load cell, which measures horizontal force via a non-elastic tether and harness that was attached around their waists. The horizontal load cell was attached to a metal vertical strut with a sliding gauge, which locked into place to avoid any movement during testing. The sliding gauge allowed the horizontal load cell to be adjusted vertically in accordance to the height of each subject so that the tether was at an angle greater than horizontal for each participant while standing, so as to maintain the horizontal position of the tether during the forward lean adopted when sprinting on the NMT. Subjects were instructed to sprint maximally from a standing split stance start (left leg forward) on the researcher's instruction and to maintain their effort for greater than 6 seconds. This procedure was repeated twice more interspersed with at least 2 minutes of passive recovery. Mechanical data were sampled at 200 Hz during the sprint period allowing instantaneous collection of vertical forces (F_v), horizontal forces (F_h) and power (P_{max}). Peak values of force and power were averaged over 10 steps at constant maximum velocity.

Table 5. Test-retest reliability based on intraclass correlation (ICC) and coefficient of variation (CV) for sprint kinetics and kinematics and Isokinetic Strength Variables

	ICC	CV (%)
Sprint Kinetics and Kinematics		
Velocity (m/s)	0.79	2.0
F_v (N)	0.85	7.2
F_h (N)	0.75	8.1
P_{max} (W)	0.66	12
Contact time (ms)	0.58	7.8
Flight time (ms)	0.77	8.2
Step frequency (Hz)	0.68	2.7
Step length (m)	0.78	3.9
Isokinetic Muscle Strength		
Concentric Knee Flexion ($N \cdot m^{-1}$)	0.94	9.3
Concentric Knee Extension ($N \cdot m^{-1}$)	0.92	5.4
Eccentric Knee Flexion ($N \cdot m^{-1}$)	0.91	6.3
Eccentric Knee Extension ($N \cdot m^{-1}$)	0.90	7.1
Concentric Hip Flexion ($N \cdot m^{-1}$)	0.87	13.8
Concentric Hip Extension ($N \cdot m^{-1}$)	0.94	8.7
Hcon:Qcon ($N \cdot m^{-1}$)	0.62	10.9
Hecc:Qcon ($N \cdot m^{-1}$)	0.82	10.7

F_v = peak vertical force; F_h = peak horizontal force; P_{max} = peak power; Hcon:Qcon = Concentric Hamstring/Quadriceps ratio; Hecc:Qcon = Eccentric to Concentric Hamstring/Quadriceps ratio; ICC = intraclass correlation; CV = coefficient of variation

Contact times (C_t) and flight times (F_t) were also recorded and averaged over the 10 steps. C_t was determined from the time of force applied to the treadmill exceeding 0 N

and returned to 0 N, where as F_t was determined from the time between the end of the ground contact period of one foot to the beginning of the ground contact period for the opposite foot. Stride frequency was determined from the following formula: $1/(C_t + F_t)$, where as stride length was determined from the following formula: running velocity/step frequency. The interclass correlation coefficient (ICC) and coefficient of variation (CV) for sprinting kinetics and kinematics, and isokinetic variables are presented in Table 1.

Unilateral Leg Power

The assessment of unilateral leg power for both the horizontal countermovement jump (HCL) and lateral countermovement jump (LCJ) was adapted from Meylan et al., (65). For the HCL, subjects began by standing on the designated testing leg with the foot at the starting line and with hands on the hips. Each subject was instructed to sink to a self selected depth as quickly as possible before jumping as far forward as possible and landing on 2 feet. For the LCJ each subject stood on the designated testing leg with the foot at the starting line and hands on the hip. Each subject was instructed to sink to a self selected depth as quickly as possible and then jumped as far laterally to the inside and landed on 2 feet. 3 trials were performed on the dominant leg, as determined by the leg used to kick the ball, interspersed with 2 minutes of passive rest between both the HCL and the LCJ.

Maximal Aerobic Velocity

Maximal running speed was determined by use of the 30:15 intermittent fitness test (30:15_{IRT}) (16). The 30:15_{IFT} protocol consists of 30s shuttle runs, which are interspersed with 15s passive recovery periods. Running velocity was initiated at 2.2 m/s (8 km/hr) and speed continued to increase 0.14 m/s (0.5 km/hr) for every 30s shuttle run completed. Subjects were required to run back and forth over a 40m track at the given pace, governed by a pre recorded beep. The velocity attained during the final stage completed was determined as the subject's maximal aerobic velocity or V_{IFT} . VO_{2max} can be further estimated from the V_{IFT} according to the following formula: $VO_{2max_{30-15IFT}} (ml.min/kg) = 28.3 - 2.15G - 0.741A - 0.0357W + 0.0586AxV_{IFT} + 1.03V_{IFT}$. G stands for Gender, female = 2, male=1, A for age, W for weight (15).

Statistical Analysis

A sub-group of 10 players performed a second testing session within 7 days of initial testing in order to determine test-retest reliability of the sprint and isokinetic variables. Intraclass correlation coefficient (ICC) and coefficient of variation (CV) were calculated for each variable. A one-way ANOVA was used to compare the physiological and anthropometrical characteristics between each age group (U17, U20 and Senior). When required, comparisons of the group means were performed using Fisher's least significant difference (43) (LSD) post hoc analysis to determine pairwise differences. Data are presented as mean $\pm$ SD throughout. Statistical significance was accepted at $p < 0.05$. The groups were then subsequently divided to determine differences, via an independent T-test between starters and non starters. Due to the relatively small sample size, differences between the starters and non starters, and age group groups were further analysed using effect size (ES) statistics. ES of <0.2 , <0.6 , <1.2 and >1.2 were considered trivial, small, moderate and large, respectively (51).

Results

The test-retest reliability data are shown in Table 5. Table 6 presents a physical profile of all U17, U20 and Senior elite female soccer players. There was a significant difference ($p < 0.05$) for body mass between all groups and therefore isokinetic strength measures and sprint kinetics have been represented in both absolute and relative values. Results for isokinetic strength show relative differences for concentric hip extension and flexion, as well as eccentric knee flexion; the U17 group displayed lower relative peak torque for concentric hip extension ($2.37 \pm 0.68 \text{ N}\cdot\text{m}$, $p < 0.05$), concentric hip flexion ($0.92 \pm 0.31 \text{ N}\cdot\text{m}$, $p < 0.05$) and eccentric knee flexion ($1.82 \pm 0.43 \text{ N}\cdot\text{m}$, $p < 0.05$) as compared to both the U20 and Senior groups. Relative horizontal force was significantly greater for the U17 group ($4.14 \pm 0.62 \text{ N/kg}$, $p < 0.05$) compared to all other groups. Differences were observed in sprint kinematics for the U17 group compared to all other groups for all variables including, greater contact time ($202.87 \pm 20.30 \text{ ms}$, $p < 0.05$), greater flight time ($87.07 \pm 16.90 \text{ ms}$, $p < 0.05$) and lower step frequency ($3.49 \pm 0.33 \text{ Hz}$, $p < 0.05$), but an increased step length ($1.52 \pm 0.30 \text{ m}$, $p < 0.05$) compared to all other groups. Differences in leg power were also observed between all groups, the Senior group jumped a greater distance in both lateral ($154.60 \pm 15.70 \text{ cm}$, $p < 0.05$) and horizontal ($162.80 \pm 12.60 \text{ cm}$, $p < 0.05$) jumps compared to the U17 and U20 groups.

The U20 group was significantly slower than both the U17 and Senior group for maximum sprinting velocity (4.89 ± 0.26 m/s, $p < 0.05$). The Senior group represented significantly higher scores (19.20 ± 1.2 km/hr, $p < 0.05$) and (50.29 ± 2.89 ml/kg/min, $p < 0.05$) for V_{IFT} and $VO_{2\max(30-15IFT)}$ respectively compared to both the U17 and U20 groups.

Table 6. Physiological and anthropometric characteristics (n=51) of Under 17, Under 20 and Senior international female soccer players

		Under 17	Under 20	Senior
Age (yr)		15.6 ± 0.98	$17.8 \pm 0.71^*$	$23.3 \pm 4.89^*$
Experience (yr)		1.90 ± 0.90	$3.20 \pm 1.20^*$	$6.00 \pm 3.80^*$
Frequency (days/week)		4.00 ± 0.00	$6.30 \pm 0.50^*$	$6.20 \pm 0.40^*$
Anthropometry				
Height (cm)		164 ± 5.15	167 ± 7.22	$168 \pm 7.80^*$
Mass (kg)		58.0 ± 5.48	$62.2 \pm 7.23^*$	$64.1 \pm 5.44^*$
Concentric Muscle Action				
Absolute Peak Torque ($N \cdot m^{-1}$)				
Knee:	Extension	119 ± 24.5	114 ± 24.7	135 ± 36.3
	Flexion	89.3 ± 20.0	$104 \pm 13.2^*$	$101 \pm 18.7^*$
Hip:	Extension	140 ± 53.9	$202 \pm 0.10^*$	$198 \pm 43.9^*$
	Flexion	53.4 ± 19.9	$76.3 \pm 12.4^*$	$81.1 \pm 20.2^*$
Relative Peak Torque ($N \cdot m^{-1}$)				
Knee:	Extension	2.04 ± 0.33	2.15 ± 0.36	2.10 ± 0.54
	Flexion	1.53 ± 0.26	1.68 ± 0.25	1.55 ± 0.26
Hip:	Extension	2.37 ± 0.68	$3.23 \pm 0.57^*$	$3.09 \pm 0.64^*$
	Flexion	0.92 ± 0.31	$1.23 \pm 0.17^*$	$1.27 \pm 0.30^*$
Eccentric Muscle Action				
Absolute Peak Torque ($N \cdot m^{-1}$)				
Knee:	Extension	138 ± 41.8	$165 \pm 33.5^*$	166 ± 47.0
	Flexion	106 ± 29.6	$133 \pm 30.9^*$	$132 \pm 24.4^*$
Relative Peak Torque ($N \cdot m^{-1}$)				
Knee:	Extension	2.40 ± 0.89	2.66 ± 0.43	2.59 ± 0.69
	Flexion	1.82 ± 0.43	$2.15 \pm 0.49^*$	2.06 ± 0.34
Ratio Flexion/Extension ($N \cdot m^{-1}$)				
Hcon:Qcon		0.75 ± 0.08	0.79 ± 0.10	0.78 ± 0.17
Hecc:Qcon		0.90 ± 0.19	1.03 ± 0.31	1.04 ± 0.32
Speed				
Velocity (m/s)		5.22 ± 0.66	$4.89 \pm 0.26^*$	5.04 ± 0.34
IFT (km/h)		18.4 ± 1.00	18.7 ± 0.90	$19.2 \pm 1.20^*$
$VO_{2\max(30-15IFT)}$ (ml/kg/min)		46.2 ± 2.09	$47.7 \pm 1.99^*$	$50.3 \pm 2.89^{*^A}$
Sprint Kinetics				
Fv Absolute (N)		1301 ± 184	$1470 \pm 239^*$	$1531 \pm 235^*$

