Investigations for the Development of a Physiological Profile in Women's Soccer

(Untersuchungen zur Entwicklung eines physiologischen Anforderungsprofils im Frauenfußball)

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D I S S E R T A T I O N

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Vanessa Martínez Lagunas, M.A.

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Gutachter:

Herr Prof. Dr. Ulrich Hartmann

Frau Prof. Dr. Petra Platen

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“Because the people who are crazy enough to think they can change the world are the ones who do.”

(Steve Jobs, 1955-2011)

DEDICATION

"This dissertation is dedicated to all present, past and future female soccer players, coaches, physical trainers, sport scientists and administrators involved in the women's game, who continue to work hard on and off the field for its further and sustained development."

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BIBLIOGRAPHICAL INFORMATION

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ABSTRACT

The present PhD thesis is compilation of various investigations for the development of a physiological profile in women's soccer. After an extensive literature review, several literature gaps in this area were identified including: physiological demands of a women's soccer match including simultaneous measurements with portable metabolic equipment and GPS technology; physical performance analysis of women's soccer competitive matches of different competition levels using GPS technology; and fitness testing and fitness profiles of female soccer players of different competitive levels by means of laboratory and field tests. The investigations that are part of this thesis targeted these gaps and provided for the first time novel and objective findings in these subjects. The popularity of women's soccer as well as the number of female soccer players worldwide has increased exponentially in the last 30 years. Furthermore, there are now multiple women's soccer international competitions and professional leagues around the globe and they will continue to increase in the next few years. Therefore, there is currently high demand for scientific research specific to the women's game in these topics which may aid coaches, physical trainers, and other practitioners to develop more effective fitness assessments and training programs for their female players in order to improve their fitness status and overall match performance according to their competitive level and positional role.

KEYWORDS: women's football, female footballers, physical and physiological match demands, fitness testing, fitness profiles, portable metabolic equipment, GPS technology, heart rate, and blood lactate

LIST OF PUBLICATIONS

The following papers published in national and international peer-reviewed journals/conference proceedings are part of the present cumulative dissertation:

I. **Martínez-Lagunas, V. (2013). Physiologische Beanspruchung eines Frauenfußballspiels (Physiological demands of a women's football match).** ***Leipziger Sportwissenschaftliche Beiträge, 54*****(1), 122-127.** Note: an English summary of this paper is presented in section 4.1.

II. **Martínez-Lagunas, V., and Hartmann, U. (2014). Validity of the Yo-Yo intermittent recovery test level 1 for direct measurement or indirect estimation of maximal oxygen uptake among female soccer players.** ***International Journal of Sports Physiology and Performance, 9,*** **825-831.**

III. **Martínez-Lagunas, V., Niessen, M., and Hartmann, U. (2014). Women's football: Player characteristics and demands of the game.** ***Journal of Sport and Health Science, 3*****(4), 258-272.**

IV. **Martínez-Lagunas, V., Niessen, M., and Hartmann, U. (2016). GPS performance analysis of women's soccer competitive matches of the second and fourth German leagues. In Favero, T., Drust, B. & Dawson, B. (Eds.),** ***International Research in Science and Soccer II*** **(pp. 93-103). Abingdon, OX: Routledge.**

These papers can be found at the end of this dissertation in their original published format.

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LIST OF ABBREVIATIONS

2L	Second German Women's Soccer League
30m-T	30m-sprint time
4L	Fourth German Women's Soccer League
70m-T	70m-sprint time
aVO_2max	Absolute maximal oxygen consumption in laboratory treadmill test
B-A 95% LA	Bland-Altman 95% limits of agreement
BF	Body fat
BH	Body height
BIA	Bioelectrical impedance analysis
BMI	Body mass index
BM	Body mass
CD	Central defender(s)
CHO	Carbohydrate turnover
CMJ-H	Counter-movement jump height (with arm swing)
CONACYT	Mexican National Council of Science and Technology
D	Distance covered
DAAD	German Academic Exchange Service
DFB	German Football Association
ED	External defender(s)
EE	Energy expenditure
EM	External midfielder(s)
F	Forward(s)
FIFA	Fédération Internationale de Football Association
FLT	Field level test
GK	Goalkeeper(s)
GPS	Global Positioning System
HR	Heart rate
HR_{max}	Maximal heart rate
HR_{peak}	Peak heart rate
ICC	Intraclass correlation coeficient

K-W H test	Kruskal-Wallis H statistical test
La	Blood lactate concentration
La_a	Blood lactate concentration above 4 mmol/L
La_b	Blood lactate concentration below 4 mmol/L
La_{post}	Maximal post-test blood lactate
La_{rest}	Blood lactate at rest
LTT	Maximal laboratory treadmill test
M-W U test	Mann-Whitney U statistical test
n	Sample size
p	Level of marginal significance within a statistical hypothesis test
PhD	Doctor of Philosophy
P-I	Publication 1
P-II	Publication 2
P-III	Publication 3
P-IV	Publication 4
$Post\text{-}lact_{max}$	Peak blood lactate concentration after a test
r	Pearson's correlation coefficient
r^2	Coefficient of determination
RER	Respiratory exchange ratio
RH	Research hypothesis(es)
RHR	Resting heart rate
RQ	Research question(s)
r_s	Spearman's rank correlation coefficient
rVO_2max	Relative maximal oxygen consumption in laboratory treadmill test
SD	Standard deviation
SEE	Standard error of the estimate
T_{alac}	Estimated free-lactate time for the sprint duration
TDC	Total distance covered
UEFA	Union of European Football Associations
v	Running velocity or speed
v_4	Velocity at the 4-mmol/L lactate threshold
v_a	Running velocity above the fixed 4 mmol/L blood lactate concentration
v_b	Running velocity below the fixed 4 mmol/L blood lactate concentration

VCO_2	Carbon dioxide production or output
VJ	Vertical jump
vLa_{max}	Maximal rate of lactate production
v_{max}	Maximal speed achieved in the 70 m sprint test
VO_2	Oxygen consumption or uptake
VO_{2max}	Maximal oxygen consumption
v_{peak}	Peak speed achieved in the LTT
YYIR1	Yo-Yo Intermittent Recovery Test Level 1
YYIR1-D	Total distance achieved in the YYIR1
YYIR1-F1	VO_{2max} estimation formula recommended by Bangsbo et al[1]
YYIR1-F2	VO_{2max} estimation formula derived from own data

1 INTRODUCTION

1.1. WOMEN'S SOCCER BACKGROUND

Soccer (also referred as football throughout the text) was traditionally considered to be a male sport and in its early years there was little encouragement and even opposition for women to participate in this sport.[2] For instance, even though Britain pioneered the first wave of football's popularity among women during World War I when female games were organized to raise money for charity, the English Football Association decided to ban women from playing soccer in 1921 stating that it was "quite unsuitable for females and should not be encouraged" and this ban was not lifted until 1971.[3]

Similarly in Germany, the German Football Association (DFB) had a very hostile attitude towards women's football. It did not allow women to play football officially until 1970.[2] Nowadays, Germany is one of the world's power houses of women's football (currently ranked #1 in the world)[4] and leads all European countries in total number of registered female players with over 200,000 participants.[5]

Women's soccer has become one of the most popular female sports in the world. There are over 30 million female soccer players worldwide and women play soccer in at least 177 different countries.[6] Through the launching of the FIFA Live Your Goals campaign, FIFA is looking to increase the number of girls and women playing football to 45 million by 2019.[7]

Moreover, the number of international competitions, professional, high-performance and recreational leagues for female players of various age groups and skill levels has increased considerably in the last five decades. For instance, the first unofficial Women's Soccer World Championships took place in Italy in 1970 and in Mexico in 1971.[2] Nevertheless, it took twenty more years until the first ever official FIFA Women's World Cup was organized in China in 1991. Since then, this competition takes place every four years. The most recent edition of this tournament (FIFA Women's World Cup Canada 2015™) was a huge success and broke several records showing the growing popularity of women's soccer worldwide. It generated nearly half a billion dollars in economic impact, drew a total of 1.53 million spectators and over 750 million TV viewers around the world, and is now the second most popular FIFA event after the Men's World Cup.[8]

More recently, FIFA has also created youth international competitions that take place every two years: the FIFA U17 and U20 Women's World Cups. They were organized for the first time in 2008 and 2006, respectively. Women's soccer became an official Olympic sport in the Summer Olympics of Atlanta 1996. Additionally, the Girls' Olympic Youth Football Tournament was introduced in 2010 for U15 players. Both the senior and youth Olympic competitions take place every four years. Finally, several countries, such as USA, Germany, France, Sweden, England, and Japan, have already established commercially sustainable and highly-competitive women's soccer professional leagues. More (professional) national and regional women's soccer competitions will be established in more countries around the world in the next few years as part of the FIFA women's football development objectives[9] and the ten key development principles for women's football.[10]

The rapid increase in the number of international, national and regional women's soccer competitions has given a large number of female footballers the opportunity to train and compete in professional environments, which at the same time has raised the performance expectations placed upon players and coaches increasing the need for specific scientific research that could help improve individual and team performance.

Despite the increased popularity and professionalization of women's football around the world, there is still limited scientific research specific to female players compared to their male counterparts, especially in the areas of players' physical and physiological characteristics and game demands. Both of these areas are important elements of the ergonomics model for the analysis of football and impact player selection and the training process.[11] For instance, in the case of men's football, there are numerous full-text peer-reviewed studies that have been published on these topics including players of several nationalities, competitive levels, age groups, and playing positions. The main findings of these studies have been discussed and summarized in various comprehensive literature reviews specific to men's football.[12-20] Nevertheless, review articles summarizing the main findings of published studies specific to the physical and physiological characteristics of female footballers and the demands of the women's game are still only a few.[21-24] Published information on elite adult female players has increased considerably in recent years. However, published reports on female players of lower competitive levels and younger age groups are still limited.

1.2. PHYSICAL AND PHYSIOLOGICAL CHARACTERISTICS OF FEMALE SOCCER PLAYERS

In the last 30 years, several investigations specific to female soccer players of various nationalities, competitive levels, and positional roles have reported on their age, anthropometry, physical and physiological characteristics. The main findings of these reports can be found in the comprehensive summary tables (1 and 2) presented in Martínez-Lagunas et al.[24]

Table 1 in Martínez-Lagunas et al.[24] shows the mean values of age (12–27 years), body height (155–174 cm), body mass (48–72 kg), and percent body fat (13–29%) that have been reported in the literature for female soccer players of various nationalities, competitive levels, and positional roles. More recent studies report the following average values for senior female national team players and those competing in the highest domestic leagues: 20–27 years for age, 161–170 cm for body height, 57–65 kg for body mass, and 14.6–20.1% for body fat percentage.[23,25,26] Some authors have found age and anthropometric predispositions for some positional roles in women's football. For instance, goalkeepers are usually the oldest, tallest and heaviest players compared to all other playing positions; and the central defenders the tallest and heaviest from the outfield playing positions followed by the forwards, central midfielders, full backs, and wide midfielders.[26]

Table 2 in Martínez-Lagunas et al.[24] summarizes the mean values that have been reported in the literature in terms of physical and physiological attributes of female football players of various groups. From this table it can be observed that on average, their maximal oxygen uptake values (VO_{2max}) range from 45.1–55.5 mL/kg/min, their performance in the Yo-Yo Intermittent Recovery Test Level 1 (YYIR1) from 780–1379 m, their maximum heart rate values (HR_{max}) from 189–202 bpm, their 30 m sprint times from 4.34–4.96 s, and their counter-movement jump or vertical jump (CMJ/VJ) from 28–50 cm. Most of these values vary according to the player's competitive level and positional role. The types of measurement methods used may also contribute to the variability of the reported values. Particularly, the measurement of players' VO_{2max} values via direct (laboratory protocol) or indirect (estimation based on total distance achieved on a field test) should be evaluated/compared with caution because the predictive power of indirect measures has recently been questioned.[27,28] The evaluation of players' physical performance characteristics is useful to identify individual physical strengths and weaknesses, to assess the effectiveness of a specific training program, to determine and compare individual and team fitness standards, and for overall players' talent identification and development purposes.[17,29]

1.3. PHYSICAL AND PHYSIOLOGICAL DEMANDS OF WOMEN'S SOCCER

The literature on the physical and physiological demands of women's soccer is by far more limited than the published reports on the physical and physiological characteristics of female soccer players. The earliest reports in this area date back to the early 1990's.[21,30] Nevertheless, more recent investigations are now available and their main findings are summarized by Martínez-Lagunas et al.[24] in tables 3 and 4. The mean values reported in these studies for total distance covered during women's soccer match-play range from 4–13 km and the distance covered at high speeds from 0.2–1.7 km (table 3)[24]. In the case of average and peak HR, the reported mean values have ranged from 147–172 bpm (74%–87% HR_{max}) and 182–194 bpm (94%–99% HR_{max}), respectively (table 4)[24]. Reported average and peak VO_2 values during women's soccer match-play are very limited and range from 28.3–37.6 mL/kg/min (52–77% VO_{2max}) and 47.4–53.0 ml/kg/min (96–98% VO_{2max}), respectively (table 4)[24]. Average reported blood lactate (La) values vary from 2.2–7.3 mmol/L (table 4).[24] The variability of all these values depends on the players' competitive level and positional role as well as methodological differences (direct vs. indirect assessments), and movement impairment caused by the measurement equipment. Moreover, it is common to identify significant reductions in the player's physical and physiological performance between and within each 45-min half of a soccer game due to the development of players' temporary fatigue during and towards the end of each half and the full game.[31] To date, only one study has included simultaneous HR, VO_2, La, and GPS (Global Positioning System) measurements during a full 90-min competitive women's soccer friendly match (11 vs. 11).[32] Therefore, further investigations of this nature should be conducted in the future using a larger sample size of players and games in order to verify the present findings and to evaluate in more detail potential competitive level and positional differences.