Fv Relative (N/kg)	22.4 ± 2.18	23.6 ± 2.07	23.8 ± 2.65
Fh Absolute (N)	239 ± 33.1	228 ± 46.2	244 ± 42.2
Fh Relative (N/kg)	4.14 ± 0.62	3.71 ± 0.38*	3.81 ± 0.62
Pmax Absolute (W)	1136 ± 225	1113 ± 309	1202 ± 253
Pmax Relative (W/kg)	19.6 ± 10.26	17.9 ± 2.23	18.7 ± 3.57
Sprint Kinematics			
Contact time (ms)	203 ± 20.3	169 ± 8.70*	168 ± 18.3*
Flight time (ms)	87.1 ± 16.8	68.4 ± 12.4*	77.2 ± 10.7*
Step frequency (Hz)	3.49 ± 0.33	4.20 ± 0.20*	4.11 ± 0.30*
Step length (m)	1.52 ± 0.30	1.20 ± 0.10*	1.24 ± 0.02*
Leg Power			
SL lat jump (cm)	141 ± 10.6	149 ± 13.6	155 ± 15.7*
SL horr jump (cm)	153 ± 9.05	157 ± 14.5	163 ± 12.6*

Values are means ± SD. *Significantly (P<0.05) different from Under 17 players; ^Significantly (P<0.05) different from Under 20 players; N = 18 U17; N = 18 U20; N = 15 Senior; Experience = years in national program; Frequency = training days with national program; SL Lat = single leg lateral jump; SL horr = single leg horizontal jump; Fv = peak vertical force; Fh = peak horizontal force; Pmax = peak power; VO_{2max(30-15IFT)} = Estimated VO_{2max}; Hcon:Qcon = Concentric Hamstring/Quadricept ratio; Hecc:Qcon = Eccentric to Concentric Hamstring/Quadricept ratio

Comparisons between the starters and non-starters of the three age groups are represented in Tables 7, 8 and 9. Starters for the U17 age group (see Table 7) displayed greater isokinetic leg strength, with a significant difference shown in absolute concentric knee flexion ($94.40 \pm 12.70 \text{ N}\cdot\text{m}$, $p<0.05$) as well as both absolute ($164 \pm 39.30 \text{ N}\cdot\text{m}$, $p<0.05$) and relative ($2.81 \pm 0.57 \text{ N}\cdot\text{m}$, $p<0.05$) eccentric knee extension. U17 Starters also produced greater VIFT ($18.90 \pm 0.40 \text{ km/hr}$, $p<0.05$) and relative vertical force ($23.66 \pm 1.92 \text{ N/kg}$, $p<0.05$) while running than the non-starters. As shown in Table 8, U20 starters had a greater absolute ($177 \pm 49.30 \text{ N}\cdot\text{m}$, $p<0.05$) and relative ($2.93 \pm 0.61 \text{ N}\cdot\text{m}$, $p<0.05$) isokinetic hip extension strength, with a significantly greater absolute ($1348 \pm 223 \text{ Nm}$, $p<0.05$) and relative ($22.46 \pm 1.60 \text{ Nm}$, $p<0.05$) vertical force production while running. There was also a pronounced increase in V_{IFT} ($19.4 \pm 0.70 \text{ km/hr}$) and derived VO_{2max(30-15IFT)} ($49.08 \pm 1.68 \text{ ml/kg/min}$, $p<0.05$) compared to non starters. Senior starters (see Table 9) had a greater peak V_{IFT} ($20.1 \pm 0.70 \text{ km/hr}$, $p<0.05$) maximal sprinting velocity ($5.20 \pm 0.40 \text{ m/s}$, $p<0.05$) and a higher derived VO_{2max(30-15IFT)}, ($51.59 \pm 2.07 \text{ ml/kg/min}$, $p<0.05$) as compared to non starters. When comparing across the age span all starters had a significantly higher V_{IFT}, and consequently a greater derived VO_{2max(30-15IFT)}, as compared to non starters.

Table 7. Physiological and anthropometric characteristics (n=18) of Under 17 international starters vs. non starters.

	Starters	Non Starters	Effect Size
Age (yr)	15.7 ± 1.10	15.5 ± 0.90	0.25
Anthropometry			
Height (cm)	166 ± 3.70	162 ± 5.50	0.84
Mass (kg)	58.3 ± 5.00	57.8 ± 6.00	0.08
Concentric Muscle Action			
Absolute Peak Torque (N·m ⁻¹)			
Knee: Extension	129 ± 22.6	112 ± 24.3	0.72
Flexion	94.4 ± 12.7*	86.1 ± 23.5	0.54
Hip: Extension	145 ± 67.8	136 ± 46.3	0.16
Flexion	50.1 ± 23.4	55.5 ± 18.2	-0.26
Relative Peak Torque (N·m ⁻¹)			
Knee: Extension	2.20 ± 0.24	1.93 ± 1.47	0.31
Flexion	1.62 ± 0.11	1.47 ± 0.31	0.70
Hip: Extension	2.51 ± 1.21	2.32 ± 0.67	0.20
Flexion	0.86 ± 0.39	0.95 ± 0.26	-0.27
Eccentric Muscle Action			
Absolute Peak Torque (N·m ⁻¹)			
Knee: Extension	165 ± 39.3*	120 ± 34.7	1.20
Flexion	114 ± 29.9	101 ± 29.7	1.01
Relative Peak Torque (N·m ⁻¹)			
Knee: Extension	2.81 ± 0.57*	2.09 ± 0.60	1.24
Flexion	1.04 ± 0.39	1.75 ± 0.46	-1.67
Ratio Flexion/Extension (N·m ⁻¹)			
Hcon:Qcon	0.74 ± 0.06	0.76 ± 0.09	-0.30
Hecc:Qcon	0.09 ± 0.13	0.09 ± 0.22	-0.22
Speed			
Velocity (m/s)	5.44 ± 0.70	5.07 ± 0.60	0.55
IFT (km/h)	18.9 ± 0.40*	18.2 ± 1.20	0.87
VO _{2max(30-15IFT)} (ml/kg/min)	47.1 ± 1.00	45.7 ± 2.46	0.78
Sprint Kinetics			
Fv Absolute (N)	1382 ± 180	1250 ± 176	-0.74
Fv Relative (N/kg)	23.7 ± 1.92*	21.6 ± 2.02	-1.05
Fh Absolute (N)	250 ± 37.9	231 ± 29.1	-0.56
Fh Relative (N/kg)	4.32 ± 0.68	4.03 ± 0.58	-0.46
Pmax Absolute (W)	1252 ± 268	1062 ± 167	-0.87
Pmax Relative (W/kg)	21.5 ± 3.93	18.4 ± 2.70	-0.92
Sprint Kinematics			
Contact time (ms)	194 ± 16.1	208 ± 21.5	0.75
Flight time (ms)	92.8 ± 15.1	83.4 ± 17.5	-0.58
Step frequency (Hz)	3.50 ± 0.28	3.50 ± 0.36	0.00
Step length (m)	1.58 ± 0.32	1.49 ± 0.30	-0.29
Leg Power			
SL lat jump (cm)	144 ± 12.8	139 ± 9.20	0.42
SL horr jump (cm)	155 ± 7.40	151 ± 10.0	0.44

Values are means $\pm$ SD. *Significantly ($P < 0.05$) different from Under 17 non starters; N = 18 U17; SL lat = single leg lateral jump; SL hor = single leg horizontal jump; Fv = peak vertical force; Fh = peak horizontal force; Pmax = peak power; $VO_{2\max(30-15IFT)}$ = Estimated $VO_{2\max}$; Hcon:Qcon = Concentric Hamstring/Quadriceps ratio; Hecc:Qcon = Eccentric to Concentric Hamstring/Quadriceps ratio

Table 8. Physiological and anthropometric characteristics (n=18) of Under 20 international starters vs. non starters.

	Starters	Non Starters	Effect Size
Age (yr)	18.0 $\pm$ 0.70	17.7 $\pm$ 0.70	0.47
Anthropometry			
Height (cm)	166 $\pm$ 6.79	168 $\pm$ 8.00	-0.19
Mass (kg)	59.9 $\pm$ 7.80	64.5 $\pm$ 6.20	-0.66
Concentric Muscle Action			
Absolute Peak Torque ($N \cdot m^{-1}$)			
Knee: Extension	132 $\pm$ 23.1	136 $\pm$ 27.6	-0.15
Flexion	102 $\pm$ 7.90	1.5 $\pm$ 17.4	-0.22
Hip: Extension	177 $\pm$ 49.3*	227 $\pm$ 25.3	-1.33
Flexion	73.1 $\pm$ 13.3	79.4 $\pm$ 11.4	-0.51
Relative Peak Torque ($N \cdot m^{-1}$)			
Knee: Extension	2.22 $\pm$ 0.38	2.10 $\pm$ 0.35	0.33
Flexion	1.73 $\pm$ 0.20	1.63 $\pm$ 0.25	0.44
Hip: Extension	2.93 $\pm$ 0.61*	3.53 $\pm$ 0.31	-1.30
Flexion	1.22 $\pm$ 0.19	1.24 $\pm$ 1.06	-0.03
Eccentric Muscle Action			
Absolute Peak Torque ($N \cdot m^{-1}$)			
Knee: Extension	153 $\pm$ 39.3	178 $\pm$ 22.0	-0.82
Flexion	117 $\pm$ 30.8	149 $\pm$ 22.8	-1.17
Relative Peak Torque ($N \cdot m^{-1}$)			
Knee: Extension	2.55 $\pm$ 0.52	2.77 $\pm$ 0.23	0.59
Flexion	1.99 $\pm$ 0.59	2.31 $\pm$ 0.33	0.70
Ratio Flexion/Extension ($N \cdot m^{-1}$)			
Hcon:Qcon	0.79 $\pm$ 0.11	0.79 $\pm$ 0.10	-0.01
Hecc:Qcon	0.94 $\pm$ 0.37	1.12 $\pm$ 0.21	0.63
Speed			
Velocity (m/s)	4.83 $\pm$ 0.30	4.96 $\pm$ 0.30	-0.91
IFT (km/h)	19.4 $\pm$ 0.70*	18.3 $\pm$ 0.60	1.87
$VO_{2\max(30-15IFT)}$ (ml/kg/min)	49.1 $\pm$ 1.68*	45.7 $\pm$ 1.12	2.45
Sprint Kinetics			
Fv Absolute (N)	1349 $\pm$ 223*	1591 $\pm$ 198	1.15
Fv Relative (N/kg)	22.5 $\pm$ 1.60*	24.7 $\pm$ 1.94	1.25
Fh Absolute (N)	218 $\pm$ 20.7	242 $\pm$ 26.4	0.83
Fh Relative (N/kg)	3.68 $\pm$ 0.49	3.73 $\pm$ 0.26	0.13
Pmax Absolute (W)	1036 $\pm$ 139	1190 $\pm$ 218	0.39
Pmax Relative (W/kg)	17.4 $\pm$ 2.54	18.3 $\pm$ 1.93	-0.39
Sprint Kinematics			
Contact time (ms)	173 $\pm$ 8.70	166 $\pm$ 7.73	0.83
Flight time (ms)	64.5 $\pm$ 9.60	72.3 $\pm$ 14.2	0.66
Step frequency (Hz)	4.22 $\pm$ 0.14	4.21 $\pm$ 0.26	0.05

Step length (m)	1.15 ± 0.08	1.18 ± 0.12	0.30
Leg Power			
SL lat jump (cm)	146 ± 12.2	152 ± 15.0	-0.44
SL horr jump (cm)	155 ± 11.1	160 ± 17.5	-0.07

Values are means ± SD. *Significantly (P<0.05) different from Under 20 non starters; N = 18 U20; SL lat = single leg lateral jump; SL horr = single leg horizontal jump; Fv = peak vertical force; Fh = peak horizontal force; Pmax = peak power; $VO_{2max(30-15IFT)}$ = Estimated VO_{2max} ; Hcon:Qcon = Concentric Hamstring/Quadriceps ratio; Hecc:Qcon = Eccentric to Concentric Hamstring/Quadriceps ratio

Table 9. Physiological and anthropometric characteristics (n=15) of Senior international starters vs. non starters.

	Starters	Non Starters	Effect Size
Age (yr)	23.4 ± 7.10	25.0 ± 5.60	-0.10
Anthropometry			
Height (cm)	165 ± 9.30	170 ± 6.40	-0.64
Mass (kg)	61.5 ± 6.60	65.9 ± 4.00	-0.84
Concentric Muscle Action			
Absolute Peak Torque (N·m ⁻¹)			
Knee: Extension	142 ± 32.3	128 ± 38.5	0.52
Flexion	101 ± 13.5	102 ± 21.9	-0.12
Hip: Extension	202 ± 54.2	196 ± 39.0	0.13
Flexion	77.8 ± 15.9	85.4 ± 22.5	-0.55
Relative Peak Torque (N·m ⁻¹)			
Knee: Extension	2.38 ± 0.49	1.93 ± 0.51	-0.90
Flexion	1.63 ± 0.23	1.54 ± 0.28	-0.35
Hip: Extension	3.27 ± 0.71	2.99 ± 0.61	-0.42
Flexion	1.22 ± 0.25	1.30 ± 0.33	0.28
Eccentric Muscle Action			
Absolute Peak Torque (N·m ⁻¹)			
Knee: Extension	175 ± 45.6	160 ± 49.5	0.33
Flexion	132 ± 30.5	132 ± 21.3	-0.02
Relative Peak Torque (N·m ⁻¹)			
Knee: Extension	2.86 ± 0.68	2.41 ± 0.67	-0.67
Flexion	2.15 ± 0.47	2.00 ± 0.22	-0.43
Ratio Flexion/Extension (N·m ⁻¹)			
Hcon:Qcon	0.70 ± 0.11	0.84 ± 0.19	0.93
Hecc:Qcon	0.92 ± 0.21	1.11 ± 0.37	0.67
Speed			
Velocity (m/s)	5.20 ± 0.40*	4.90 ± 0.20	1.00
IFT (km/h)	20.1 ± 0.70*	18.6 ± 1.10	1.76
$VO_{2max(30-15IFT)}$ (ml/kg/min)	51.6 ± 2.07	49.4 ± 3.13	0.83
Sprint Kinetics			
Fv Absolute (N)	1540 ± 275	1524 ± 222	-0.06
Fv Relative (N/kg)	23.1 ± 2.62	25.0 ± 2.46	0.77
Fh Absolute (N)	240 ± 55.7*	246 ± 34.2	0.13
Fh Relative (N/kg)	3.88 ± 0.68	3.75 ± 0.61	-0.02
Pmax Absolute (W)	1212 ± 349	1195 ± 189	-0.07
Pmax Relative (W/kg)	19.5 ± 4.16	18.2 ± 3.28	-0.34

Sprint Kinematics			
Contact time (ms)	168 ± 25.8	168 ± 13.1	0.01
Flight time (ms)	76.2 ± 11.6	77.9 ± 10.7	0.16
Step frequency (Hz)	4.16 ± 0.49	4.08 ± 0.22	-0.23
Step length (m)	1.28 ± 0.27	1.20 ± 0.10	-0.44
Leg Power			
SL lat jump (cm)	151 ± 13.6	157 ± 17.2	-0.39
SL horr jump (cm)	159 ± 9.90	165 ± 14.3	-0.51

Values are means ± SD. *Significantly (P<0.05) different from Senior non starters; N = 15 SR; SL lat = single leg lateral jump; SL horr = single leg horizontal jump; Fv = peak vertical force; Fh = peak horizontal force; Pmax = peak power; VO_{2max(30-15IFT)} = Estimated VO_{2max}; Hcon:Qcon = Concentric Hamstring/Quadricept ratio; Hecc:Qcon = Eccentric to Concentric Hamstring/Quadricept ratio

Discussion

To our knowledge, this is the first study to report the physiological characteristics of female soccer players at the international level across a wide age range (14-36 yrs) with specific attention paid to starters vs non starters, providing insight into the physical qualities that are important for playing success. This study also provides normative data for elite players competing at the international level across a wide age range. The results of this study support previous findings in that gains in speed, strength, leg power and aerobic capacity show continual improvement into adulthood (60-62, 77, 89). Furthermore, the current findings support the notion that physiological gains are greater during the early to mid teenage years.

Playing frequency within the national training pool was significantly higher for the U20 and Senior groups than the U17 groups, but with no effect for the starters vs non-starters, as all players train on the same set schedule. Experience within the national pool showed a significant difference between groups, but only a large effect size was shown for the U17 starters over non-starters. Moderate effect sizes were shown for height within the U17 starters compared to non-starters, suggests that players who are physically more mature, regardless of chronological age, are more often selected as starters. This reflects the inclusion of player identification and development models, which have been adapted within the New Zealand Football framework (46); younger players are being developed earlier and subsequently earning starting positions at the international game earlier.

A focus for this study was evaluating player's isokinetic hip and knee flexor and extensor (16) strength using dynamometry across the groups. As a significant difference in body mass was detected between groups, isokinetic strength measures were represented in absolute and relative to body mass. The findings for peak torque across all age groups in all conditions are in agreement with previous authors in that peak torque increases with age throughout maturation (10, 31, 47, 76). While the relative peak torque increase in concentric knee flexion and extension was stable between groups, relative peak torque for both hip flexion and extension was significantly stronger for the U20 group compared to both the U17 and Senior groups of players. This supports the findings of Forbes et al., (37) that peak torque increases are not necessary linear with age, muscle group or mode of contraction, and that each display a different pattern. Le Gall et al. (58) found no difference in knee flexion or extension strength in male soccer players aged 14 to 17 years. Therefore, we speculate that the difference observed in the current study and that of Forbes et al., (37) is specific to elite athletes, more specifically soccer players and in particular the impact of elite training pathways. Rochcongar and colleagues (76) also reported specific concentric knee extensor strength gains at the U20 equivalent in their sample of 166 elite junior soccer players, where an increase in absolute peak torque of 35% was shown after the mean age of 15 (our U17 age bracket). Our data is consistent with these overall gains in strength between the ages of 15 and 20 years. Further to this, hip flexion and extension was significantly weaker in the under 17 population compared to all other groups. Why this occurs is outside the realm of this study, however for clinicians, trainers and coaches the above findings could prove insightful for targeted strength training, with the U17 or late pubertal athletes highlighted as an area where a marked improvement may be generated. Hence there may be a window of opportunity where younger athletes can make strength gains, (6, 62) potentially resulting in improved performance.

It is interesting to note that for leg power, only the Senior group was significantly greater compared to the younger athletes. The phenomenon is supported by the relationship between strength and power which dictates that an individual cannot possess a high level of power without first being relatively strong. This assertion is supported by the robust relationship that exists between maximal strength and

maximal power production (26). As the Senior athletes have greater overall concentric and eccentric muscle strength, their ability to generate power should be heightened. Starters of both the U17 and Senior group had significantly stronger values compared to non-starters for both isokinetic strength and leg power (i.e. horizontal and lateral jumping distance). Those who can transition strength into leg power may be more likely to become a Senior starter.