The most recent published report encompassing the largest cohort of elite female soccer players that has been studied to date analyzed and compared the physical demands of most matches that took place during the FIFA Women's World Cup Canada 2015™ and Germany 2011™.[26] It included a total of 721 female national team players of 26 different countries, 80 matches, and 2,188 individual match performance data sets. The average total distance covered by the field players and goalkeepers was 10,717–10,821 m and

5,521–5,792 m, respectively.[26] The goalkeepers covered significantly less average distance compared to all other positional roles; the central defenders (10,020–10,094 m) covered the lowest and the central midfielders the largest average total distance (11,230–11,397 m) compared to the other outfield positions.[26] In terms of distance covered at high intensity (>16 km/h), the goalkeepers also covered the lowest amount (73–92 m) compared to the outfield players (1271–1272 m).[26] The central midfielders (16-18 km/h), wide midfielders (>18 km/h), forwards (>20 km/h) and full-backs (>23 km/h) covered the longest distances at the indicated (in parentheses) high-intensity speed thresholds compared to the other outfield positions.[26]

In addition to the positional differences mentioned above, relevant differences in the physical performance results of individual teams by tournament (2011 vs. 2015), match period (e.g. full game, first and second half, 15-min intervals), tournament phase (group phase vs. knockout rounds), confederation membership, and final tournament ranking were identified. Nevertheless, it was concluded that an integrated review of physical and technical-tactical parameters as well as match outcome should be conducted in order to obtain a more objective and comprehensive analysis of overall team match performance.[26]

The analysis of the FIFA All-Star players and FIFA Official Award winners (e.g. adidas golden Glove, adidas golden, silver and bronze Ball, adidas golden, silver and bronze Boot, and Hyundai Young Player Award) showed that for the most part these world-class players not only displayed better overall soccer skills than their non-All-Star counterparts but also recorded higher physical match performances than them. This indicates that the All-Star players and major award winners also possessed superior fitness levels than the other non-All-Star players.[26]

2 DISSERTATION AIMS

This dissertation is submitted in the form of a series of research papers that are interrelated and embrace the overall thesis topic of **“Investigations for the Development of a Physiological Profile in Women’s Soccer”**. The main aims of this thesis are listed below including the publication that addresses each one of them.

1) Compilation of an updated review of literature on player characteristics and game demands in women’s soccer – **(P-III)**[24]
2) Assessment of internal physiological responses of female soccer players during match-play simulations including the collection of heart rate, lactate, and oxygen consumption data as well as their external physical load by means of total distance and distances covered at various speeds – **(P-I)**[32]
3) Physical performance analysis of women’s soccer league matches of different competition levels using GPS (Global Positioning System) technology – **(P-IV)**[33]
4) Fitness testing and fitness profiles of female soccer players of different competition levels by means of both laboratory and field tests to determine players’ anthropometric characteristics, aerobic and anaerobic endurance, speed, and explosive power – **(P-II**[28] **and unpublished results)**

The main structure of the present thesis is shown in Figure 1.

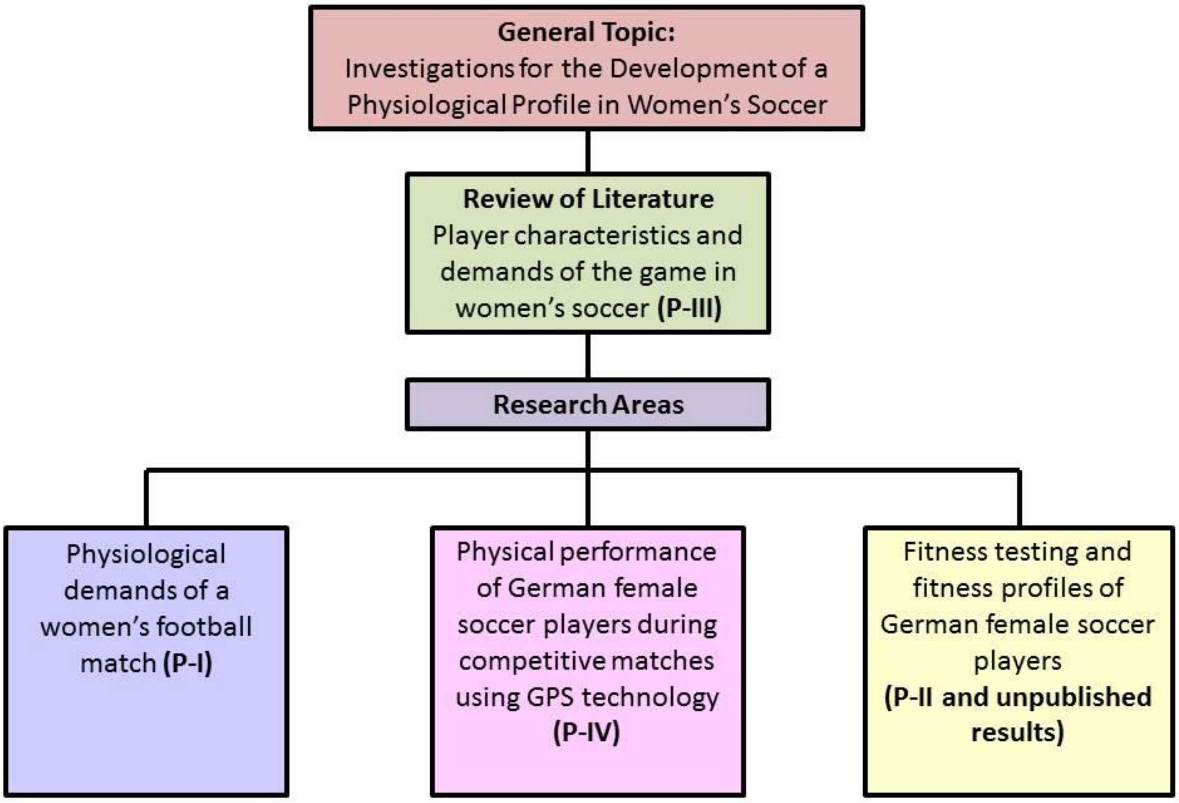


Figure 1: Thesis structure diagram.

3 STATE OF THE ART

This chapter will describe the main methodological procedures and equipment used for the data collection of the present dissertation.

3.1. PORTABLE METABOLIC, HEART RATE AND BLOOD LACTATE MEASUREMENTS

For the assessment of physiological variables such as oxygen consumption and heart rate, players were equipped with a portable metabolic system including a breathing mask and a volume sensor (MetaMax 3B, CORTEX Biophysik, Leipzig, Germany), and a HR monitor (Polar Team^2, Polar Electro Oy, Kempele, Finland). Proper calibration of each portable metabolic system was performed before each test according to the manufacturer's guidelines. Vogler et al[34] showed that the validity of this system was satisfactory compared to the criterion values, although it slightly overestimated VO_2 by 3–4 %. Its reliability was reported to be excellent, showing typical errors of only 2–3 %.[34] All metabolic parameters were monitored breath-by-breath and exported into 5-s intervals for data analysis. At least two of the following criteria had to be met for VO_{2max} determination: VO_2 plateau despite increasing speed, respiratory exchange ratio (RER) > 1.15, attainment of individual HR_{max}, and/or peak blood lactate concentration of $\geq$ 8 mmol/L after maximal testing.[35] Other metabolic measurements included: oxygen uptake (VO_2), carbon dioxide output (VCO_2), respiratory exchange ratio (RER), energy expenditure (EE) and estimated percent carbohydrate turnover (CHO).

Blood samples were taken from the hyperemic earlobe. Blood samples were collected in 20-µL capillary tubes and were immediately inserted into pre-filled "safe-lock" reaction tubes containing a lysing stabilizing agent. After light shaking of the sealed reaction tubes, the blood samples were either stored in cooling containers with ice (if the lactate analysis could be performed right after testing) or refrigerated overnight at about 5°C (if lactate analysis could not take place until the next morning). Blood lactate concentration was determined through the enzymatic-amperiometric method using the BIOSEN S_line lactate analyzer (EKF-diagnostic, Barleben, Germany). Prior to its use, this system was calibrated with a standard 12 mmol/L solution according to the manufacturer's instructions. A precursor model of this device has been found to be valid (r^2 = 0.91–0.97) and reliable (CV of 1.4 %) over an ample range of blood lactate values.[36]

Figure 2: Portable metabolic, heart rate and blood lactate measuring equipment.

3.2. GLOBAL POSITIONING SYSTEM (GPS) MEASUREMENTS

Players' physical match performance was monitored by means of GPS devices with a sampling frequency of 5 Hz (SPI-Pro, GPSports Systems, Canberra, Australia). The validity and reliability of this GPS model has been reported elsewhere.[37,38] The GPS measurements included total distance, distance covered at different speed zones, and running speed. Six arbitrary speed zones based on the work of Hewitt et al[39] were used: strolling (0-5 km/h), walking (5-8 km/h), low-speed running (8-12 km/h), moderate-speed running (12-16 km/h), high-speed running (16-20 km/h) and sprinting (>20 km/h). These speed zones are similar to those used in other reports on female soccer players.[40-42]

Figure 3: GPS measuring equipment.

3.3. TEST PROTOCOLS

3.3.1. ANTHROPOMETRY ASSESSMENT

Players' body height was recorded to the nearest 0.1 cm using a stadiometer (Tanita HR001, Amsterdam, Netherlands). Body mass and percentage body fat (BF) were obtained to the nearest 0.1 kg and 0.1 %, respectively, using an electronic body composition monitor (BC-601, Tanita Europe, Amsterdam, Netherlands). This body composition monitor uses the leg-to-leg bioelectrical impedance analysis (BIA) method to estimate body fat. Its validity, reliability and limitations for this purpose have already been discussed elsewhere in the literature.[43,44] Determination of body fat percentage was conducted for all players using the "athlete" mode after entering their age, gender, body height, and activity level. Players were asked to limit their liquid consumption to a maximum of 1 % of body weight during the 2 h prior to anthropometrical assessment. An empty bladder prior to this testing was also required. Moreover, players wore a light T-shirt, shorts, and no socks/shoes. We strictly followed the manufacturer's guidelines to conduct these measurements. Body mass index was calculated based on players' body mass and height (BMI = body mass / body height^2; expressed in kg/m^2).

Figure 4: Anthropometry assessment.

3.3.2. AEROBIC CAPACITY TESTS

3.3.2.1. Maximal Laboratory Treadmill Test (LTT)

This test was performed under laboratory conditions on a motorized treadmill (Bari-Mill, WOODWAY, Weil am Rhein, Germany) with an inclination of 1 %. Before the start of the test, players completed a 10-min warm-up at 8 km/h. After a short break to obtain a blood sample, the VO_{2max} test protocol got started. The start speed was 12 km/h, which was increased by 1 km/h every 30 s until players reached volitional exhaustion. This exhaustive incremental test protocol was slightly modified from the one used by Krustrup et al[45] and meets common VO_{2max} assessment protocol characteristics that have been stated elsewhere.[46]

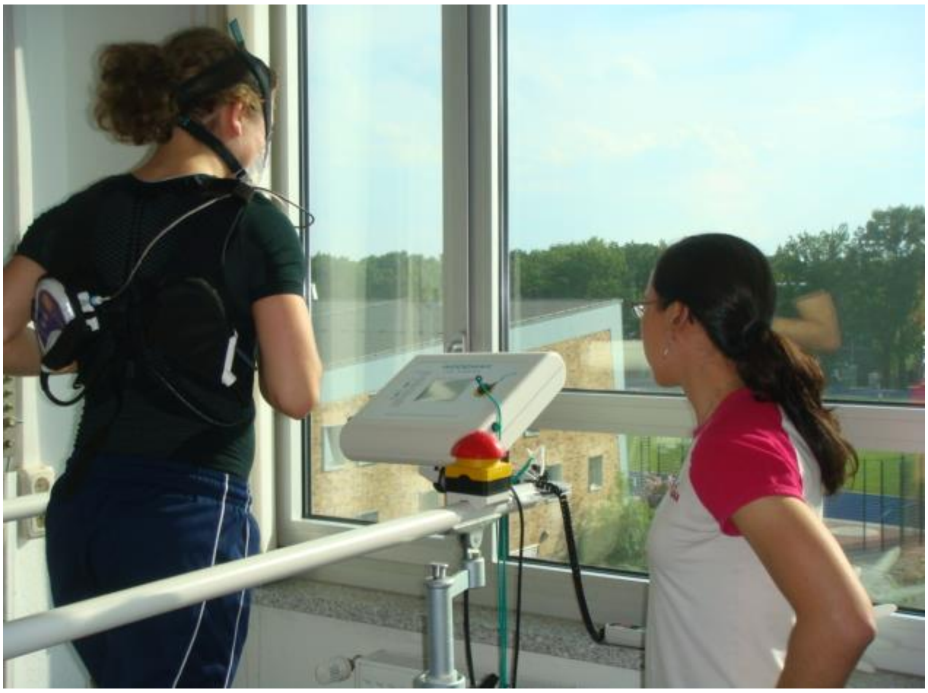


Figure 5: Maximal laboratory treadmill test.

3.3.2.2. Yo-Yo Intermittent Recovery Test Level 1 (YYIR1)

This test was conducted indoors on a wooden sports floor according to established procedures.[1,47] After completing a standardized warm-up for 10 min, the players performed the YYIR1, which consisted of 2 x 20 m shuttle-runs at progressively increasing speeds with a 10-s active recovery period in-between runs. The YYIR1 started at a speed of 10 km/h. The speed was then increased by 2 and 1 km/h for the next two speed levels, respectively. Thereafter, the speed was increased by 0.5 km/h until the participants twice failed to reach the markers of the test course in time or felt unable to complete another shuttle-run at the dictated speed. A table with a more detailed description of the YYIR1 protocol can be found elsewhere.[48]

Figure 6: Yo-Yo Intermittent Recovery Test Level 1.

3.3.2.3. Field Level Test (FLT)

The field level test (FLT) was used for determination the players' velocity at a blood lactate concentration of 4 mmol/L (v_4). It was performed on a 400 m dry tartan track. Cone markers were placed every 50 m on the tartan track. An electronic acoustic signal device was programmed and used to dictate the speed that the players had to maintain throughout each test level. Every acoustic signal indicated how fast the players had to reach each 50-m marker. The specific test protocol used is shown in Table 1.

Blood samples were collected from the players' earlobe at rest, immediately after completing each test level, and after a 7 min active recovery (light jogging) period. Blood lactate concentration was measured using the same procedures and lactate analyzer described before. A 1–3 min break was allowed between each test level in order to collect the blood samples. All players wore a HR monitor (Polar Team[2], Polar Electro Oy, Kempele, Finland) during the test and HR was recorded at 5-s intervals. Velocity at a blood lactate concentration of 4 mmol/L (v_4) was determined arithmetically based on linear interpolation of the players' blood lactate and running velocity values above and below the fixed 4 mmol/L blood lactate concentration obtained during the field level test.[49] The specific equation used for this purpose was:

$$v_4 = v_b + (4 – La_b) * (v_a – v_b) / (La_a – La_b)$$

These abbreviations correspond to v: running velocity (km/h); La: blood lactate concentration (mmol/L), $_b$: below the fixed 4 mmol/L blood lactate concentration, and $_a$: above the fixed 4 mmol/L blood lactate concentration.[50]

Table 1: Test protocol of the field level test.

	Speed		**400-m time**		**50-m time**	**Distance**	**Level duration**
Level	**m/s**	**km/h**	**min:s**	**s**	**s**	**m**	**min:s**
1	2.0	7.2	03:20	200.0	25.0	1200	10:00
2	2.5	9.0	02:40	160.0	20.0	1200	08:00
3	3.0	10.8	02:13	133.3	16.7	1200	06:39
4	3.5	12.6	01:54	114.3	14.3	1200	05:42
5	4.0	14.4	01:40	100.0	12.5	1200	05:00
6	4.5	16.2	01:28	88.9	11.1	1200	04:24
7	5.0	18.0	01:20	80.0	10.0	1600	05:20
8	5.5	19.8	01:13	72.7	9.1	1600	04:52
9	6.0	21.6	01:07	66.7	8.3	1600	04:28
10	6.5	23.4	01:01	61.5	7.7	2000	05:05

Figure 7: Field level test assessment.

3.3.3. SPEED, ANAEROBIC ABILITY AND EXPLOSIVE POWER TESTS

3.3.3.1. Speed and Anaerobic Ability Test

Anaerobic ability (maximal rate of lactate production (vLa_{max})) and speed performance (30-m and 70-m sprint times) were both evaluated during a 70-m sprint test. The sprint times were measured using an electronic wireless timing system (SMARTSPEED™, Fusion Sport, Coopers Plains, Australia). This single beam system is equipped with an advanced error correction technology that avoids measurement errors due to hand breaks and false starts. This technology assures that the athlete's torso remains as the only point of measurement throughout the test. It has been demonstrated that this system shows a maximal typical error of < 0.03 s and CV of < 2 % for common sprint-test distances.[51] The timing gates/units of this system were placed at the 0, 30, and 70-m sprint lines at a height of approximately 1 m. Players started the sprint 1 m behind the first timing gate from a standing start. Players commenced the sprint when they felt ready. The time measurement started when the players passed through the first timing gate. Additionally, they were instructed to sprint maximally up to a pair of cones that was placed 2 m after the 70-m line. Players' 30-m and 70-m sprint times were recorded to the nearest 0.01 s.

Players performed a single 70-m sprint during this testing session because this sprint test was also used to determine players' anaerobic ability by means of vLa_{max}.[50] For this purpose, blood samples were collected from the players' earlobe at rest, after the warm-up period, and at 1, 3, 5, 7, 10, and 12 min after the 70-m sprint test. Blood lactate concentration was measured using the same procedures and lactate analyzer described before. Players' vLa_{max} was computed according to Heck and Schulz[50] using the following formula:

$$vLa_{max} = La_{post} – La_{rest} / 70\text{-}mT – T_{alac}$$

These abbreviations correspond to vLa_{max}: maximal rate of lactate production (mmol/L/s); La_{post}: maximal post-sprint blood lactate (mmol/L); La_{rest}: blood lactate at rest (mmol/L); 70-m sprint time (s); T_{alac}: estimated free-lactate time for the sprint duration (s). The numerical value used for T_{alac} was 3 s, which Heck and Schulz[50] recommended for a sprint lasting about 10 s (duration in which most players completed the 70-m sprint).

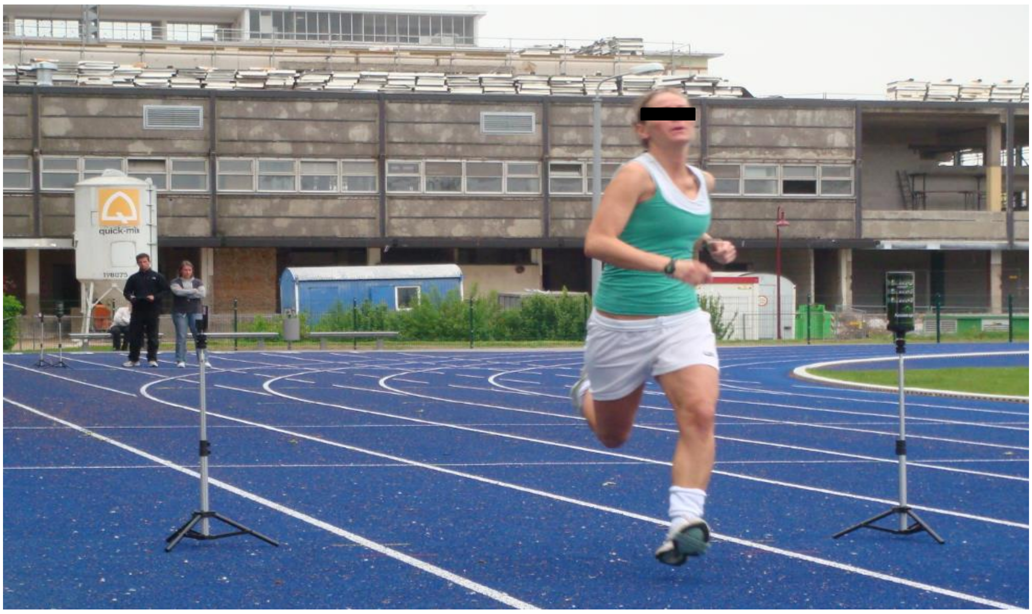


Figure 8: 70-m sprint test to assess players' anaerobic ability and speed.

3.3.3.2. Counter-Movement Jump Test (CMJ)

CMJ height was assessed using an electronic contact mat system (SMARTJUMP™, Fusion Sport, Coopers Plains, Australia). Correct jumping technique was explained and demonstrated to the players prior to the test. Players were instructed to begin from a standing position with free hands, to perform a quick crouching action bending their knees to about 90 degrees, followed by a jump for maximal height while keeping straight knees in the air. Free hand movement (arm swing) was allowed throughout the CMJ in order to make the test as soccer-specific as possible. A maximum of two sub-maximal attempts focusing on proper jumping technique were allowed as a practice before the test. Players performed 3 maximal CMJ, with about 2 min of recovery in-between. The highest jump was used for data analysis. The SMARTJUMP system measures flight time during the CMJ and calculates jump height using the following equation: CMJ height = $1/8\ (g \cdot t^2)$, where g = acceleration due to gravity (9.81 m/s) and t = flight time. This formula is generally used by other commercially available electronic contact mats.[52] The test-retest-reliability of the three CMJ trials was very good resulting in an intraclass correlation coefficient (ICC) of 0.95.

Figure 9: Counter-movement jump test.

4 OWN AREAS OF RESEARCH

4.1. PHYSIOLOGICAL DEMANDS OF A WOMEN'S FOOTBALL MATCH (ENGLISH SUMMARY FROM "PHYSIOLOGISCHE BEANSPRUCHUNG EINES FRAUENFUßBALLSPIELS)" – (P-I)[32]

OBJECTIVE:

The purpose of the present study was to investigate for the first time the physiological and physical demands of a women's football match by means of simultaneous measurements with portable metabolic and GPS (Global Positioning System) devices.

METHODS:

A training game (11 vs. 11) under close to real competitive game conditions (match-play simulation) was organized after a preceding familiarization game (total playing time 90 minutes (2 x 3 x 15 min), with 3 substitutions per team allowed and a 15-minute half-time break). A total of 28 female football players competing in the second and fourth German leagues participated in this study. From these players, 10 outfield players (21.3 ± 2.9 years, 163.1 ± 7.2 cm, 60.0 ± 4.6 kg) were selected to wear the measuring devices throughout the entire duration of the training game (6 and 4 players per team, respectively). Figure 10 shows images of the methodological preparation and implementation of the present study. The following parameters were recorded: 1) metabolic measurements (including oxygen uptake (VO_2), carbon dioxide output (VCO_2), respiratory exchange ratio (RER), energy expenditure (EE) and estimated percent carbohydrate turnover (CHO)), 2) heart rate (HR), 3) blood lactate concentration (La, at rest, after each of the three 15-minute intervals in the first and second halves and after the half-time break), and 4) GPS measurements (including running distance (D) and speed (v)). The maximum oxygen uptake (VO_{2max}) and heart rate (HR_{max}) of the players were determined using a maximal test on a treadmill under laboratory conditions.

RESULTS:

Table 2 shows selected results of the present study. The average blood lactate concentration at rest was 0.98 ± 0.25 mmol/L, the average blood lactate concentrations measured during the game were <3.0 mmol/L, and the peak blood lactate value was 6.61 mmol/L. The average

VO_2 and HR peak values achieved during the game were 53.0 ± 3.8 mL/kg/min and 182 ± 8 bmp. This corresponds to 98 ± 2% of the average VO_{2max} and 94 ± 5% of the average HR_{max}. The average and maximum speed throughout the game was 4.9 ± 1.0 km/h and 24.3 ± 2.4 km/h, respectively.

CONCLUSION:

Most parameters showed diminished values during the second half compared to the first half of the match. The findings of the present study were somewhat lower compared to published 1) metabolic data of male footballers and 2) heart rate, blood lactate, and GPS values of women's football competitive matches. Possible reasons for the discrepancy of results may include: gender, anthropometry, physical condition, level of play and motivation of the participating players, playing conditions, methodological differences, and movement limitations caused by the measuring devices. A detailed analysis of the game demands provides valuable information for the design of efficient and individualized fitness training programs specific for female football players.

Figure 10: Study methodology in pictures (P-I)[32] – from study preparation to implementation.

Table 2: Selected results from the women's football match-play simulation (mean ± standard deviation) (P-I)[32].

Game Interval	Metabolic Variables (n = 9) (VO_{2max}: 3.20 ± 0.30 L/min or 54.2 ± 4.3 mL/kg/min)					HR & La (n = 10) (HR_{max}: 193 ± 8 bpm)		GPS (n = 10)	
	VO_2 (L/min)	VO_2 (mL/kg/min)	RER	EE_{total} (kcal)	CHO (%)	HR (bpm)	La (mmol/L)	D_{total} (m)	$D_{>16 km/h}$ (m)
1st 15 min	1.97±0.45	33.1±7.4	0.92±0.12	145.1±24.6	70.5±23.1	160±10	2.83±1.88	1406±263	118±66
2nd 15 min	1.63±0.45	27.5±7.5	0.90±0.11	120.2±24.7	66.3±27.3	154±12	1.82±0.83	1186±253	86±41
3rd 15 min	1.79±0.47	30.0±7.3	0.92±0.11	129.0±32.2	73.2±29.9	156±14	2.79±1.64	1231±332	123±83
1st half	1.79±0.48	30.1±7.8	0.91±0.11	394.3±78.6	70.0±26.0	157±11	2.48±1.54	3823±819	326±181
4th 15 min	1.63±0.47	27.6±7.5	0.92±0.11	120.0±22.7	71.1±26.2	147±11	2.08±0.68	1170±233	118±72
5th 15 min	1.61±0.39	27.2±6.5	0.91±0.12	118.7±18.3	68.8±30.2	149±9	1.97±0.69	1170±242	108±50
6th 15 min	1.50±0.43	25.4±6.9	0.88±0.11	110.5±23.5	62.1±30.7	145±10	1.51±0.80	1068±238	79±83
2nd half	1.58±0.43	26.7±7.0	0.91±0.11	349.3±63.3	67.3±28.2	147±9	1.85±0.74	3407±695	305±187
Full Game	**1.68±0.47**	**28.4±7.6**	**0.91±0.11**	**743.5±137.3**	**68.7±26.9**	**152±10**	**2.17±1.24**	**7230±1474**	**631±358**

4.2. GPS PERFORMANCE ANALYSIS OF WOMEN'S SOCCER COMPETITIVE MATCHES OF THE SECOND AND FOURTH GERMAN LEAGUES – (P-IV)[33]

OBJECTIVE:

The aim of the present study was to compare the physical demands of women's soccer competitive matches of the second (2L) and fourth (4L) German leagues using GPS technology.

METHODS:

Twenty-two outfield female soccer players from a local club who were competing in the second (2L) and fourth (4L) German National Leagues took part in this study. Eight players competed only in the 2L, 8 players only in the 4L, and the remaining 6 players participated in both leagues as they played up or down based on coaching decisions. The data of the 6 players who played games in both leagues were included for analysis in each league. Therefore, the total number of players considered for each league was 14 (8+6). Players' physical match performance was monitored by means of a GPS device with a sampling frequency of 5 Hz (SPI-Pro, GPSports Systems, Canberra, Australia). Additionally, players' heart rate (HR) was continuously monitored every 5 s during match-play by means of the Polar Team^2 System, Polar Electro Oy, Kempele, Finland. A total of 10 competitive matches were evaluated in this study (5 matches for each competitive league). The participating players were monitored during 1-5 matches in each league and only the data sets of the players who completed the whole match (90 min) were used for data analysis. Therefore, a total of 34 and 26 complete data sets were considered for data analysis in the 2L and 4L, respectively. Additionally, these data sets were classified further according to the positional role that the coaching staff assigned to the players in each match considering only the data sets of the players who played the whole match in that particular position. Thus, our positional analysis included 17, 13 and 4 complete data sets of defenders, midfielders and forwards in the 2L; and 12, 10, and 4 in the 4L, respectively. The variables evaluated were total distance (TDC), distance covered at different speed zones, speed, and heart rate. Six arbitrary speed zones based on the work of Hewitt et al[39] were used: strolling (0-5 km/h), walking (5-8 km/h), low-speed running (8-12 km/h), moderate-speed running (12-16 km/h), high-speed running (16-20 km/h) and sprinting (>20 km/h).

RESULTS:

Table 3 and Figures 11 and 12 summarize the main results obtained in the present study.