A major finding of this paper was the consistently greater maximal running velocity and derived $VO_{2max(30-15IFT)}$, across all age groups, as well as between starters and non-starters. Large effect sizes were shown for both measures between starters and non-starters with the most profound difference found at the U20 level. V_{IFT} is related not to just a measure of maximal aerobic function, but anaerobic capacity, neuromuscular, change of direction qualities, inter-effort recovery ability and repeat sprint ability providing a broad picture of a players ability on the park (15). As these qualities are the foundation for which an elite soccer player is built on (19, 20), the relationship between V_{IFT} and it's derived $VO_{2max(30-15IFT)}$, is of greatest importance. Reaching end stage V_{IFT} , elicits $VO_{2max(30-15IFT)}$ (17, 18) therefore providing a clear indication of a players performance capability, as supported by Helgerud et al., (44) VO_{2max} is an important variable of match performance. As velocities attained in a match are a direct indication of the level or standard of play (16), the measure of V_{IFT} not only provides an indication of a subjects performance capability, but also reflects their position as a starter or non-starter.

As sprinting is an essential component of soccer and can distinguish between the level of play (74), we further investigated sprint kinematics, kinetics and maximum speed across the U17, U20 and Senior groups. While sprinting can be divided into a number of phases, the focus for this paper was in attaining maximal velocity over a 6 second period (29). The sprint kinetics we measured displayed a unique pattern across all age brackets. Vertical force (F_v) increased in a linear fashion across the age groups, where as both horizontal force (F_h) and power (P_{max}) were greatest for the U17 age bracket, followed by the Senior group and U20 with significantly lower outputs. When compared to the maximum sprinting velocity associated with these measures the trend is apparent again, at the U17 group sprinting at greater velocity than the older

players. In terms of sprint kinematics the U17 group, although having an increased contact time and decreased step frequency with each foot strike, covered greater distance (step length) and flight time with each step forwards than both the U20 and Senior groups. As more time is spent on the ground, they were able to produce more peak horizontal force and peak power, while generating speed throughout the sprint compared to the older athletes. This increased contact time may be explained by the observed lower isokinetic muscle strength and muscle stiffness associated with their developmental age compared to the U20 and Senior teams (54). As a whole the older and thus physically more mature athletes are able to generate a higher step frequency that in turn will benefit them in longer distances, as shown by the linear increase in high intensity running capacity (IRT) across the age groups. Thus despite the increased maximum sprinting ability of the U17 players, they are smaller, weaker and have a decreased running capacity at high intensity in comparison with the U20 and Senior teams. It should be noted that several members of the U17 group were track sprinters who also competed at national level, and thus are exceptionally fast for their age. Three of these players were starters, while one is a non-starter. It is unlikely that other comparative U17 groups will possess athletes with these attributes.

While this paper is a cross sectional analysis, precaution must be noted for the interpretation of the results, as the maturational process is unique to each individual assessed and therefore cross over between chronological age groups may be present for physical maturation milestones. The data suggests there is little difference in sprint kinetics and kinematics post maturation as denoted by the findings of the U20 and Senior squads, but there may be a window of accelerated adaptation to training (6) for increased development of these characteristics, before the completion of sexual maturation.

Practical Applications

This study contributes to the literature by providing normative data for coaches, trainers and clinicians working with elite and international level female soccer players across all FIFA eligible age brackets. The ability to objectively assess the physical performance of female soccer players and in turn compare those results to the normative data collected will not only improve, but guide player development systems,

monitoring and selection at the national and international level. The inclusion of starters and non-starters may lead to greater specificity in training and group selection as opposed to pure chronological comparisons. Our data suggests that players should aim at implementing individualized training for the development of speed, maximal aerobic velocity and leg strength prior to completion of sexual maturation in order to meet the physical requirements of the senior level international game.

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CHAPTER 4: POSITIONAL DIFFERENCES AND DETERMINANTS OF SPEED IN ELITE FEMALE SOCCER PLAYERS

Abstract

The purpose of this study was to profile position-specific physiological characteristics of FIFA eligible female soccer players, and to identify the inter-relationships between strength, power, sprint kinetics and kinematics, and measures of acceleration and maximal velocity. Anthropometry (height and body mass), lower body strength (isokinetic hip and knee flexion and extension peak torques at $60^{\circ} \cdot s^{-1}$), sprint kinetics and kinematics (over-ground and non-motorized treadmill), leg power (unilateral jumping) and maximal aerobic velocity (multi-stage fitness test) of 33 international female soccer players were assessed. Players were assigned into positional groups based on their most recent international appearance for New Zealand. Significant differences ($p < 0.05$) were found between player's positions for some anthropometric characteristics. Isokinetic strength and maximal velocity were the only physiological measures of significant difference between playing position, mainly between strikers and central mid-fielders. Maximum sprint velocity significantly correlated with isokinetic strength, sprint kinetics and kinematics, and leg power ($r = 0.36$ to 0.87 , $p < 0.05$), whereas acceleration significantly correlated with isokinetic knee strength and horizontal jumping power ($r = 0.36$ and $r = 0.36$ respectively, $p < 0.05$). It is suggested that improving unilateral leg strength and power may be effective in enhancing maximal speed for elite players.

Key Words: acceleration, maximal velocity, stance kinetics, sprint kinematics, strength, power

Introduction

Successful outcomes in international soccer are reliant on an integrated approach, incorporating technical proficiency, tactical knowledge and an exceptionally high level of physical conditioning. The ability to objectively assess physical performance has become a vital component for player development systems, player monitoring and youth player identification at the national and international level (19, 66, 74, 91). As evidenced in the literature, elite or selected players routinely achieve higher performance outcomes on sprint, strength and jump tests as compared to sub-elite (24, 40, 73, 85) or non-selected players (40, 47). This further demonstrates the importance of evaluating the physical characteristics for soccer.

After a rapid growth in popularity over recent decades, there are currently more than 4 million female soccer players registered in football associations worldwide (35). Despite this rapid increase in female participation, relatively few studies have described the physical demands of women's soccer (56, 67, 68), with even fewer investigating specific positional related differences at the elite level (67, 87, 88). Sedano et al. (81) and Mujika et al. (70) reported decreases in sprint and vertical jump ability among female soccer players as a function of level played, whereas Vescovi et al. (88) reported no positional differences for sprinting skill or CMJ ability in university age players. These reports are in stark contrast to players assessed at the elite and/or international level of play. Haugen et al., (41) reported moderate to large effect size differences across playing position as well as performance level. These findings are in accordance with elite male players (28, 82). This discrepancy between findings suggests that there is a need to further investigate position related differences at the international level. Refining our understanding of the position related differences might provide insight into best practice for implementation of specific training interventions.

The capability of a soccer player to produce high speed actions has been identified as a critical match performance indicator for success (68). While high speed actions only contribute to ~11% of a total distance covered within a match, these actions are linked to critical moments leading directly to obtaining possession, and to further the scoring or conceding of goals (73). Current literature indicates that the acceleration phase is

much shorter for sport speed, as opposed to track speed, therefore attaining maximal velocity earlier within the sprint would be deemed critical (5). The acceleration phase and maximum velocity phase are further divided by unique body orientation, force application techniques, stride length and frequency; including shin angle on ground contact with a lower heel recovery (79). Current literature supports the discriminative qualities between acceleration and maximal velocity in elite male soccer players (21, 59). As sport speed for female athletes may be different from male athletes, it may also be plausible that the relationships between strength and power measures and speed measures (i.e. acceleration and maximal speed) may also differ.

Current research has utilized a correlational approach with isokinetic or isoinertial dynamometry to explain the relationship between strength and power measures with sprint performance. The relationships between speed and isokinetic assessments with concentric hip and knee actions in male athletes are currently unclear (1, 2). Isoinertial assessments, such as squats and bilateral jumps, have also been investigated with mixed findings. The strongest correlations with speed performance have been reported with single or multiple unilateral jumps, usually in the horizontal direction ($r = >0.80$) (22, 64). Current research has identified these relationships for male athletes, leading to the need for further investigation utilizing female athletes. Relationships between sprinting kinetics and kinematics and speed measures have also been investigated (1, 14). Significant relationships have been reported between sprint performance and forward oriented ground reactions forces, but not magnitude of ground reactions forces (53, 69). No previous studies, to our knowledge, have investigated isokinetic or isoinertial predictors of speed in elite female soccer players. Such information is vital for identification and development of speed given its implications for game performance.

The purpose of this study was to identify the position specific physiological characteristics of FIFA eligible female soccer players, and to identify the inter-relationships between strength, power, sprinting kinetics and kinematics, and measures of acceleration and maximal velocity.

Methods

Experimental Approach to the Problem

A battery of laboratory and field based assessments were performed during the final training period leading into a FIFA sanctioned international competition (2012 U20 FIFA Women's World Cup and the 2012 FIFA Tournament at the London Olympics). Comparisons were made across player positions; goalkeeper (GK), center back (CB), central midfield (CMF), fullback/wide (FB/WIDE) and strikers (ST) to provide a position specific profile of these physiological characteristics at the international level. In addition, inter-relationships of strength, power, and sprint kinetics and kinematics with measures of acceleration and maximal velocity of international female soccer players across both the U20 and Senior FIFA age brackets were analyzed.

Subjects

Subjects included 33 elite female soccer players (20.3 ± 4.3 yr), all who represented New Zealand within the 2012 calendar year of competition, including but not limited to the U20 FIFA Women's World Cup in Japan and the FIFA Women's Football tournament at the London Olympics. Testing was carried out during the training build up to each featured event and all players were tested within 4 weeks of each other. On average the training group held 6 training sessions per week, with all players participating in 1, 90-minute game per week throughout the testing period. The training group consisted of goalkeepers (GK, $N = 2$), center backs (CB, $N = 7$), fullback/wide players (FB/Wide, $N = 9$), central midfielders (CMF, $N = 9$) and strikers (STRIKER, $N = 6$). Players had a minimum of 2 and 3 yrs of experience training within the national program at the U20 and SR level, respectively. All players were free from any injury that would prevent maximal effort during performance testing. All procedures described in this study were approved by the Auckland University of Technology Ethics Committee. All subjects and guardians, where appropriate were fully informed of all experimental procedures before giving their informed consent to participate.