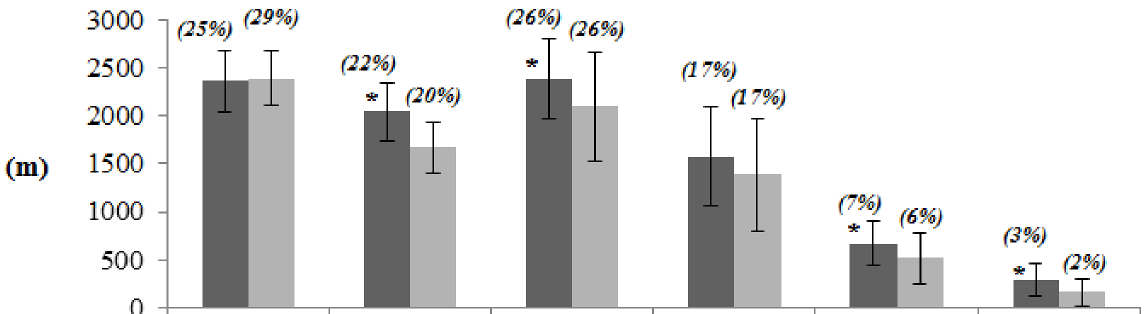
CONCLUSION:

In conclusion, the physical demands of 2L competitive matches are higher than those of 4L matches, especially in terms of TDC (12%, indicates percent difference), distance covered at > 16 km/h (30%), and average peak speed (5% difference) resulting in a higher average HR (2%). Furthermore, positional differences exist in terms of total distance covered and distance covered at various speeds (e.g. 8-12, 12-16, and 16-20 km/h) in both leagues. These physical demands are significantly lower for defenders than for midfielders and forwards. Midfielders tend to face the highest physical demands during match-play in both leagues. Thus, players' physical preparation should meet the specific demands of their competitive level and positional role.

Table 3: Total distance covered and average heart rate by competitive league (P-IV)[33].

Variable	*2L (n=34)*	*4L (n=26)*
TDC	(m)	(m)
First half	4,735±498*	4,277±706
Second half	4,587±438*	3,947±732
Full game	**9,322±903***	**8,224±1415**
HR	**(bpm)**	**(bpm)**
First half	173±7 (90% HR_{max})*#	168±10 (88% HR_{max})#
Second half	169±+6 (88% HR_{max})*	162±10 (86% HR_{max})
Full game	**171±6 (89% HR_{max})***	**165±9 (87% HR_{max})**

Results presented as mean±SD.
*Significantly higher than 4L, #higher than second half ($p < 0.05$).
2L: second German national league, 4L: fourth German national league, TDC: total distance covered, HR: average heart rate, HR_{max}: maximal heart rate, n: number of complete data sets analyzed for each league.



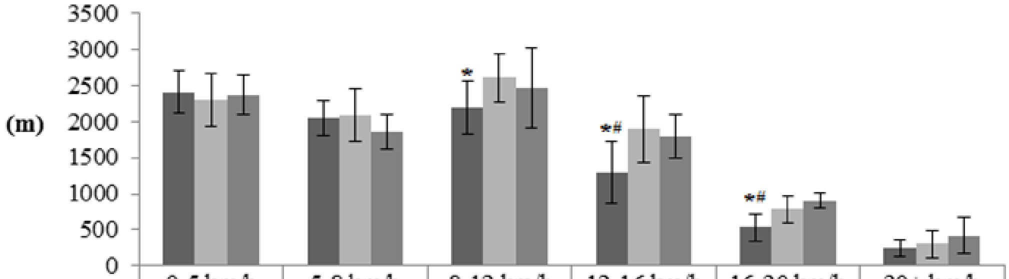
	0-5 km/h	5-8 km/h	8-12 km/h	12-16 km/h	16-20 km/h	20+ km/h
2L (n=34)	2361	2040	2384	1576	671	290
4L (n=26)	2393	1672	2098	1384	515	162

Distance covered (m) at different speed zones (km/h)

Figure 11: Distance covered at six different speed zones according to Hewitt et al[39] by competitive league (P-IV)[33].

*Significantly higher than 4L (p < 0.05), 2L: second German National League, 4L: fourth German National League, n: number of complete data sets analyzed for each league. The numbers shown above the bars represent the corresponding percentages from the total distance covered in each league.

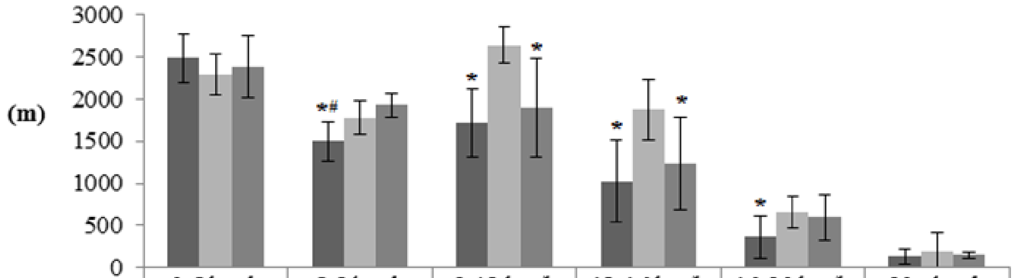
a) 2L



	0-5 km/h	5-8 km/h	8-12 km/h	12-16 km/h	16-20 km/h	20+ km/h
Defenders (n=17)	2408	2042	2199	1285	532	250
Midfielders (n=13)	2300	2094	2601	1889	781	303
Forwards (n=4)	2363	1859	2465	1794	905	417

Distance covered (m) at different speed zones (km/h)

b) 4L



	0-5 km/h	5-8 km/h	8-12 km/h	12-16 km/h	16-20 km/h	20+ km/h
Defenders (n=12)	2483	1498	1716	1027	368	132
Midfielders (n=10)	2291	1778	2637	1872	657	201
Forward (n=4)	2378	1928	1896	1237	599	153

Distance covered (m) at different speed zones (km/h)

Figure 12: Distance covered at six different speed zones according to Hewitt et al[39] by playing position a) in the 2L and b) in the 4 L (P-IV)[33].

n = number of complete data sets included for analysis in each playing position.*****Significantly lower than midfielder, **#**lower than forward ($p < 0.05$). 2L: second German National League, 4L: fourth German National League.

4.3. VALIDITY OF THE YO-YO INTERMITTENT RECOVERY TEST LEVEL 1 FOR DIRECT MEASUREMENT OR INDIRECT ESTIMATION OF MAXIMAL OXYGEN UPTAKE AMONG FEMALE SOCCER PLAYERS – (P-II)[28]

OBJECTIVE:

To evaluate the validity of the Yo-Yo Intermittent Recovery Test Level 1 (YYIR1) for the direct assessment and the indirect estimation of maximal oxygen consumption (VO_{2max}) in female soccer players compared with a maximal laboratory treadmill test (LTT).

METHODS:

Eighteen female soccer players (21.5 ± 3.4 y, 165.6 ± 7.5 cm, 63.3 ± 7.4 kg; mean ± SD) completed an LTT and a YYIR1 in random order (1 week apart). Their VO_{2max} was directly measured via portable metabolic equipment during both tests and indirectly estimated from a published non-gender-specific formula (YYIR1-F1).[1]

RESULTS:

The measured VO_{2max} values in LTT and YYIR1 were 55.0 ± 5.3 and 49.9 ± 4.9 mL/kg/min, respectively, while the estimated VO_{2max} values from YYIR1-F1 corresponded to 45.2 ± 3.4 mL/kg/min. Large positive correlations between the VO_{2max} values from YYIR1 and LTT (r = .83, P < .001, 90% confidence interval = .64–.92) and YYIR1-F1 and LTT (r = .67, P = .002, .37–.84) were found. However, the YYIR1 significantly underestimated players' VO_{2max} by 9.4% compared with LTT (P < .001) with Bland-Altman 95% limits of agreement ranging from –20.0% to 1.4%. A significant underestimation from the YYIR1-F1 (P < .001) was also identified (17.8% with Bland-Altman 95% limits of agreement ranging from –31.8% to –3.8%).

CONCLUSION:

The YYIR1 and YYIR1-F1 are not accurate methods for the direct assessment or indirect estimation of VO_{2max} in female soccer players. The YYIR1-F1 lacks gender specificity, which might have been the reason for its larger error. The gender-specific estimation formula derived from the data of our study sample (YYIR1-F2) might be more appropriate to estimate VO_{2max} among female soccer players. However, this must be evaluated in future studies.

4.4. FITNESS PROFILES OF GERMAN FEMALE SOCCER PLAYERS (UNPUBLISHED RESULTS)

OBJECTIVE:

The aim of this study was to compare the anthropometric and physical characteristics of a group of 24 adult female soccer players competing in the second (n = 11) and fourth (n = 13) leagues in Germany. Differences according to playing position (independent of the competitive level) and relationships among the assessed variables were also evaluated.

METHODS:

A total of 4 goalkeepers (GK), 4 central defenders (CD), 4 external defenders (ED), 4 central midfielders (CM), 5 external midfielders (EM), and 3 forwards (F) participated in this study. Players were tested towards the end of their competitive season for anthropometry (body height [BH], body mass [BM], body mass index [BMI], percentage body fat [% BF]); aerobic capacity (maximal oxygen uptake [VO_{2max}], velocity at a blood lactate concentration of 4.0 mmol/L [v_4], and total distance covered in the Yo-Yo intermittent recovery test level 1 [YYIR1-D]); anaerobic ability (maximal rate of lactate production [vLa_{max}]); explosive power (countermovement jump height [CMJ-H]); and speed (30-m and 70-m sprint times [30-mT and 70-mT]). Non-parametric tests and a significance level of $p \leq 0.05$ were used for statistical analysis.

RESULTS:

Table 4 summarizes the fitness profiles of the participating players according to their competitive level. Players of the second and fourth league differed significantly only in their YYIR1 performance. Second division players covered on average a 20% longer distance in the YYIR1 than the fourth division players. Significant differences according to playing position were identified for body height (GK > CD, EM, F and ED > F), body mass (GK > CM, EM, F; CD > CM, F; and F < ED, EM), and absolute VO_{2max} (GK > CD, CM, F and EM > F) (Table 5). Spearman's correlational analysis revealed significant relationships between % BF and several fitness test results including negative correlations with relative VO_{2max} and YYIR1-D (r_s = – 0.61 and – 0.62) and a positive correlation with 30-mT and 70-mT (r_s = 0.76 and 0.70). Furthermore, the results of the three aerobic capacity tests were highly correlated (r_s = 0.59–0.75). The YYIR1-D and the CMJ-H showed significant negative correlations with 30-mT and 70-mT (r_s = – 0.46 to – 0.58). Both sprint results were positively correlated (r_s = 0.94) and negatively related to vLa_{max} (r_s = – 0.46 to – 0.58).

CONCLUSION:

This study offered for the first time objective data on the anthropometric and physical characteristics of adult female soccer players competing in the second and fourth German leagues. It also confirmed the existence of significant competitive-level and positional role differences and relationships among the assessed variables.

Table 4: Fitness profiles of adult German female soccer players according to their competitive level (2L vs. 4L).

Variable	2L (*n* = 11)	4L (*n* = 13)	*p* value from M-W U test
Anthropometry			
BH (cm)	166.2 ± 8.8 (152.1–179.9), 165.8	165.3 ± 5.7 (157.0–174.5), 165.1	$p = 0.772$
BM (kg)	63.0 ± 8.1 (52.7–79.4), 60.3	63.0 ± 6.0 (54.8–73.4), 61.4	$p = 0.706$
BMI (kg/m ^{2})	22.7 ± 1.5 (20.4–24.9), 22.2	23.1 ± 1.5 (20.1–25.7), 23.1	$p = 0.523$
BF (%)	19.0 ± 2.5 (14.9–23.1), 19.1	21.5 ± 4.3 (16.5–30.1), 19.5	$p = 0.223$
Aerobic capacity			
aVO_{2max} (L/min^1)	3.5 ± 0.6 (2.8–4.3), 3.4	3.3 ± 0.4 (2.8–4.3), 3.3	$p = 0.728$
rVO_{2max} (mL/min/kg)	54.6 ± 5.1 (48.6–67.0), 56.0	52.7 ± 5.4 (45.9–62.4), 52.9	$p = 0.324$
$v_4^{\#}$ (km/h)	12.6 ± 0.5 (11.9–13.4). 12.7	11.4 ± 1.4 (9.4–13.4), 11.3	$p = 0.070$
YYIR1-D (m)	1102 ± 316 (600–1640), 1080[a]	886 ± 399 (520–2080), 800	$p = 0.048$[a]
Anaerobic ability			
vLa_{max} (mmol/L/s)	0.84 ± 0.20 (0.53–1.31), 0.82	0.85 ± 0.10 (0.66–1.11), 0.85	$p = 0.794$
Explosive power			
CMJ-H (cm)	38.1 ± 4.2 (32.0–44.0), 39.7	35.5 ± 5.9 (25.5–46.7), 33.3	$p = 0.183$
Speed			
30-mT (s)	4.55 ± 0.19 (4.33–4.91), 4.53	4.67 ± 0.20 (4.43–5.05), 4.64	$p = 0.156$
70-mT (s)	10.00 ± 0.39 (9.58–10.60), 9.80	10.31 ± 0.52 (9.58–11.34), 10.35	$p = 0.192$

Descriptive statistics are presented as mean ± SD (min–max), median. 2L: second division players; 4L: four division players; M-W U: Mann-Whitney U test; *p*: level of significance; BH: body height; BM: body mass; BMI: body mass index; BF: body fat; aVO_{2max}: absolute maximal oxygen consumption in laboratory treadmill test; rVO_{2max}: relative maximal oxygen consumption in laboratory treadmill test; v_4: velocity at a blood lactate concentration of 4 mmol/L in field level test; YYIR1-D: distance covered in Yo-Yo intermittent recovery test level 1; vLa_{max}: maximal rate of lactate production after 70-m sprint; CMJ-H: countermovement jump height (with arm swing); 30-mT: 30-m sprint time; 70-mT: 70-m sprint time; $^{\#}$ in the case of v_4 $n = 8$ for 2L group. [a]Significantly different from 4L, $p \leq 0.05$.

Table 5: Fitness profiles of adult German female soccer players according to their playing position (mean ± SD, range, median).

Variable	GK (n = 4)	CD (n = 4)	ED (n = 4)	CM (n = 4)	EM (n = 5)	F (n = 3)	*p* value K-W H test
Anthropometry							
BH (cm)	173.8 ± 4.4 (170.3–179.9), 172.5	166.8 ± 7.8 (157.0–174.5), 167.9	168.8 ± 5.3 (165.1–176.5), 166.8	161.5 ± 6.5 (152.1–167.2), 163.3[a]	163.9 ± 5.0 (157.8–171.0), 163.9[a]	158.1 ± 4.5 (153.8–162.8), 157.6[a, c]	$p = .043$
BM (kg)	72.6 ± 5.0 (67.8–79.4), 71.5	65.6 ± 6.0 (60.3–73.4), 64.4	63.4 ± 6.3 (57.4–70.8), 62.7	58.2 ± 2.2 (56.0–61.1), 57.8[a, b]	62.0 ± 4.3 (57.8–68.9), 60.5[a]	54.7 ± 1.9 (52.7–56.5), 54.8[a, b, c, d]	$p = .009$**
BMI (kg/m ^{2})	24.0 ± 0.6 (23.2–24.5), 24.2	23.5 ± 1.7 (22.0–25.1), 23.5	22.3 ± 2.3 (20.4–25.7), 21.5	22.5 ± 2.0 (20.1–24.9), 22.5	23.0 ± 0.6 (22.0–23.5), 23.1	21.9 ± 0.5 (21.3–22.2), 22.1	$p = .328$
BF (%)	22.4 ± 2.2 (19.5–24.8), 22.7	22.7 ± 5.0 (18.0–28.4), 22.2	21.3 ± 5.9 (17.4–30.1), 18.9	19.6 ± 1.7 (17.2–20.8), 20.2	17.1 ± 1.7 (14.9–19.2), 16.7	19.5 ± 2.6 (16.8–22.0), 19.8	$p = .110$
Aerobic capacity							
aVO_{2max} (L/min ^{1})	3.9 ± 0.3 (3.6–4.3), 3.9	3.2 ± 0.3 (2.8–3.4), 3.3[a]	3.3 ± 0.4 (2.8–3.7), 3.3	3.1 ± 0.3 (2.8–3.4), 3.1[a]	3.7 ± 0.5 (3.1–4.3), 3.4	2.9 ± 0.1 (2.8–3.0), 2.9[a, d]	$p = .022$
rVO_{2max} (m/min/kg)	53.7 ± 1.7 (52.5–56.0), 53.2	49.3 ± 4.8 (46.0–56.2), 47.5	52.3 ± 5.7 (45.9–58.1), 52.6	53.4 ± 5.5 (48.6–61.1), 51.9	58.7 ± 5.8 (53.4–67.0), 56.3	52.8 ± 3.4 (49.3–56.1), 52.9	$p = .245$
$v_4^{\#}$ (km/h)	12.2 ± 0.9 (11.0–13.1), 12.4	11.1 ± 1.3 (9.8–12.7), 10.9	11.3 ± 0.7 (10.6–11.9), 11.3	12.0 ± 2.3 (9.4–13.3), 13.2	12.5 ± 0.8 (11.5–13.4), 12.6	12.1 ± 1.9 (10.0–13.4), 13.0	$p = .460$
YYIR1-D (m)	870 ± 418 (520–1440), 760	830 ± 220 (640–1120), 780	940 ± 321 (720–1400), 820	910 ± 76 (800–960), 940	1288 ± 578 (600–2080), 1120	1000 ± 327 (640–1280), 1080	$p = .642$

Table 5: (continued)

Variable	GK (n = 4)	CD (n = 4)	ED (n = 4)	CM (n = 4)	EM (n = 5)	F (n = 3)	*p* value K-W H test
Anaerobic ability							
vLa_{max} (mmol/L/s)	0.69 ± 0.15 (0.53–0.82), 0.71	0.89 ± 0.15 (0.76–1.11), 0.85	0.89 ± 0.05 (0.83–0.95), 0.88	0.83 ± 0.15 (0.66–1.01), 0.82	0.95 ± 0.20 (0.82–1.31), 0.87	0.82 ± 0.06 (0.76–0.87). 0.82	p = .108
Explosive power							
CMJ-H (cm)	37.8 ± 2.4 (35.4–40.0), 37.9	37.6 ± 8.2 (25.5–43.1), 40.9	36.0 ± 7.3 (30.4–46.7), 33.5	35.6 ± 4.2 (31.3–39.8), 35.6	36.8 ± 5.0 (30.9–42.7), 36.8	36.4 ± 6.6 (32.0–44.0), 33.3	p = .942
Speed							
30-mT (s)	4.79 ± 0.14 (4.64–4.91), 4.80	4.62 ± 0.21 (4.45–4.93), 4.55	4.57 ± 0.14 (4.48–4.78), 4.50	4.72 ± 0.25 (4.53–5.05), 4.64	4.44 ± 0.14 (4.33–4.67), 4.43	4.57 ± 0.20 (4.35–4.73), 4.64	p = .104
70-mT (s)	10.58 ± 0.30 (10.20–10.94), 10.59	10.19 ± 0.52 (9.80–10.93), 10.02	10.04 ± 0.27 (9.77–10.40), 10.00	10.39 ± 0.70 (9.76–11.34), 10.24	9.78 ± 0.34 (9.58–10.38), 9.64	10.13 ± 0.48 (9.58–10.46), 10.35	p = .112

Descriptive statistics are presented as mean ± SD (min–max), median. GK: goalkeepers; CD: central defenders; ED: external defenders; CM: central midfielders; EM: external midfielders; F: forwards; K-W H: Kruskal-Wallis H test, *post-hoc* tests performed by means of Mann-Whitney U tests; *p*: level of significance; BH: body height; BM: body mass; BMI: body mass index; BF: body fat; aVO_{2max}: absolute maximal oxygen consumption in laboratory treadmill test; rVO_{2max}: relative maximal oxygen consumption in laboratory treadmill test; v_4: velocity at a blood lactate concentration of 4 mmol/L in field level test; YYIR1-D: distance covered in Yo-Yo intermittent recovery test level 1; vLa_{max}: maximal rate of lactate production after 70-m sprint; CMJ-H: countermovement jump height (with arm swing); 30-mT: 30-m sprint time; 70-mT: 70-m sprint time; [#] in the case of v_4 $n = 3$ for ED and CM, and $n = 4$ for EM. [a]Significantly different from GK; [b]significantly different from CD; [c]significantly different from ED; [d]significantly different from EM. All $p \leq 0.05$, except **$p \leq 0.01$.

5 CONCLUSIONS AND OUTLOOK

5.1. MAIN FINDINGS

- The detailed literature review completed on player characteristics and game demands in women's soccer (P-III)[24] permitted the identification of literature gaps in this subject and allowed us to target specific areas of research for the present thesis including: physiological demands of a women's football match including simultaneous measurements with portable metabolic and GPS technology; physical performance analysis of women's soccer competitive matches of different competition levels using GPS technology; and fitness testing and fitness profiles of female soccer players of different competition levels by means of both laboratory and field tests.
- To the best of our knowledge, the investigation of the physiological demands of a women's football match with parallel measurements of HR, VO_2, blood lactate, and GPS data may have been the first of its kind worldwide (P-I).[32] It showed that most measured parameters decreased during the second half compared to the first half of the match, which may have been the result of fatigue towards the end of the match. Our study findings were also somewhat lower compared to published 1) metabolic data of male footballers and 2) heart rate, blood lactate, and GPS values of women's football competitive matches. The discrepancy of results may have been due to gender, anthropometry, physical condition, level of play and motivation of the participating players, playing conditions, methodological differences, and movement limitations caused by the measuring devices. Nevertheless, a detailed analysis of physiological game demands provides valuable information for the design of efficient and individualized fitness training programs specific for female football players.
- The physical performance analysis of women's soccer competitive matches of the second (2L) and fourth (4L) German leagues using GPS technology revealed that the physical demands of 2L competitive matches were higher than those of 4L matches (P-IV).[33] Especially in terms of TDC (12%, indicates percent difference), distance covered at > 16 km/h (30%), and average peak speed (5% difference) resulting in a higher average HR (2%). Furthermore, positional differences were identified in terms of total distance covered and distance covered at various speeds (e.g. 8-12, 12-16, and 16-20 km/h) in both leagues. These physical demands were significantly lower for defenders than for

midfielders and forwards. Midfielders faced the highest physical demands during match-play in both leagues. Thus, players' physical preparation should meet the specific demands of their competitive level and positional role.

- The Yo-Yo Intermittent Recovery Test Level 1 (YYIR1) has gained large popularity in the soccer world due to its specificity and practicality to assess players' ability to perform repeated intense exercise. It may also offer an alternative to estimate VO_{2max} based on a non-gender specific prediction equation (YYIR1-F1). However, it was still unknown if this formula would yield accurate results to predict VO_{2max} of female soccer players. Therefore, this study aimed to evaluate the validity of the YYIR1 for the direct assessment (via portable metabolic equipment) and the indirect estimation of VO_{2max} (from a non-gender-specific formula, YYIR1-F1) among female soccer players in comparison to a maximal laboratory treadmill test (LTT). The study results showed that the YYIR1 and YYIR1-F1 are not accurate methods for the direct assessment or indirect estimation of VO_{2max} in female soccer players (P-II).[28] The YYIR1-F1 lacks gender specificity, which might have been the reason for its larger error. The gender-specific estimation formula derived from the data of our study sample (YYIR1-F2) might be more appropriate to estimate VO_{2max} among female soccer players. However, this must be evaluated in future studies.
- The analysis of fitness profiles of female soccer players of the second and fourth German leagues confirmed the existence of significant competitive-level and positional role differences and relationships among the assessed variables. In terms of competitive level, players of the second and fourth league differed significantly only in their YYIR1 performance. Second division players covered on average 20 % longer distance in the YYIR1 than the fourth division players. Significant differences according to playing position were identified for body height (GK > CD, EM, F and ED > F), body mass (GK > CM, EM, F; CD > CM, F; and F < ED, EM), and absolute VO_{2max} (GK > CD, CM, F and EM > F). Spearman's correlational analysis revealed significant relationships between % BF and several fitness tests results including negative correlations with relative VO_{2max} and YYIR1-D (r_s = – 0.61 and – 0.62) and a positive correlation with 30-mT and 70-mT (r_s = 0.76 and 0.70). Furthermore, the results of the three aerobic capacity tests were highly correlated (r_s = 0.59–0.75). The YYIR1-D and the CMJ-H showed significant negative correlations with 30-mT and 70-mT (r_s = – 0.46 to – 0.58).

Both sprint results were positively correlated (r_s = 0.94) and negatively related to vLa_{max} (r_s = – 0.46 to – 0.58).

5.2. PRACTICAL APPLICATIONS

- The physical capacities of players should be tested regularly through objective and standardized performance assessment in order to identify their strengths and weaknesses. This can also be useful for evaluating the effectiveness of a specific training program, setting individual and team fitness standards, and talent identification/development.
- Based on this information physical training should be individualized according to the players' current fitness levels, positional role, and level of competition. This will help players to cope more efficiently with the demands of the game.
- Coaches and practitioners working with female players should be educated on relevant female-specific characteristics through coaching courses specific to the women's game.
- The information presented in this thesis and its resulting publications provide an objective point of reference about player characteristics and game demands at various levels of women's soccer. This data may assist coaches and sport scientists to design more effective training programs and science-based strategies for the further improvement of players' soccer performance and game standards.

5.3. STRENGTHS AND LIMITATIONS

- The main strengths of the current thesis include the simultaneous utilization of state of the art technology such as portable metabolic and GPS devices to quantify the physiological and physical demands of women's soccer match-play (first investigation of this type worldwide). Additionally, the analysis of the physical performance and fitness profiles of female soccer players of lower competition levels (e.g. second and fourth national leagues) has strengthened the body of current literature because information in this area was previously scarce. The majority of published reports had focused only on players competing at the highest levels such as national team/international level and/or first division leagues. Finally, it was also a novelty worldwide to evaluate simultaneously whether the VO_{2max} of female soccer players could be accurately assessed (via portable metabolic equipment) or estimated (from a non-gender-specific formula based on distance covered) during the YYIR1 compared to the gold standard (a maximal laboratory treadmill test). Both methods were found not to be accurate for this purpose compared to the gold standard. Nevertheless, a new estimation formula specific for female soccer players (YYIR1-F2) was derived from this study for the first time, which will require further validation in future studies.

- There are a few limitations associated with the current thesis that must be acknowledged. First, due to the time-consuming and labor-intensive nature of the methodological procedures utilized in each study sample sizes were relatively small. Therefore, the generalization of our findings to other groups of players should be made with caution. Second, comparisons of our study results with other investigations that used different speed zones or thresholds to define the various locomotor activities[40] and/or other match analysis systems should also be performed with caution because large absolute between-system differences exist when comparing video-based time motion analysis, semi-automatic multi-camera, and GPS systems.[53] This also includes the potential limitation of current GPS technology to underestimate distance and speed measures during high-intensity efforts.[54] Finally, although proper familiarization trials were conducted prior to official data collection, movement limitations caused by the measuring equipment (portable metabolic, GPS, and/or HR devices) may have negatively influenced our study results. Thus, this should also be considered when interpreting the findings of this thesis.

5.4. FUTURE DIRECTIONS

- Due to the increased popularity and participation numbers of women's soccer worldwide, there is a high demand of scientific research specific to female players of various age groups, nationalities, competitive levels (higher and lower divisions), and positional roles (including detailed analysis of the goalkeeping demands and more specific field player classifications).
- To date, most investigations in the areas of player characteristics and demands of the game are of a descriptive nature. Therefore, there is need for more experimental studies that evaluate the effectiveness of certain training and recovery interventions (e.g., 1 *vs.* 2 competitive matches per week) on players' characteristics (e.g., anthropometry, physiological, and physical capacities) and on their football performance during match-play. The latter is not only important in terms of physical/physiological aspects but also

regarding technical, tactical, and mental/psychological elements because soccer performance is influenced by all these factors, and thus, all should be taken into account.