Procedure

All subjects were required to avoid strenuous exercise 24 hours before testing and therefore testing was scheduled immediately following their prescribed rest day. All subjects performed a standardized warm-up consisting of 10-15 minutes that included general exercises such as jogging, shuffling, sprinting, multi-directional movements,

and dynamic stretching. Performance was assessed in a single session with the tests completed in the following order: anthropometrical assessment, sprint kinetics and kinematics, unilateral jumping, and isokinetic strength. Maximal aerobic velocity was further assessed during a group training session within the 4-week testing period.

Isokinetic Strength Assessment

Maximal torque generated by the knee extensors, knee flexors, hip flexors and hip extensors was obtained on an isokinetic dynamometer (Cybex Norm, Phoenix Healthcare, Nottingham, UK). The motor axis was visually aligned with the axis of the knee joint for knee flexion and extension, and at the axis of the hip joint for hip flexion and extension. The subject was either seated (trunk reclined to 15° from the vertical plane) or laying horizontal and stabilized so that only the knee or leg was moving with a single degree of freedom. The subject's dominant leg was assessed, as determined as the preferred kicking leg. All subjects performed testing in the following order: concentric knee flexion and extension, eccentric knee flexion and extension and concentric hip flexion and extension at the set experimental maximal velocity of 60°•s⁻¹, chosen to allow safe and reliable measurement of concentric and eccentric strength. After a standardized warm up consisting of 2 rounds of 3 to 5 submaximal (~50% and ~80%) contractions, 5 maximal repetitions were performed for the concentric measures, whereas 3 maximal repetitions were performed for the eccentric measures. All subjects were encouraged to provide maximal effort during all tests performed. For all trials, peak torque (PT, N•m) was recorded and averaged for the 5 repetitions during concentric knee and hip flexion and extension, as well as the 3 repetitions during eccentric knee flexion and extension. Test-retest reliability of peak torque was assessed prior to the current study and revealed acceptable absolute (CV ≤ 5.4 to 13.8) and relative reliability (ICC ≥ 0.87 to 0.94) (63).

Sprinting Kinetics and Kinematics

Sprint kinetics and kinematics were assessed on a non-motorized treadmill (NMT) (Woodway, Force 3.0, Waukesha, WI, USA). The NMT sprint performance variables were measured after a warm-up on the NMT consisting of 3 minutes continuous jogging interspersed with 3 sprints at gradually increasing speeds (~60% of their perceived maximal speed). During the maximum effort sprints that followed, the

subjects ran over the NMT with 4 embedded vertical load cells mounted under the running surface and were connected to a mounted horizontal load cell, which measures horizontal force via a non-elastic tether and harness that was attached around their waists. The horizontal load cell was attached to a metal vertical strut with a sliding gauge, which locked into place to avoid any movement during testing. The sliding gauge allowed the horizontal load cell to be adjusted vertically in accordance to the height of each subject so that the tether was at an angle greater than horizontal for each participant while standing, so as to maintain the horizontal position of the tether during the forward lean adopted when sprinting on the NMT. Subjects were instructed to sprint maximally from a standing split stance start (left leg forward) on the researcher's instruction and to maintain their effort for greater than 6 seconds. This procedure was repeated twice more interspersed with at least 2 minutes of passive recovery. Mechanical data were sampled at 200 Hz during the sprint period allowing instantaneous collection of vertical forces (F_v), horizontal forces (F_h) and power (P_{max}). Peak values of force and power were averaged over 10 steps at constant maximum velocity. Contact times (C_t) and flight times (F_t) were also recorded and averaged over the 10 steps. C_t was determined from the time of force applied to the treadmill exceeding 0 N and returned to 0 N, where as F_t was determined from the time between the end of the ground contact period of one foot to the beginning of the ground contact period for the opposite foot. Stride frequency was determined from the following formula: $1/(C_t + F_t)$, where as step length was determined from the following formula: running velocity/step frequency. Test-retest reliability of sprint kinetics and kinematics was assessed prior to the current study and revealed acceptable absolute ($CV \leq 2.0$ to 12) and relative reliability ($ICC \geq 0.58$ to 0.85) (63).

Unilateral Leg Power

The assessment of unilateral leg power for both the horizontal countermovement jump (HCL) and lateral countermovement jump (LCJ) was adapted from Meylan et al. (65). For the HCL, subjects began by standing on the designated testing leg with the foot at the starting line and with hands on the hips. Each subject was instructed to sink to a self selected depth as quickly as possible before jumping as far forward as possible and landing on 2 feet. For the LCJ each subject stood on the designated testing leg with the foot at the starting line and hands on the hip. Each subject was instructed to

sink to a self selected depth as quickly as possible and then jumped as far laterally to the inside and landed on 2 feet. Three trials were performed on the dominant leg, as determined by the leg used to kick the ball, interspersed with 2 minutes of passive rest between both the HCJ and the LCJ.

Maximal Aerobic Velocity

Maximal running speed was determined by use of the 30:15 intermittent fitness test (30:15_{IFT}) (16). The 30:15_{IFT} protocol consists of 30 s shuttle runs, which are interspersed with 15 s passive recovery periods. Running velocity was initiated at 2.2 m/s (8 km/hr) and speed continued to increase 0.14 m/s (0.5 km/hr) for every 30s shuttle run completed. Subjects were required to run back and forth over a 40 m track at the given pace, governed by a pre recorded beep. The velocity attained during the final stage completed was determined as the subject's maximal aerobic velocity or V_{IFT}. VO₂max can be further estimated from the V_{IFT} according to the following formula: VO₂max_{30-15IFT} (ml.min/kg) = 28.3 - 2.15G - 0.741A - 0.0357W + 0.0586A x V_{IFT} + 1.03V_{IFT}. G stands for Gender, female = 2, male = 1, A for age, W for weight (15).

Statistical Analysis

Pearson correlation coefficients were used to determine the relationships between strength, power, sprint kinetic and kinematic and sprint performance variables. The variables included: isokinetic measures (peak torques for both concentric and eccentric knee flexion and extension at 60°s⁻¹ and concentric hip flexion and extension 60°s⁻¹), unilateral jumping, sprint kinetics and kinematics (Fv, Fh, Pmax, Ct, Ft, Hz and length), and sprint performance measures (10-m over ground and maximal velocity on a non-motorized treadmill). Further, the interpretation for the magnitude of the correlation is noted as trivial (0.0-0.1), small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9) and nearly perfect (0.9-1) (50). Further, a one-way ANOVA was used to compare the physiological and anthropometrical characteristics between the five playing position classifications (GK, CB, Wide/FB, CMF, Striker). When required, comparisons of the positional group means were performed using Fisher's least significant difference (LSD) post hoc analysis to determine pairwise differences. Statistical significance was accepted at p < 0.05. Data are presented as mean ± SD throughout.

Results

The values for each of the variables for the positional based comparison can be observed in Table 10. The main positional difference was between strikers and central midfield players. The strikers produced significantly greater concentric (153 ± 37.4 N•m, $p < 0.05$) and eccentric knee extension (183 ± 45.4 N•m, $p < 0.05$), maximal sprinting velocity (5.20 ± 0.42 m/s, $p < 0.05$) and step length (1.31 ± 0.25 m, $p < 0.05$). Goalkeepers had a significantly lower score for maximal aerobic velocity (17.5 ± 0.71 km/hr, $p < 0.05$), as compared to all other positions. No other variables could provide discriminative positional difference on performance variables.

The interrelationships between isokinetic strength variables can be observed in Table 11. Peak torque values significantly inter-correlated during most knee actions ($r = 0.39$ to 0.76 , $p < 0.05$), but few significant correlations were found between hip and knee actions. Knee extension actions were significantly correlated with vertical force and step length during sprinting ($r = 0.39$ to 0.45 and 0.39 to 0.40 , $p < 0.01$), and concentric hip extension was significantly correlated with vertical force, horizontal force and horizontal power ($r = 0.35$ to 0.56 , $p < 0.01$) during sprinting

Table 10. Physiological and Anthropometric characteristics of international female U20 and Senior soccer players, by position

	GK			CB			FB/WIDE			CMF			STRIKER		
Age (yr)	28.0	±	11.31	21.4	±	5.50*	18.1	±	1.67*	19.9	±	2.67*	20.5	±	2.87*
Experience (yr)	11.0	±	9.90	4.29	±	2.56*	3.56	±	1.33*	3.67	±	2.00*	4.83	±	1.60*
Frequency (days/week)	6.50	±	0.71	6.14	±	0.69	5.56	±	1.59	5.00	±	1.22	6.17	±	0.75
Anthropometry															
Height (cm)	177	±	1.84	174	±	2.32	165	±	7.85*^	164	±	6.35*^	167	±	6.68^
Mass (kg)	68.1	±	6.08	69.1	±	4.52	60.2	±	5.88^	59.4	±	5.19*^	64.3	±	5.86
Concentric Muscle Action															
Absolute Peak Torque (N·m ⁻¹)															
Knee: Extension	134	±	58.2	149	±	13.8	132	±	20.3	114	±	28.7^	153	±	37.4++
Flexion	110	±	29.3	106	±	17.9	101	±	11.3	95.1	±	13.4	17.7	±	7.21
Hip: Extension	200	±	4.87	206	±	29.6	200	±	35.2	188	±	61.2	212	±	55.5
Flexion	76.1	±	14.4	87.4	±	21.6	72.9	±	11.4	75.5	±	19.5	81.7	±	9.62
Eccentric Muscle Action															
Absolute Peak Torque (N·m ⁻¹)															
Knee: Extension	192	±	80.3	172	±	27.78	167	±	37.5	141	±	32.7	183	±	45.4++
Flexion	154	±	30.8	135	±	22.6	117	±	30.0	132	±	15.5	146	±	38.2
Speed															
Velocity (m/s)	4.99	±	0.05	4.94	±	0.26	5.00	±	0.25	4.77	±	0.21	5.20	±	0.42++
10-m (sec)	1.84	±	0.09	1.92	±	0.09	1.91	±	0.09	1.96	±	0.09	1.90	±	0.10
IRT (km/h)	17.5	±	0.71	19.2	±	1.07*	18.8	±	0.62	19.2	±	1.12*	19.3	±	1.13*
VO _{2max} (30-15IRT) (ml/kg/min)	47.8	±	4.89	49.6	±	3.26	47.7	±	1.13	49.2	±	2.70	49.7	±	3.36
Sprint Kinetics															
Fv Absolute (N)	1635	±	261	1639	±	162	1464	±	270	1398	±	170^	1488	±	306