- There is also considerable scope for further research specific to female players in topics such as the effects of the menstrual cycle and contraceptive pills use, potential pregnancy and lactation, common injury risks (particularly knee and head injuries), and health concerns (e.g., female athlete triad, iron deficiency, and anemia) on soccer performance and return to play.
- More investigations are needed to quantify the physiological demands placed upon larger samples of female players, competitive matches, and training sessions at different periods of the training/competitive year in terms of on-field oxygen consumption, heart rate, blood lactate concentrations, and physical performance measured in terms of distance, speed, accelerations, and decelerations.
- Finally, the most relevant research findings in these areas should be integrated into coaching education courses and materials specific to the women's game in order to further educate coaches and other practitioners currently working with female soccer players. This will greatly enhance the future development of the women's soccer worldwide.

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EIGENSTÄNDIGKEITSERKLÄRUNG

Hiermit versichere ich, dass ich die vorliegende Arbeit ohne unzulassige Hilfe Dritter und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe; die aus fremden Quellen direkt oder indirekt ubernommenen Gedanken sind als solche kenntlich gemacht.

Bei der Auswahl und Auswertung des Materials sowie bei der Herstellung des Manuskripts habe ich keine Unterstutzungsleistungen anderer als der angegebenen Personen in der Danksagung erhalten.

Weitere Personen waren an der geistigen Herstellung der Arbeit nicht beteiligt. Insbesondere habe ich nicht die Hilfe eines Promotionsberaters in Anspruch genommen. Dritte haben von mir weder unmittelbar noch mittelbar geldwerte Leistungen fur Arbeiten erhalten, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen.

Die Arbeit wurde bisher weder im In- noch im Ausland in gleicher oder ahnlicher Form einer anderen Prüfungsbehorde vorgelegt.

Leipzig, den 12. Juli 2018

Vanessa Martínez Lagunas

AUTHOR'S RESUME

Personal Information

Last name	Martínez Lagunas
First name	Vanessa
Date of birth and place	20.03.1982 in Toluca, Mexico

Education

04/2008 – 07/2018	PhD in Sports Science University of Leipzig, Germany
01/2005 – 08/2007	Master of Arts in Kinesiology/Exercise Physiology University of Texas at Austin, USA
08/2002 – 12/2004	Bachelor of Science in Kinesiology/Health Promotion and Fitness with Minor in Biology University of Texas at Austin, USA
08/1999 – 05/2002	Bachelor of Science (continued in USA) Instituto Tecnológico y de Estudios Superiores de Monterrey, Campus Toluca and Campus Monterrey, Mexico

Professional Experience in Teaching and Research

04/2008 – 11/2012	*Temporary Research Assistant*, Institute of Movement and Training Science II, University of Leipzig
01/2005 – 05/2007	*Research and Teaching Assistant*, Kinesiology and Health Education Department, University of Texas at Austin

Awards and Scholarships

12/2012	1st Place in the Oral Presentation Category Annual Scientific Contest for Young Scientists of the Faculty of Sports Science, University of Leipzig
05/2011	Tom Reilly New Investigation Award (1st Place in the Oral Presentation Category) 7th World Congress on Science and Football, Nagoya, Japan
08/2007 – 03/2012	CONACYT-DAAD PhD Scholarship Holder

Soccer Qualifications and Experience

06/2011 – 03/2012	UEFA Pro Coaching License from the German FA (DFB)
Since 08/2013	Head Coach Women's Soccer, University of Manitoba (Canada)
08/2009 – 05/2011	Assistant Coach U-17/U-16 German Women's National Teams
Since 2013	UEFA Technical Expert
Since 2012	FIFA Technical Study Group Member
Since 2008	FIFA Women's Football Instructor

Soccer Playing Experience

2009 – 2011	1. FC Lokomotive Leipzig (Germany)
2008 – 2009	Leipziger FC 07 (Germany)
2007 – 2008	Bayern Munich (Germany)
2002 – 2004	University of Texas at Austin (USA)
1999 – 2004	Mexico Women's National Team
2000 – 2002	Instituto Tecnológico y de Estudios Superiores de Monterrey, Campus Monterrey (Mexico)
1999 – 2000	Instituto Tecnológico y de Estudios Superiores de Monterrey, Campus Toluca (Mexico)
1996 – 1999	Universidad Autónoma del Estado de México (Mexico)

ORIGINAL PUBLICATIONS

PUBLICATION 1 (P-I)[32]

***Note:** this study was awarded the 1st place during the 2012 Scientific Contest for Young Scientists of the Sports Science Faculty at the University of Leipzig.

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Vanessa Martínez Lagunas
(1. Preisträgerin Referate wissenschaftlicher Nachwuchs)

Physiologische Beanspruchung eines Frauenfußballspiels[1]

Summary

The purpose of the present study was to investigate for the first time the physiological and physical demands of a women's football match by means of simultaneous measurements with portable spirometry and GPS (Global Positioning System) devices. Ten field players wore these devices during a full 90-minute training game (11 vs. 11). Most parameters showed diminished values during the second half compared to the first half of the match. The findings of the present study were somewhat lower compared to published 1) spirometry data of male footballers and 2) heart rate, blood lactate, and GPS values of women's football competitive matches. A detailed analysis of the game demands provides valuable information for the design of efficient and individualized fitness training programmes specific for female football players.

Zusammenfassung

Die vorliegende Studie hatte zum Ziel, die physiologische und körperliche Beanspruchung eines Frauenfußballspiels erstmalig vor allem durch portable Spirometrie- und GPS(Global Positioning System)-Geräte parallel zu quantifizieren. Zehn Feldspielerinnen trugen während eines gesamten 90-minütigen Trainingsspiels (11 vs. 11) die Messapparaturen. Die meisten erhobenen Pa-

[1] Betreuer der Arbeit ist Herr Univ.-Prof. Dr. Ulrich Hartmann, Institut für Bewegungs- und Trainingswissenschaft der Sportarten II, Sportwissenschaftliche Fakultät, Universität Leipzig.

rameter zeigten während der 2. Halbzeit verminderte Werte. Im Vergleich zu publizierten 1) Spirometriedaten männlicher Fußballer und 2) Herzfrequenz-, Blutlaktat-, und GPS-Werte aus Frauenfußball-Wettkampfspielen waren unsere Befunde etwas niedriger. Eine Detailanalyse der Spielanforderungen liefert wertvolle Informationen für die Gestaltung eines effizienten und individualisierten Konditionstrainings spezifisch für Fußballerinnen.

Schlagworte: portable Spirometrie, GPS-Technologie, Herzfrequenz, Laktat

1. Einleitung

Trotz einer hohen Zunahme der Popularität im Frauenfußball in den letzten Jahren ist der aktuelle Stand der Forschung bezüglich physiologischer und energetischer Spielanforderungen noch sehr begrenzt. Aus diesem Grund war es Ziel der vorliegenden Untersuchung, die physiologische und körperliche Beanspruchung eines Frauenfußballspiels erstmalig mittels innovativer Technik, vor allem durch portable Spirometrie- und GPS (Global Positioning System) -Geräte, parallel zu quantifizieren.

2. Methodik

Ein Trainingsspiel (11 vs.11) unter nahezu realen Spielbedingungen wurde nach einem vorangegangenen Probespiel organisiert (gesamte Spielzeit 90 min (2 x 3 x 15 min), wobei 3 Auswechselungen pro Team erlaubt und eine 15-minütige Halbzeitpause gegeben waren. Insgesamt nahmen 28 Fußballerinnen der 2. Bundes- und Landesliga an dieser Studie teil. Davon wurden 10 Feldspielerinnen (21,3 ± 2,9 Jahre, 163,1 ± 7,2 cm, 60,0 ± 4,6 kg) ausgewählt, die die Messgeräte während der gesamten Spieldauer trugen (6 bzw. 4 Spielerinnen pro Mannschaft). Abbildung 1 zeigt Bilder der Vorbereitungen und Durchführung der vorliegenden Untersuchung. Die folgenden Parameter wurden erhoben: 1) Spirografische Messgrößen bzw. Berechnungen (u. a. Sauerstoffaufnahme (VO_2), Kohlendioxidabgabe (VCO_2), respiratorischer Quotient (RER), Energieumsatz (EU) und geschätzter prozentualer Kohlenhydratumsatz (KHU)), 2) Herzfrequenz (HF), 3) Blutlaktatkonzentration (La, in Ruhe, jeweils nach den drei 15-minütigen Blöcken der 1. und 2. Halbzeit sowie nach der Halbzeitpause) und 4) GPS-Messgrößen (u. a. Laufstrecken (D) und -geschwindigkeiten (v)). Die maximale Sauerstoffaufnahme (VO_{2max}) und Herzfrequenz (HF_{max}) der Spielerinnen wurden anhand eines Vita-Max-Tests auf einem Laufband unter Laborbedingungen bestimmt.

Abb. 1. Untersuchungsmethodik in Bilder: Von der Vorbereitungen bis zur Durchführung

3. Ergebnisse

Nachfolgend stellt die Tabelle 1 ausgewählte Ergebnisse der vorliegenden Studie dar. Die durchschnittliche La-Konzentration in Ruhe betrug 0,98 ± 0,25 mmol/l, die im Spiel ermittelten Werte waren < 3,0 mmol/l, der höchste gemessene Einzelwert lag bei 6,61 mmol/l. Die mittleren VO_2- und HF-Peak-Werte, die im Spiel erreicht wurden, lagen bei 53,0 ± 3,8 ml/min/kg bzw. 182 ± 8 S/min, was 98 ± 2 % der gemittelten Maximalwerte der VO_2 bzw. 94 ± 5 % der HF entspricht. Die mittlere und höchste Laufgeschwindigkeit während des gesamten Spiels betrug 4,9 ± 1,0 km/h bzw. 25,0 ± 0,9 km/h.

Tab. 1. *Ausgewählte Befunde des Trainingsspiels (Mittelwert ± Standardabweichung)*

Spiel-abschnitt	Spirometrie (n = 9) (VO_{2max}: 3,20 ± 0,30 l/min bzw. 54,2 ± 4,3 ml/min/kg)					HF & La (n = 10) (HF_{max}: 193 ± 8 S/min)		GPS (n = 10)	
	VO_2 (l/min)	VO_2 (ml/min/kg)	RER	EU_{total} (kcal)	KHU (%)	HF (S/min)	La (mmol/l)	D_{total} (m)	$D_{>16\ km/h}$ (m)
1. 15 min	1,97 ± 0,45	33,1 ± 7,4	0,92 ± 0,12	145,1 ± 25,5	70,5 ± 23,1	160 ± 10	2,83 ± 1,88	1406 ± 263	118 ± 66
2. 15 min	1,63 ± 0,45	27,5 ± 7,5	0,90 ± 0,11	120,2 ± 24,7	66,3 ± 27,3	154 ± 12	1,82 ± 0,83	1186 ± 253	86 ± 41
3. 15 min	1,79 ± 0,47	30,0 ± 7,3	0,92 ± 0,11	129,0 ± 32,2	73,2 ± 29,9	156 ± 14	2,79 ± 1,64	1231 ± 332	123 ± 83
1. HZ_{Bilanz}	1,79 ± 0,48	30,1 ± 7,8	0,91 ± 0,11	394,3 ± 78,6	70,0 ± 26,0	157 ± 11	2,48 ± 1,54	3823 ± 819	326 ± 181
4. 15 min	1,63 ± 0,47	27,6 ± 7,5	0,92 ± 0,11	120,0 ± 22,7	71,1 ± 26,2	147 ± 11	2,08 ± 0,68	1170 ± 233	118 ± 72
5. 15 min	1,61 ± 0,39	27,2 ± 6,5	0,91 ± 0,12	118,7 ± 18,3	68,8 ± 30,2	149 ± 9	1,97 ± 0,69	1170 ± 242	108 ± 50
6. 15 min	1,50 ± 0,43	25,4 ± 6,9	0,88 ± 0,11	110,5 ± 23,5	62,1 ± 30,7	145 ± 10	1,51 ± 0,80	1068 ± 238	79 ± 83
2. HZ_{Bilanz}	1,58 ± 0,43	26,7 ± 7,0	0,91 ± 0,11	349,3 ± 63,3	67,3 ± 28,2	147 ± 9	1,85 ± 0,74	3407 ± 695	305 ± 187
gesamtes Spiel	**1,68 ± 0,47**	**28,4 ± 7,6**	**0,91 ± 0,11**	**743,5 ± 137,3**	**68,7 ± 26,9**	**152 ± 10**	**2,17 ± 1,24**	**7230 ± 1474**	**631 ± 358**

4. Diskussion und Ausblick

In Übereinstimmung mit der Literatur (Davis & Brewer, 1993; Ferrauti et al., 2006; Krustrup et al., 2005; Martínez-Lagunas et al., 2010; Weber et al., 1998) weisen die vorliegenden Befunde bei den meisten erhobenen Parametern während der 2. Halbzeit tendenziell verminderte Werte auf (ca. 4-25 %, außer RER). Ebenfalls niedriger sind die Ergebnisse im Vergleich zu publizierten 1) Spirometriedaten männlicher Fußballspieler (ca. 12-45 %) (Ferrauti et al., 2006; Gatterer, 2007) und 2) HF- (ca. 9-10 %) (Krustrup et al., 2005; Martínez-Lagunas et al., 2010), La- (ca. 46-64 %) (Davis & Brewer, 1993; Weber et al., 1998) und GPS-Werten (ca. 21-30 %) (Hewitt et al., 2009; Martínez-Lagunas et al., 2010) aus Frauenfußball-Wettkampfspielen.

Mögliche Gründe hierfür sind: Geschlecht, Anthropometrie, Kondition, Spielniveau und Motivation der Probanden, Spielbedingungen, methodische Unterschiede sowie Beeinträchtigung durch die Messapparaturen. Obwohl diese Art von Untersuchung sehr aufwendig ist, sollte eine Verifizierung der Daten mit Hilfe einer größeren Anzahl von Probanden und Spielen auf unterschiedlichen Wettbewerbniveaus durchgeführt werden. Dadurch würde ermöglicht, die physiologischen Beanspruchungen im Frauenfußball für eine große Breite und im Detail besser aufzuklären sowie mögliche konditionelle Entwicklungspotenziale aufzuzeigen und abzuleiten.