Fh Absolute (N)	263	±	17.4	245	±	48.3	227	±	31.5	231	±	36.4	237	±	38.2
Pmax Absolute (W)	1294	±	110	1197	±	294	1126	±	201	1093	±	202	1186	±	255
Sprint Kinematics															
Contact Time (ms)	171	±	2.57	169	±	15.8	167	±	7.36	168	±	9.65	171	±	25.4
Flight Time (ms)	71.1	±	22.4	73.8	±	9.61	68.8	±	16.1	70.4	±	10.2	79.7	±	9.00
Step Frequency (Hz)	4.14	±	0.34	4.13	±	0.21	4.23	±	0.18	4.21	±	0.21	4.03	±	0.47
Step Length (m)	1.21	±	0.12	1.20	±	0.11	1.19	±	0.10	1.14	±	0.09	1.31	±	0.25††
Leg power															
SL Lateral Jump (cm)	137	±	24.5	154	±	14.8	153	±	15.3	145	±	14.2	160	±	5.87
SL Horizontal Jump (cm)	155	±	3.89	160	±	11.4	160	±	18.7	156	±	12.4	167	±	11.9

Values are means ± SD. * Significantly different from GK, $P \leq 0.05$. ^ Significantly different from CB, $P \leq 0.05$. † Significantly different from FB. Wide Players, $P \leq 0.05$. †† Significantly different from CMF Players, $P \leq 0.05$. N = 33; Experience = years in national program; Frequency = training days with national program; SL Lateral = single leg lateral jump; SL Horizontal = single leg horizontal jump; Vmax = peak vertical force; Hmax = peak horizontal force; Pmax = peak power; VO2max(30-15IRT) = Estimated VO_{2max}

The interrelationships between sprint kinetic and kinematic measures can also be observed from Table 11. Step length was moderate and significantly correlated with horizontal force ($r = 0.35$) and horizontal power ($r = 0.40$). Flight time was strongly and significantly related to all three sprint kinetic measures ($r = 0.55$ to 0.56). Horizontal force and power during sprinting were moderate and significantly correlated with horizontal jump distance ($p = 0.43$ and 0.47 , respectively) but not lateral jump distance.

The strength, jump and sprinting measures related to acceleration (10-m time) and maximal velocity are also detailed in Table 11. Eccentric knee flexion peak torque and single leg horizontal jump distance were the best correlates ($r = 0.36$, $p < 0.05$) of acceleration performance. Concentric hip extension, eccentric knee extension, horizontal power, as well as stride length and frequency were significantly related to maximum velocity ($r = 0.46$ to 0.87 , $p < 0.01$).

Table 11. Intercorrelation matrix between strength, jumping, sprinting mechanics and speed measures

		Con Knee		Ecc Knee		Con Hip		Fv	Fh	Pmax	Ct	Ft	Hz	Length	SLhorr	SLlat	Velocity	10M
		Ext	Flex	Ext	Flex	Ext	Flex											
Con	Ext	1.00																
Knee	Flex	0.73**	1.00															
Ecc	Ext	0.76**	0.57**	1.00														
Knee	Flex	0.21	0.39*	0.44*	1.00													
Con	Ext	0.25	0.30	0.39*	0.30	1.00												
Hip	Flex	0.21	0.39*	0.10	0.10	0.48**	1.00											
Fv		0.39*	0.30	0.45**	0.28	0.56**	0.39*	1.00										
Fh		-0.04	-0.13	0.03	0.00	0.35*	0.09	0.46**	1.00									
Pmax		0.04	-0.06	0.11	0.01	0.42*	0.12	0.53**	0.98**	1.00								
Ct		0.15	0.09	0.16	0.16	0.02	-0.33	-0.31	-0.15	-0.18	1.00							
Ft		0.23	0.08	0.19	-0.07	0.19	0.23	0.55**	0.56**	0.56**	-0.15	1.00						
Hz		-0.29	-0.14	-0.22	-0.04	-0.13	0.11	-0.14	-0.34	-0.32	0.67**	0.62**	1.00					
Length		0.40*	0.17	0.39*	0.02	0.34	-0.04	0.23	0.35*	0.40*	0.61**	0.57**	0.89**	1.00				
SLhorr		-0.11	-0.11	-0.13	-0.14	0.14	0.15	0.11	0.43*	0.47**	-0.06	0.36*	-0.23	0.27	1.00			
SLlat		0.02	-0.03	-0.09	-0.14	0.34	0.16	0.07	0.21	0.24	0.12	0.13	-0.19	0.29	0.76**	1.00		
Velocity		0.40*	0.15	0.46**	-0.02	0.52**	0.05	0.36*	0.42*	0.55**	0.34	0.43*	0.56**	0.87**	0.33	0.35*	1.00	
10M		0.11	0.02	0.10	0.36*	-0.03	-0.06	-0.04	-0.22	-0.27	0.28	-0.09	-0.19	0.03	0.36*	-0.19	-0.18	1.00

** . Correlation is significant at the 0.01 level (2-tailed). * . Correlation is significant at the 0.05 level (2-tailed). Con = Concentric; Ecc = Eccentric; Ext = Extension; Flex = Flexion; Fv = Vertical Force; Fh = Horizontal Force; Pmax = Power; Ct = Contact Time; Ft = Flight Time; Hz = Step Frequency; Length = Step Length; SLhorr = Single Leg Horizontal Jump; SLlat = Single Leg Lateral Jump; 10m = 10m Split

Discussion

This was the first study, to our knowledge, to profile position specific physiological characteristics of FIFA eligible female soccer players, and to identify the relationships of strength, power, and sprint kinetics and kinematics with measures of acceleration and maximal velocity. The main findings of this study were that the foremost positional difference were shown between strikers and central midfield players, for isokinetic knee extension strength, sprint velocity and step length, as compared to all other positions. Secondly, concentric hip extension, eccentric knee extension, horizontal power, as well as stride length and frequency were significantly related with maximum velocity ($r = 0.46$ to 0.87 , $p < 0.01$), whereas eccentric knee flexion peak torque and single leg horizontal jump distance were the best correlates ($r = 0.36$, $p < 0.05$) of acceleration performance.

Our observations that anthropometric positional differences are present are in accordance with the observations made with male players (12, 73) where goal keepers and center backs tend to be taller and heavier than other positions. This is contradictory to observations made in previous publications for female participation (88), where no anthropometrical differences were noted. As previous reports of female participation have reviewed a lower standard of play (NCAA Division 1) it is plausible that female players participating at the international level display a closer representation to male anthropometrical attributes as opposed to female trends.

Physiological differences among playing positions were identified in the present study between strikers and central midfield players, but no other positions. These findings complement those of Vescovi et al. (87) with professional women's soccer players, where midfield players achieved less total sprint distance and decreased maximal speed in comparison with forwards and defenders. The decreased sprint speed and duration were in accordance to the type of actions performed by midfield players, as compared to strikers during competition (12, 56, 67, 87-89). Midfield players have been shown to have a higher maximal oxygen uptake than forwards (56). Mohr et al., (67) reported that individual differences in high intensity running distances were related to position, with central defenders running less than midfield players and attackers, thus reflecting the difference in maximal oxygen uptake. In the present

study, this was not shown, as there were no significant differences in oxygen uptake by playing position. Therefore, the discrepancy between forward and central midfield sprint profiles may be a product of actions performed in the game and or training environment, as opposed to the overall fitness levels of the individual players. It appears that higher playing levels require a higher standard of fitness regardless of playing position.

Sprint kinematics play a role in the development of sport speed. This was evident with our findings where step length was significantly lower, along with maximal velocity, for the midfield players in comparison with the strikers. The achievement of maximal velocity is dependent on increasing step length and/or step frequency (13). In the present study, there were no significant differences in frequency for the players evaluated. Central midfield players rarely sprint over 30m in distance, and therefore throughout a game have limited opportunity to achieve maximal velocity; this is in stark contrast to strikers, who spend more of their sprint time at maximal velocity. This contrast is reflected in the present study, as certain physiological characteristics of players were position specific.

The interrelationships between isokinetic strength variables demonstrated that peak torque values were significantly inter-correlated during most knee actions, while there were few significant correlations found between hip and knee actions. Further, only low correlations were observed between eccentric and concentric knee actions. The lack of correlations between concentric hip and both concentric and eccentric knee actions demonstrates the independent nature of each assessment. In order to accurately assess an athlete, it is suggested that a thorough lower limb isokinetic testing battery should be considered.

The relationship between isokinetic measures and sprint performance yielded eccentric knee flexion peak torque to be the best correlate ($r = 0.36$, $p < 0.05$) of acceleration performance, where concentric hip extension and eccentric knee extension were significantly related with maximum velocity ($r = 0.46 - 0.87$, $p < 0.01$). These results support the previous findings that the quadriceps are dominant in movement patterns associated with jumping, kicking and acceleration; the hamstrings

are dominant with activities where maximal velocities are attained (24). Such findings further suggest that the determinants of acceleration and maximal velocity differ (13).

Sprint kinetics and kinematics are paramount to speed development, as indicated by the significant correlations with maximal velocity in this study ($r = 0.36 - 0.89$, $p > 0.05$). Given the interaction between step length and frequency, increasing step length by increasing flight time can potentially limit step length. This is due to the standardization of leg length which is a predetermined constant; the longer the legs, the greater the air time, usually leading to a decrease in step frequency (13). Therefore, flight time may be considered a determinant of step length. Ground contact is the only point in which an athlete can exert force to produce movement. Moderate correlations ($r = 0.36 - 0.55$, $p > 0.05$) were shown between horizontal and vertical force application and speed. Thus improving sprint performance may be related to improving step length with increased force generation during ground contact.

During competition, the goal of acceleration is different from maximal sprinting. The first steps are intended to change position and achieve the highest possible velocity in the shortest period of time. It has been suggested that this specific sports training can limit step length in favour of step frequency to facilitate change of direction (13), and therefore, it is plausible that the initial 10m acceleration period may elicit a different strategy than maximal velocity sprints in field sport players.

There is an important contribution of leg power in sprint performance (5, 13, 65). As indicated in the present study, single leg horizontal leg power was significantly correlated with acceleration ($r = 0.36$, $p > 0.1$), whereas single leg lateral leg power was significantly correlated with maximal velocity ($r = 0.35$, $p > 0.1$). Thus it could be suggested that training should incorporate unilateral jumping in multi directions in order to improve sprinting performance in elite female soccer players.

Practical Applications

This study contributes to the literature by providing insight into the associations between strength, power and sprint kinetic and kinematic measures with speed

determinants, including acceleration and maximal velocity. Further to this, positional comparisons were made, providing valid information regarding positional characteristics of international female soccer players. For technical coaches and strength and conditioning specialists working with female players at the elite level, it is important to note that the positional differences in sprint time may be a factor of game environment and tactical structure, and that regardless of position a very high level of aerobic fitness is required for performance. Furthermore, it was shown that the predictors of maximum sprint velocity and acceleration are different, leading to the suggestion that improved sprint kinematics combined with increasing both concentric and eccentric leg strength may be effective in enhancing force generation for further development of speed in elite players.

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CHAPTER 5: DISCUSSION AND RECOMMENDATIONS

Preface

This chapter is the synthesis of this thesis with an outline of the key physiological characteristics associated with elite female soccer, in an effort to provide a physical development framework for elite female soccer players. The goal of this chapter is to present the practical applications of these findings, in context with the current literature, to enhance the scientific knowledge of the key physiological characteristics associated with the development of female soccer players for international game play. The chapter ends with a conclusion of the thesis as a whole.

Discussion

The early identification and physical development of female soccer players is becoming increasingly important for soccer federations worldwide. Many factors can contribute to the development of an international soccer player, from technical skill, tactical knowledge to mental acuity, but it is the physical development that provides the framework for all facets of the game to be established. However, there is limited knowledge around the key demands of the game from a female perspective and a direct relationship between these demands and the physical characteristics displayed by female players at the elite level. This master's thesis has sought to uncover the key physiological characteristics of female soccer players at the international level across a wide age range, with specific attention paid to the identification of player suitability for the international game, with references to age related, position related and playing time related differences.

On the basis of the literature review focusing on the physiological demands and characteristics of women's soccer at the elite level, it was established that while the physiological demands of the sport are similar to that of their male counterparts, female players lack critical lower limb strength and power. It was also shown that these characteristics have a link to on-field technical performance and tactical choices, leading to either positive or negative performance outcomes. In addition, a female soccer player must strive to achieve the highest level of both aerobic and anaerobic

conditioning, in addition to increased strength and power to help enable positive and impactful performances at the elite or international level.

Given the lack of published information for strength, power and speed measures for elite female soccer players, it was necessary to establish normative data for this cohort of athletes. It was established that there are significant differences between the FIFA age group classifications (U17, U20 and Senior level), including differences between starters and non-starters, as well as positional differences noted post maturation.

Due to the novelty of utilizing the Woodway instrumented treadmill to collect sprint kinetics and kinematic data with this cohort of athletes, analysis of the between-day reliability was necessary. It was established that the collection of vertical force, horizontal force, horizontal power, as well as flight time, contact time, step length and step frequency demonstrated sufficient between-day reliability to be used as a base line classification tool for sprint kinetics and kinematics for female soccer players. Further it was also established that isokinetic hip extension, hip flexor, knee flexion and knee extension strength measures demonstrated sufficient between-day reliability. As a result, these measures could be used with confidence to establish normative data for this cohort, and potentially be used to track this cohort of athletes over time and throughout their development as elite female soccer players.

Identification of key physiological determinants of international female soccer players

Many factors contribute to the physical development of elite female soccer players. The identification of the key determinants of speed, strength, power and aerobic capacity across the FIFA age groups (Under 17, Under 20 and Senior) provides a benchmark for the physical development of these athletes for international level competition. Through early identification, key physiological characteristics may be developed through focused curriculum to ensure they are achieved in order to maximize potential at the highest level.

Strength

The evaluation of player's isokinetic hip and knee flexor and extensor strength using dynamometry was completed in order to determine normative data for this cohort of athletes extending across a wide age range (14 - 36yrs). While the findings were in agreement with previous literature in that peak torques across all age groups increase with age throughout maturation (10, 31, 47, 76), the relative peak torques for both hip flexion and extension was significantly greater for the U20 group of athletes (age 18-20yrs). In contrast, the U17 group displayed significantly weaker hip flexion and extension peak torques, raising the question for the potential for a targeted training window for which accelerated strength gains may be generated.

The positional comparison between post maturational players revealed a significant difference in knee extension strength between strikers and midfield players. This difference may be reflected in positional play, as indicated by Vescovi et al. (87) where midfield players achieved less total sprint distance and decreased maximal speed in comparison with forwards. Furthermore, knee extension and hip extension strength were shown to be significantly related to maximum velocity ($r = 0.46 - 0.87$, $p < 0.01$), something forwards routinely achieve throughout a match, in comparison with central midfielders.

Leg Power

Leg power is the product of strength and speed (86). For many of the actions required in soccer, maximal power is vital during movements which require high levels of velocity during athletic movements (55), including sprinting, jumping, tackling, passing, throwing and striking. This relationship between maximal strength and maximal power indicates that a person cannot achieve high levels of power, without first being relatively strong (25). Senior starters possessed significantly greater isokinetic strength and leg power results above all other groups, resulting in the assertion that the development of power is a vital determining physiological characteristic of international play.

Sprint Kinetics and Kinematics

Speed is a primary component to the physical development of a soccer player. Speed can distinguish between the level of play and the ability to sustain high intensity

activity leading to successful performance outcomes (73). Sprint kinetics and kinematics are paramount to speed, as shown by the significant correlations with maximal velocity ($r = 0.36 - 0.89$, $p > 0.05$). During soccer play however, the role of acceleration is different from that of maximal speed. The initial steps dictate a change of position and the development of the highest possible velocity in the shortest time period possible. The results of our data suggest that there is little difference in sprint kinetics and kinematics post maturation, but there may be a window of opportunity of accelerated adaptation to training for increase development prior to completion of sexual maturation.

Maximal Aerobic Capacity

V_{IFT} is not solely a measure of maximal aerobic function, but is inclusive of anaerobic capacity, neuromuscular strength, change of direction qualities, inter-effort recovery ability and the repeat sprint ability of a soccer player (15). As such, the relationship between V_{IFT} and performance is an indicator of a player's performance capability. Our data represents a linear progression of maximal running velocity and derived $VO_{2max(30-15IFT)}$ across all age groups, as well as increased values for starters over non starters. While playing positions showed no significant differences, it appears that the higher the playing level, the higher the standard of fitness required, regardless of playing position.

Recommendations

- Introduce specific neuromuscular training programs focused on both concentric and eccentric strength development for both the hip and knee dominant movement patterns prior to the end of maturation.
- Introduce specific plyometric training programs for the transition of leg strength to power prior to the end of maturation.
- Introduction of sprint techniques for the development of improved sprint kinematics to enhance force generation for speed development.
- A primary focus for the development of maximal aerobic capacity to establish the foundation for which an elite soccer player can be built.

Future Directions

Given the scarcity of research for women's soccer specific physical development, the need for further studies assessing the impact of training interventions is warranted. Physical profiling could be useful as a tool for player identification, however, further research should be continued to examine how these measures may be useful for athletic development. Future research should continue to define which exercises are best used with female soccer players, as well as to examine how assessment measures can be used for monitoring impactful physical development.

Conclusions

This thesis consists of a series of studies evaluating the physiological characteristics of different playing levels, age groups, positions and status as a starter or non-starter of international female soccer players. Correlations were also evaluated between characteristics assessed. The ability to objectively assess the physical performance of female soccer players and to further compare those results to normative data will not only improve but help to guide player development systems, player monitoring and ultimately selection and the national and international level.

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APPENDICES

Appendix 1: Ethics Approval, Auckland University of Technology Ethics Committee



MEMORANDUM

Auckland University of Technology Ethics Committee (AUTC)

To: Matt Brughelli
 From: Rosemary Godbold, Executive Secretary, AUTC
 Date: 14 June 2012
 Subject: Ethics Application Number 12/95 Effects of an intermittent sprint protocol on sprint mechanics and isokinetic dynamometry in elite female soccer players.

Dear Matt

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTC) at their meeting on 30 April 2012 and I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTC's meeting on 9 July 2012.

Your ethics application is approved for a period of three years until 14 June 2015.

I advise that as part of the ethics approval process, you are required to submit the following to AUTC:

- A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/research/research-ethics/ethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 14 June 2015;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/research/research-ethics/ethics>. This report is to be submitted either when the approval expires on 14 June 2015 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTC is notified of any adverse events or if the research does not commence. AUTC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all written and verbal correspondence with us. Should you have any further enquiries regarding this matter, you are welcome to contact me by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 6902. Alternatively you may contact your AUTC Faculty Representative (a list with contact details may be found in the Ethics Knowledge Base at <http://www.aut.ac.nz/research/research-ethics/ethics>).

On behalf of AUTC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Dr Rosemary Godbold
 Executive Secretary
 Auckland University of Technology Ethics Committee

Appendix 2: Participant information sheet

Participant Information Sheet



Date Information Sheet Produced:

08-04-2012

Project Title

Effects of intermittent sprint protocols on sprint mechanics and isokinetic dynamometry in elite female soccer players.

An Invitation

I, Sarah Manson invite you to participate in this study; which will benefit you, as well lead to my Master's qualification. Your participation is voluntary and you may withdrawal from the study at any time prior to the conclusion of data collection. Your involvement or status as a player within New Zealand Football will not be affected by weather you choose to participate or not.

What is the purpose of this research?

The purposes of this research are to: 1) develop an understanding of the relationships between intermittent sprint fatigue and performance in female athletes, including muscle strength and force production; 2) identify athletes at risk for lower body musculoskeletal injury with objective and reliable biomechanical testing.