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Martínez Lagunas, Vanessa, Institut für Bewegungs- und Trainingswissenschaft der Sportarten II, Sportwissenschaftliche Fakultät, Universität Leipzig

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Validity of the Yo-Yo Intermittent Recovery Test Level 1 for Direct Measurement or Indirect Estimation of Maximal Oxygen Uptake in Female Soccer Players

Vanessa Martínez-Lagunas and Ulrich Hartmann

Purpose: To evaluate the validity of the Yo-Yo Intermittent Recovery Test Level 1 (YYIR1) for the direct assessment and the indirect estimation of maximal oxygen consumption (VO_{2max}) in female soccer players compared with a maximal laboratory treadmill test (LTT). ***Methods:*** Eighteen female soccer players (21.5 ± 3.4 y, 165.6 ± 7.5 cm, 63.3 ± 7.4 kg; mean ± SD) completed an LTT and a YYIR1 in random order (1 wk apart). Their VO_{2max} was directly measured via portable spirometry during both tests and indirectly estimated from a published non-gender-specific formula (YYIR1-F1). ***Results:*** The measured VO_{2max} values in LTT and YYIR1 were 55.0 ± 5.3 and 49.9 ± 4.9 mL · kg^{-1} · min^{-1}, respectively, while the estimated VO_{2max} values from YYIR1-F1 corresponded to 45.2 ± 3.4 mL · kg^{-1} · min^{-1}. Large positive correlations between the VO_{2max} values from YYIR1 and LTT (r = .83, P < .001, 90% confidence interval = .64–.92) and YYIR1-F1 and LTT (r = .67, P = .002, .37–.84) were found. However, the YYIR1 significantly underestimated players' VO_{2max} by 9.4% compared with LTT (P < .001) with Bland-Altman 95% limits of agreement ranging from –20.0% to 1.4%. A significant underestimation from the YYIR1-F1 (P < .001) was also identified (17.8% with Bland-Altman 95% limits of agreement ranging from –31.8% to –3.8%). ***Conclusions:*** The YYIR1 and YYIR1-F1 are not accurate methods for the direct assessment or indirect estimation of VO_{2max} in female soccer players. The YYIR1-F1 lacks gender specificity, which might have been the reason for its larger error.

Keywords: women's football, aerobic endurance, field test, prediction, gold standard

Soccer is an intermittent team sport that places high aerobic demands on both male[1,2] and female[3,4] players. Thus, the determination of players' maximal oxygen uptake (VO_{2max}), the most commonly used objective measure of aerobic fitness,[5] may be of interest to the soccer community. In addition, a high VO_{2max} has been shown to enhance recovery from high-intensity intermittent exercise,[6] which may be helpful in soccer due to its intermittent nature.

There are, however, a few differences regarding VO_{2max} research findings between male and female soccer players that should be highlighted. For instance, it has been suggested that VO_{2max} could be important for male players because it may be positively associated with their team performance in an elite soccer league,[7] although the results of that study might have been misinterpreted by its authors due to a weak study design and a small team sample size. To our knowledge, there are currently no published reports in this regard specific to female soccer players. Furthermore, the amount of total distance that male players cover during a game is positively related to VO_{2max}.[8] In contrast, a positive association between total distance covered during a game and VO_{2max} could not be demonstrated among female soccer players.[3] The amount of high-intensity running is considered a more precise measure of physical performance during men's[8,9] and women's[3] soccer matches than the total distance covered. Thus, it seems that aerobic power in female players is more important than in their male counterparts because VO_{2max} has been found to be positively correlated to the amount of high-intensity running during elite women's soccer games,[3] whereas no such relationship was identified during elite men's soccer match play.[8]

The authors are with the Faculty of Sports Science, University of Leipzig, Leipzig, Germany. Address author correspondence to Vanessa Martínez-Lagunas at lagunas@uni-leipzig.de.

Currently, the gold standard for determining VO_{2max} in soccer players consists of maximal laboratory testing on a treadmill.[10] Nevertheless, its implementation is expensive (due to costly facility, equipment, and expertise requirements) and time consuming (especially for testing large squads). For these reasons, alternative field tests that allow a proxy assessment (estimation) of VO_{2max} have been developed.[9,11,12] These tests usually require minimal equipment and expertise. They can be conducted in a field setting (outside laboratory facilities) and allow for simultaneous testing of several athletes at a time, making their implementation very attractive for diverse users.

One of these field tests is the Yo-Yo Intermittent Recovery Test Level 1 (YYIR1), which has gained large popularity in the soccer community due to its specificity and practicality.[9] Its main purpose is to evaluate players' ability to perform repeated intense exercise according to test performance (ie, total distance covered).[8,9] In addition, it may also offer an alternative to estimate VO_{2max} based on a prediction equation published by Bangsbo et al.[9] Nonetheless, that formula has not been validated separately for either gender yet, and the authors did not specify in their report the gender and physical characteristics of the 141 subjects from whom this prediction equation was derived. Those authors confirmed later by e-mail correspondence that the majority of their subjects were male players (>90%). Thus, it is still unknown if this formula will yield accurate results to predict VO_{2max} of female soccer players. It has been shown that gender-distinct prediction equations provide a more accurate estimation of VO_{2max} when a similar field test (20-m shuttle-run test) is used,[13] but to date no gender-specific equation has been proposed to predict VO_{2max} from YYIR1 performance.

It should also be noted that up to now no study has simultaneously evaluated whether VO_{2max} can be accurately assessed (via portable spirometry) or estimated (through an indirect formula based on distance covered) during the YYIR1. Therefore, a comparison of both direct and indirect VO_{2max} values obtained during the YYIR1 with direct VO_{2max} measurements obtained during laboratory testing (gold standard) is still lacking.

The aim of the current study was to evaluate the validity of the YYIR1 for the direct assessment (via portable spirometry) and the indirect estimation of VO_{2max} (from a non-gender-specific formula recommended by Bangsbo et al[9]) in female soccer players in comparison with a maximal laboratory treadmill test (LTT).

Methods

Subjects

Eighteen female soccer players (21.5 ± 3.4 y, 165.6 ± 7.5 cm, 63.3 ± 7.4 kg; mean ± SD) competing in the Second German National League participated in this study. This investigation conformed to the standards set by the Declaration of Helsinki's ethical principles for research involving humans. All participating players completed a medical screening questionnaire and signed a written informed-consent form after receiving verbal and written explanation of the study procedures and its potential risks. All athletes were in good health and free of injuries at the time of testing.

Design

A cross-sectional study design was used to determine the validity of the YYIR1 for the direct assessment and the indirect estimation of VO_{2max} in female soccer players compared with a maximal LTT (gold standard).

General Procedures

Players completed an LTT and a YYIR1 in random order and on different days separated by 1 week during the second half of their competitive season. Players' VO_{2max} was directly measured during both tests using the same portable spirometry system (MetaMax3B, Cortex Biophysik, Leipzig, Germany). Vogler et al[14] reported that the validity of this system was satisfactory compared with the criterion values, although it slightly overestimated VO_2 by 3% to 4%. Its reliability was excellent, showing typical errors of only 2% to 3%.[14] Before each test, proper pressure, volume, and gas calibrations were conducted according to the manufacturer's guidelines.

Players performed both tests under similar temperature (LTT 24.0°C ± 1.5°C and YYIR1 22.2°C ± 1.2°C) and pressure (LTT 751 ± 5 mm Hg and YYIR1 751 ± 2 mm Hg) conditions, as well as time of the day (between 3 and 8 PM). They were instructed to keep their dietary habits as constant as possible and to avoid strenuous physical activity before each test (ie, at least 48 h after a game and no or only light training 24 h before testing). In addition, we asked players to avoid large meals for at least 2 hours and the consumption of beverages containing caffeine for at least 8 hours before each testing session. Participants were verbally encouraged to give their maximal effort during each test.

Spirometry data were collected breath by breath throughout the full duration of each test and exported into 5-second intervals. Individual VO_{2max} was defined as the average of the highest VO_2 value closest to the end of each test and the VO_2 values before and after it. Furthermore, at least 2 of the following criteria had to be met: a VO_2 plateau (≤2.1 mL · kg^{-1} · min^{-1}) despite increasing speed, a respiratory-exchange ratio ≥1.15, an attainment of ≥95% age-predicted maximal heart rate (220 – age), and/or a peak blood lactate concentration of ≥8 mmol/L after maximal testing.

Heart rate (HR) was continuously monitored every 5 seconds with a heart-rate monitor (Polar Team,[2] Polar Electro Oy, Kempele, Finland) during both tests. Individual maximal heart rate (HR_{max}) was defined as the highest value reached in a 5-second period toward the end of each test. Blood samples were taken from the earlobe at rest, after the warm-up period, and 1, 3, 5, 7, 10, and 12 minutes after each test. Blood samples were collected in 20-μL capillary tubes and immediately inserted into prefilled reaction tubes containing a lysing stabilizing agent. Blood lactate concentration was determined using the Biosen S-Line lactate analyzer (EKF-Diagnostic, Barleben, Germany). Total test duration, distance covered, maximal velocity achieved, VO_{2max}, HR_{max}, and maximal posttest blood lactate concentration were documented for each test.

Players' VO_{2max} (mL · kg^{-1} · min^{-1}) was also indirectly estimated from their distance covered in the YYIR1 using the non-gender-specific formula recommended by Bangsbo et al[9] (YYIR1-F1):

$$VO_{2max} = \text{YYIR1 distance (m)} \times 0.0084 + 36.40$$

Test Protocols

Maximal Laboratory Treadmill Test. The maximal LTT was performed under laboratory conditions on a motorized treadmill (Bari-Mill, Woodway, Weil am Rhein, Germany) with an inclination of 1%. After a 10-minute warm-up period at 8 km/h, the test began at 12 km/h. Subsequently, the speed was increased by 1 km/h every 30 seconds until the player reached volitional exhaustion. This exhaustive incremental test protocol was slightly modified from the one used by Krustrup et al[3] and meets common VO_{2max} assessment-protocol characteristics that have been stated elsewhere.[15]

Yo-Yo Intermittent Recovery Test Level 1. The YYIR1 was conducted indoors on a wooden sports floor according to established procedures.[8,9] After completing a standardized warm-up for 10 minutes, the players performed the YYIR1, which consisted of 2 × 20-m shuttle runs at progressively increasing speeds with a 10-second active recovery period between runs. The YYIR1 started at a speed of 10 km/h. The speed was then increased by 2 and 1 km/h for the next 2 speed levels, respectively. Thereafter, the speed was increased by 0.5 km/h until the participants twice failed to reach the markers of the test course in time or felt unable to complete another shuttle run at the dictated speed. A table with a more detailed description of the YYIR1 protocol can be found elsewhere.[16]

All players were experienced with the YYIR1 protocol because they had been exposed to it before as part of their team's regular fitness-testing sessions. They were not familiar with the LTT protocol but had previous intense treadmill-running experience. Furthermore, the investigators explained the LTT and YYIR1 protocols to the players before the start of each test.

Statistical Analysis

Descriptive statistics are presented as mean ± SD (range) unless otherwise indicated. Data were checked graphically (histograms and boxplots) and statistically (Shapiro-Wilk test) for normality. Pearson product–moment correlations, paired t tests, and linear-regression analysis were conducted for data analysis. The following criteria were used to classify the magnitudes of correlation: $r < .1$ trivial, r = .1 to .3 small, r = .3 to .5 moderate, and $r > .5$ large.[17] The 90% confidence intervals of the reported correlations were calculated. In addition, Bland-Altman 95% limits of agreement were calculated and plotted to examine individual differences between the estimated and measured VO_{2max} values according to known procedures.[18] Statistical significance was set at $P < .05$. Data were analyzed using

Excel 2010 (Microsoft Corp, Redmond, WA, USA) and IBM SPSS Statistics Version 19 (IBM Corp, Armonk, NY, USA).

Results

Table 1 shows relevant test results from the YYIR1 and LTT. Although the total duration, distance covered, and maximal velocity attained during both tests are dissimilar due to their specific protocols, the players attained comparable HR_{max} and maximal posttest blood lactate concentration in both tests, with no statistically significant differences detected ($P > .84$ and $P > .24$, respectively).

Table 2 reveals large correlation coefficients between the measured VO_{2max} in YYIR1 and LTT ($P < .001$) and between YYIR1-F1 and the measured VO_{2max} in LTT ($P = .002$). In general, the measured and estimated VO_{2max} values obtained in YYIR1 were lower than those obtained in LTT (Table 2). Bland-Altman plots with their corresponding 95% limits of agreement display considerable discrepancy and a significant VO_{2max} mean difference ($P < .001$) between measured VO_{2max} in YYIR1 and LTT (Figure 1[A]) and between estimated VO_{2max} from YYIR1-F1 and measured VO_{2max} in LTT (Figure 1[B]). The individual relationship between distance covered in YYIR1 and the VO_{2max} measured in LTT is illustrated in Figure 2, which also includes the regression lines and equations of YYIR1-F1 (published non-gender-specific formula from Bangsbo et al[9]) and YYIR1-F2 (a new gender-specific formula derived through linear-regression analysis from the data of this study):

$$VO_{2max} = \text{YYIR1 distance (m)} \times 0.0088 + 45.73$$

Players with a similar VO_{2max} showed a large variation in distance covered during the YYIR1 (refer to Figure 2).

Discussion

The primary objective of the current study was to evaluate the validity of the YYIR1 in assessing or estimating VO_{2max} among female soccer players compared with an LTT. To our knowledge, no other study has previously included direct VO_{2max} measurement during the YYIR1. Most studies have mainly evaluated the correlation coefficient (r) between YYIR1 performance (distance covered) and VO_{2max} assessed during laboratory testing,[3,8,9] which is not enough to demonstrate the validity of the YYIR1 to predict VO_{2max}.[18] For example, Krustrup et al[3] found a positive significant association ($r = .55$, $P = .04$) between YYIR1 performance and VO_{2max} among female soccer players but did not report its corresponding linear-regression equation. The results of the current study showed that the YYIR1 did not provide an accurate measurement or prediction of VO_{2max} (from YYIR1-F1) despite large correlation coefficients between the obtained VO_{2max} values ($r = .67–.83$, $P < .003$). The YYIR1 significantly underestimated measured VO_{2max} by 9.4% compared with the LTT, with Bland-Altman 95% limits of agreement ranging from –20.0% to 1.4%, while the prediction from YYIR1-F1 underestimated VO_{2max} values by 17.8%, with Bland-Altman 95% limits of agreement ranging from –31.8% to –3.8%.