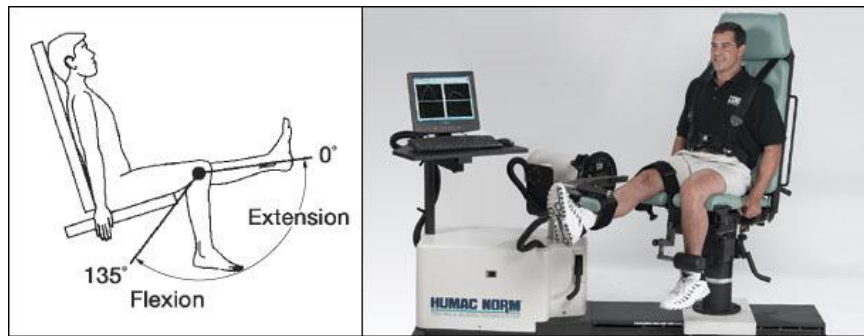
How was I identified and why am I being invited to participate in this research?

By selection and commitment to the New Zealand Football player pool 2012: Youth Football Ferns, Junior Football Ferns & Football Ferns, your contact information was provided to me, the researcher, from New Zealand Football Administration/Coaches. I, the researcher, then contact you for involvement within this study.

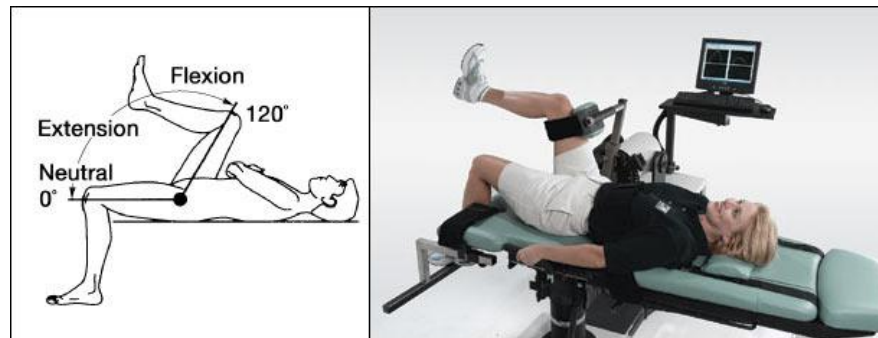
What will happen in this research?

Isokinetic Dynamometry

An isokinetic dynamometer will be used to measure the amount of torque (or force in Nm) of which you can exert throughout the range of motion of hip extension (gluteal muscles), knee flexion (hamstrings) and knee extension (quadriceps). You will perform 5 maximum concentric contractions (i.e. hip extension, knee flexion and knee extension), proceeded by two warm up sets (one at 50% effort and one at 80% effort) for both legs, in random order at a slow angular velocity of $60^{\circ}\cdot s^{-1}$. You will also be assessed for 3 eccentric contractions of the knee flexors for both legs in random order at an angular velocity of $60^{\circ}\cdot s^{-1}$. During all trials you will receive verbal encouragement.



Athlete position for isokinetic knee flexion and extension for both concentric and eccentric muscle testing



Athlete position for isokinetic hip flexion and extension, concentric muscle testing

Running Kinetic and Kinematic Testing

You will run on a nonmotorized force treadmill (Force Treadmill Dynamometer, Woodway 3.0, Waukesha, Wisconsin, USA). You will perform running bouts at 40, 60, 80, and 100% of your maximum velocity (maximum speed) on the Woodway treadmill. The maximum velocity bouts will be performed first to determine a baseline for the subsequent bouts. After the baseline is determined, you will be asked to build up to maximum velocity over a 4-second period and then to maintain maximum velocity for another 5 seconds. Throughout the running you will be given verbal encouragement for the 5-second period to maintain maximum running velocity. The mechanical variables will be collected during the 5-second period. Long rest periods (>3 minutes) will be provided to minimize the effects of fatigue. During the slower-moderate running bouts, you will be asked to build up to 40, 60, or 80% of maximum velocity over a 4-second period and then maintain these velocities for 8-10 seconds while vertical and horizontal forces will be collected. To help maintain a constant velocity over the 8-10 seconds, a real-time profile of running velocity will be projected on a screen in front of you



Image and setup for athlete running on Woodway non-motorized force treadmill

Functional Jump Profile

You will be assessed for your single-leg horizontal countermovement jump (HCJ), single-leg lateral countermovement jump (LCJ) on both legs. For the HCJ, you will begin by standing on the designated testing leg with the foot at the starting line and with hands on the hips. You will drop to a self-selected depth before jumping as far forward as possible and landing on 2 feet. The LCJ will have you standing on the designated testing leg with the foot at the starting line and hands on the hip. You will drop to a self-selected height and then jump as far laterally to the inside and land on 2 feet.

What are the discomforts and risks?

With any form of exercise there is some risk of muscle soreness and/or injury. This testing is intensive in nature and does have some inherent risk associated with it, including musculoskeletal injury or soreness.

How will these discomforts and risks be alleviated?

Risk will be mitigated by ensuring that qualified researchers are present to operate all equipment and conduct the testing. Adequate warm up and cool down procedures will also be implemented to ensure a further reduction of muscle soreness and injury. If at anytime, you the athlete, feels discomfort (either physical, psychological or emotional) you are free to withdrawal from the testing without penalty.

What are the benefits?

By participating in this study, you are providing us the opportunity to collect data which will help identify risk factors for musculoskeletal injury, as well as help us understand the connection between muscle fatigue and force production. You will be able to compare your results to these groups of interest and gain some insight into your individual injury risk. A summary of your results and the study will be available to you on completion of the project.

How will my privacy be protected?

Everything that you will fill out will only be seen by the project supervisor (Dr. Matt Brughelli) and myself (Sarah Manson).

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

What are the costs of participating in this research?

There are no costs to participate, apart from scheduling your time to be available for testing. The first testing session will last approximately 1.5 hours, with 2 supplementary sessions to follow. Overall the total duration of testing will be less than 5 hours. The testing session will occur approximately 1 week apart during regular training hours.

What opportunity do I have to consider this invitation?

After you have read through this form, you will have plenty of opportunity to ask any questions you would like about the study up to the test occasion. One week prior to testing, there will be an orientation session for you to familiarise yourself with the practical step by step processes of the tests, to ask any further questions and to

receive feedback about your technique. After your concerns have been satisfied, you will need to decide whether or not you would like to participate in the research.

How do I agree to participate in this research?

If you would like to participate in this research, please fill in and sign the attached *Consent Form*. If you do not wish to participate in this research, alternative arrangements will be made for you. Please also understand that you may withdraw from testing at any time without any adverse consequences.

Will I receive feedback on the results of this research?

Yes, after the initial reliability phase of the project is completed you can receive a summary of your individual results once the information is ready for distribution. Please check the appropriate box on the *Consent Form* if you would like this information.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr. Matt Brughelli matt.brughelli@aut.ac.nz, telephone: 09 921 9999, extension 7025.

Whom do I contact for further information about this research?

Please contact Sarah Manson, sarahamanson@gmail.com, telephone: 021-0821-7053.

Researcher Contact Details:

Please contact Sarah Manson, sarahamanson@gmail.com, telephone: 021-0821-7053.

Project Supervisor Contact Details:

Dr. Matt Brughelli matt.brughelli@aut.ac.nz, telephone: 09 921 9999, extension 7025.

Approved by the Auckland University of Technology Ethics Committee on 14 June 2012, ATEC Reference number 12/95.

Appendix 3: Participant consent form

Consent Form

**Project title:**

Effects of intermittent sprint protocols on sprint mechanics and isokinetic dynamometry in elite female soccer players.

Project Supervisor:

Matt Brughelli, PhD

Researcher:

Sarah Manson

- ☐ I have read and understood the information provided about this research project in the Information Sheet.
- ☐ I have had an opportunity to ask questions and to have them answered.
- ☐ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ☐ I agree to take part in this research.
- ☐ I wish to receive a copy of the report from the research (please tick one):
Yes ☐ No ☐

Participant's signature

Participant's name:

Participant's Contact Details (if appropriate):

.....
.....

Date:

Approved by the Auckland University of Technology Ethics Committee on 14 June 2012, AUTEK Reference number 12/95.

Note: The participant should retain a copy of this form

Appendix 4: Parent/Guardian consent form

Parent/Guardian Consent Form

**Project title:**

Effects of intermittent sprint protocols on sprint mechanics and isokinetic dynamometry in elite female soccer players.

Project Supervisor:

Matt Brughelli, PhD

Researcher:

Sarah Manson

- ☐ I have read and understood the information provided about this research project in the Information Sheet dated dd mmmm yyyy.
- ☐ I have had an opportunity to ask questions and to have them answered.
- ☐ I understand that I may withdraw my child/children and/or myself or any information that we have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ☐ If my child/children and/or I withdraw, I understand that all relevant information obtained will be destroyed.
- ☐ I agree to my child/children taking part in this research.
- ☐ I wish to receive a copy of the report from the research (please tick one):
Yes ☐ No ☐

Child/children's name/s :

Parent/Guardian's signature :

Parent/Guardian's name:

Parent/Guardian's Contact Details (if appropriate):

.....
.....

Date:

Approved by the Auckland University of Technology Ethics Committee on 14 June 2012, AUTEK Reference number 12/95.

Note: The participant should retain a copy of this form

Appendix 5: Participant assent form

Assent Form

**Project title:**

Effects of intermittent sprint protocols on sprint mechanics and isokinetic dynamometry in elite female soccer players.

Project Supervisor:

Matt Brughelli, PhD

Researcher:

Sarah Manson

- ☐ I have read and understood the sheet telling me what will happen in this study and why it is important.
- ☐ I have been able to ask questions and to have them answered.
- ☐ I understand that while the information is being collected, I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.
- ☐ If I stop being part of the study, I understand that all information about me will be destroyed.
- ☐ I agree to take part in this research.

Participants Signature

Participants Name:

Participant Contact Details (if appropriate):

.....

Date:

Approved by the Auckland University of Technology Ethics Committee on 14 June 2012, AUTEK Reference number 12/95.

Note: The Participant should retain a copy of this form.