Possible reasons that may explain these findings include the intermittent nature of the test and longer test duration, as well as the skill and energy cost associated with the constant changes of direction required in the YYIR1 compared with LTT.[16,19] The fact that YYIR1-F1 is a non-gender-specific formula for VO_{2max} prediction based on YYIR1 performance may also play a role in justifying these findings. It has been shown that gender-distinct prediction equations provide a more accurate estimation of VO_{2max}, which may be basically due to the physical and physiological differences that exist between men and women.[13] Moreover, the strength of the relationship between YYIR1 performance and laboratory-assessed VO_{2max} has been found to be lower in female players ($r = .55$, $P < .05$[3] and $r = .67$, $P = .002$ in the current study) compared with their male counterparts ($r = .71$, $P < .05$).[8] Thus, it seems logical to speculate that the slope and constant of the VO_{2max} prediction based on YYIR1 performance should be specific to player gender to minimize its prediction error. Consequently, the gender-specific equation derived from the data of our study sample (YYIR1-F2) might provide a more accurate VO_{2max} prediction for female soccer players than the non-gender-specific equation (YYIR1-F1) from Bangsbo

Table 1 Comparison of Test Results Between YYIR1 and LTT, Mean ± SD (Range), N = 18

Test	Duration (min)	Distance (m)	Maximal velocity (km/h)	HR_{max} (beats/min)	Posttest La_{max} (mmol/L)
YYIR1	8.5 ± 3.2 (4.2–16.6)	1051 ± 399 (520–2080)	15.2 ± 0.7 (14.5–17.0)	190 ± 7 (179–204)	10.2 ± 2.5 (4.4–14.9)
LTT	2.7 ± 0.4 (2.0–3.7)	628 ± 106 (450–928)	16.1 ± 0.8 (15.0–18.0)	190 ± 6 (182–202)	10.8 ± 2.1 (7.1–14.6)

Abbreviations: HR_{max}, maximal heart rate; LTT, maximal laboratory treadmill test; La_{max}, maximal blood lactate concentration; YYIR1, Yo-Yo Intermittent Recovery Test Level 1.

Table 2 Measured and Estimated VO_{2max} From YYIR1 and LTT, Mean ± SD (Range), N = 18

Test pair	Maximal oxygen consumption (mL · kg⁻¹ · min⁻¹)	r (90% confidence interval)	SEE (mL · kg⁻¹ · min⁻¹)
YYIR1	49.9 ± 4.9 (41.0–57.3)	.83* (.64–.92)	3.0
LTT	55.0 ± 5.3 (45.9–67.1)		
YYIR1-F1	45.2 ± 3.4 (40.8–53.9)[a]	.67† (.37–.84)	4.0
LTT	same as above		

Abbreviations: LTT, maximal laboratory treadmill test; r, Pearson product–moment correlation coefficient; SEE, standard error of the estimate; YYIR1, Yo-Yo Intermittent Recovery Test Level 1.

[a] Via estimation formula recommended by Bangsbo et al.[9]

*$P < .001$. †$P = .002$.

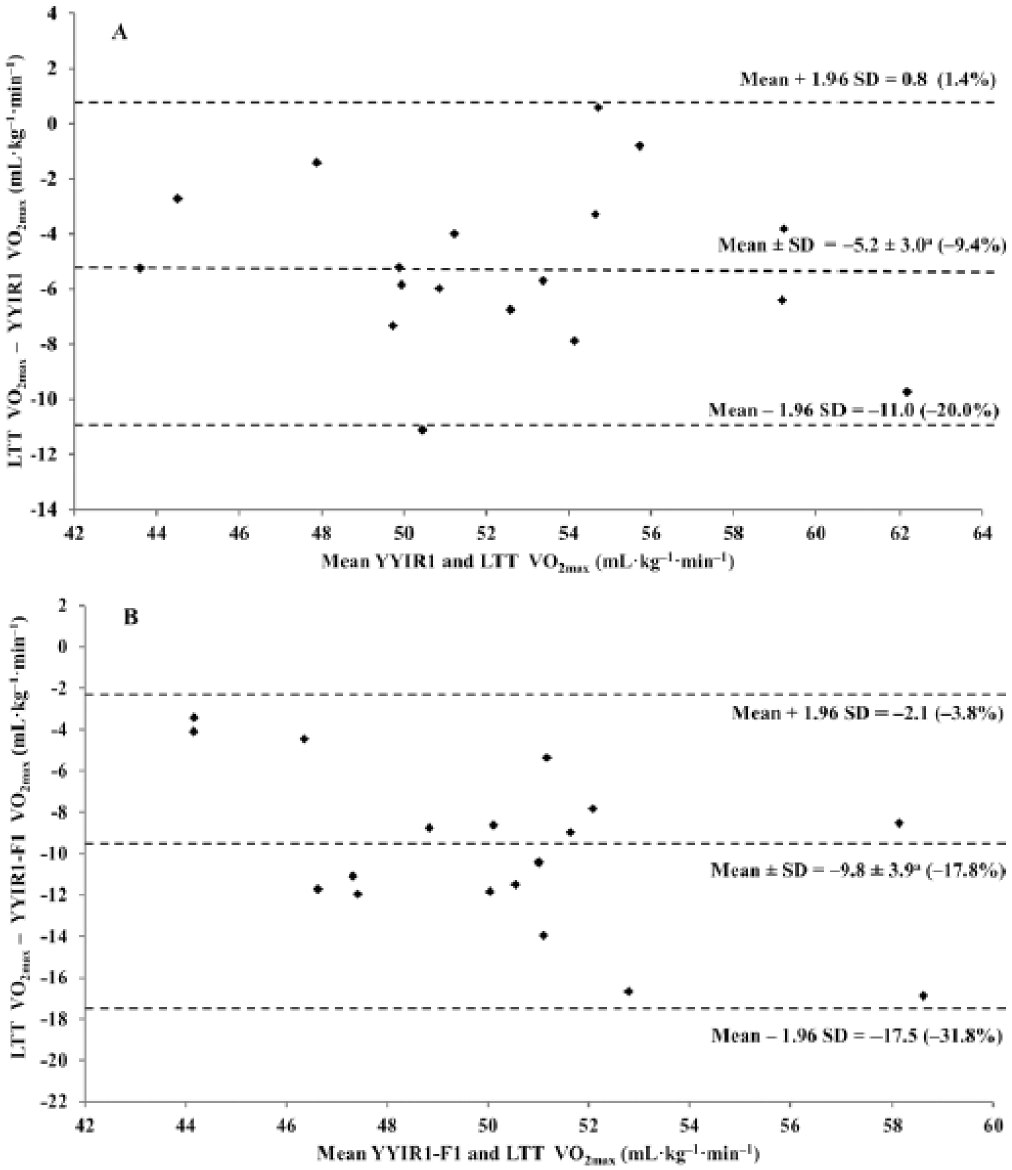

Figure 1 — Bland-Altman plots[18] of (A) measured VO_{2max} in YYIR1 and LTT and (B) estimated VO_{2max} from YYIR1-F1 and measured VO_{2max} in LTT. The broken middle line shows the mean difference (systematic bias) between the 2 measurement methods, and the 2 extreme broken lines represent the 95% limits of agreement (± 1.96 SD around the mean difference). Abbreviations: LTT, maximal laboratory treadmill test; VO_{2max}, maximal oxygen consumption; YYIR1, Yo-Yo Intermittent Recovery Test Level 1; YYIR1-F1, VO_{2max}-estimation formula recommended by Bangsbo et al.[9] [a]Significant at $P < .001$.

et al.[9] However, this equation still needs to be cross-validated with independent samples in future studies. To our knowledge, this is to date the first gender-specific equation that has been proposed to predict VO_{2max} from YYIR1 performance. Field tests with a continuous exercise protocol, such as the Cooper 12-minute-run test,[11] the 20-m shuttle-run test,[12] or the Yo-Yo Endurance Test,[16] might also be better alternatives than the YYIR1 to predict VO_{2max} in female soccer players. Nonetheless, further research is required in this area.

The relevance of VO_{2max} determination in soccer has been mainly questioned due to the lack of association between VO_{2max} and the amount of high-intensity running performed during match play in male soccer players.[8–10] However, a positive correlation

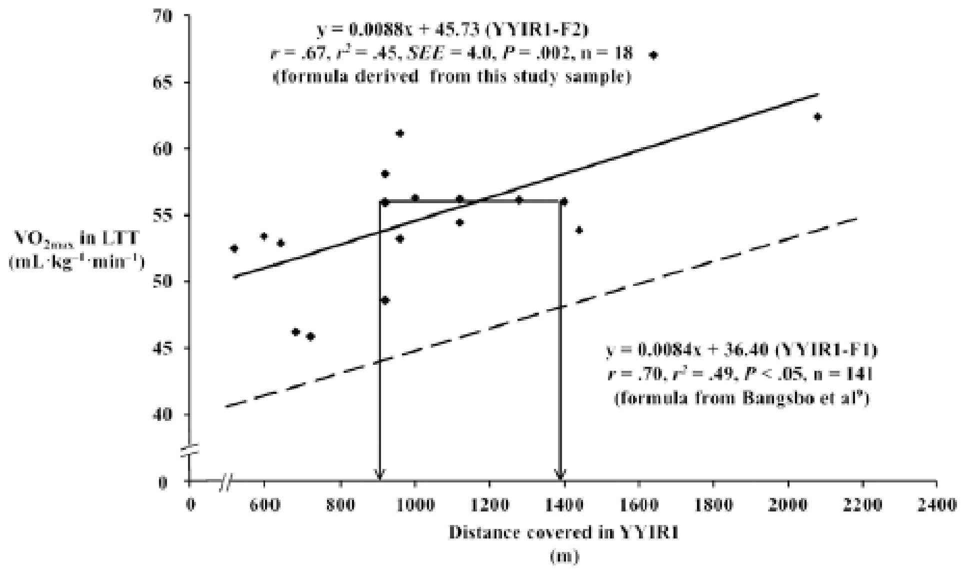

Figure 2 — Individual relationship between distance covered in the Yo-Yo Intermittent Recovery Test Level 1 (YYIR1) and measured oxygen consumption (VO_{2max}) during the maximal laboratory treadmill test (LTT). This figure also shows the regression lines of the VO_{2max}-estimation formula derived from the data of our study sample (YYIR1-F2, solid line) and the formula recommended by Bangsbo et al[9] (YYIR1-F1, broken line). The vertical lines indicate the variation of the distance covered in YYIR1 (920–1400 m) for a given VO_{2max} of 56 mL · kg^{-1} · min^{-1}. Abbreviations: *r*, Pearson product–moment correlation coefficient; r^2, coefficient of determination; SEE, standard error of the estimate.

between these 2 variables has been documented among female soccer players ($r = .81$, $P < .001$),[3] which may indirectly support a higher relevance of VO_{2max} determination in this population. In general, although VO_{2max} cannot be considered the single best indicator of soccer-specific physical performance, it may be useful to compare soccer players with different populations of athletes in relation to their general aerobic endurance.[10] Moreover, VO_{2max} may also help differentiate elite and subelite players and teams and players of various playing positions[7,10] and to detect large changes in fitness status as a result of specific training regimens (eg, after preseason training).[20–22]

It should be noted that VO_{2max} is not the only physiological determinant of endurance performance; other factors such as lactate threshold, running economy, and morphological components (eg, muscle capillary density, muscle fiber type, etc) also play an important role.[23–25] This argument is also supported by our study findings depicted in Figure 2, which show that players with a similar VO_{2max} (eg, 56 mL · kg^{-1} · min^{-1}) achieved very different performance levels in the YYIR1 (920–1400). Thus, individual differences in other physiological factors such as those just mentioned may explain this large individual performance variation in the YYIR1 at a given VO_{2max}.

The mean measured (LTT 55.0 mL · kg^{-1} · min^{-1}, YYIR1 49.9 mL · kg^{-1} · min^{-1}) and estimated (YYIR1-F1 45.2 mL · kg^{-1} · min^{-1}) VO_{2max} values of our female soccer player sample can be placed within the upper range of the VO_{2max} values that have been reported in the literature for other female soccer players (38.6–57.6 mL · kg^{-1} · min^{-1}).[2-4] However, the mean YYIR1 distance covered by our study participants (1051 m) is lower than the reported YYIR1 performance for top-elite (1600 m), moderate-elite (1360 m), and subelite (1160 m) female soccer players.[9] Our YYIR1 performance data are also lower than those of first-division Danish female soccer players (1379 m).[3] The relatively high VO_{2max} values of our study participants may indicate that they possess well-developed general aerobic endurance. Yet, their soccer-specific endurance still needs improvement, as evidenced by the low mean total distance they achieved during the YYIR1. The comparable HR_{max} and posttest maximal blood lactate attained by the participating players in both the LTT and the YYIR1 show that they gave their maximal effort during both tests before reaching volitional fatigue.

Despite the lack of precision of the YYIR1 to accurately assess or estimate VO_{2max} in female soccer players, the test can be used for other purposes in women's soccer. For instance, the fact that the study participants achieved identical mean HR_{max} values during the YYIR1 and LTT suggests that the YYIR1 can be employed to determine HR_{max} among female soccer players in a practical and inexpensive way. Other investigations have reported similar findings in male participants.[8] In addition, the YYIR1 could also provide a good indication of physical match performance among female players, because it is closely related to the amount of high-intensity running covered during match play.[3] It may also provide a more sensitive measure of soccer-specific physical performance based on players' standard of play.[8–10] The YYIR1 performance differences among female soccer players of various competitive levels mentioned in the previous paragraph also support this possibility. For example, Danish players of the first division studied by Krustrup et al[3] outperformed our study participants (German second-division players) by almost 24% in this test, despite the fact that on average our players had a 10% higher laboratory-assessed VO_{2max} than the Danish players (although methodological differences in assessing

VO_{2max} between the 2 studies might have also contributed to this discrepancy). Thus, the YYIR1 can also be useful for talent identification and selection in women's soccer.

We acknowledge that there are a few limitations associated with the current study. For instance, our sample size was limited due to the time-consuming and labor-intensive nature of our methodology and the difficulty of recruiting large numbers of players for this investigation. Thus, generalization of our findings to other groups of players should be made with caution. The fact that we used a short and intense incremental treadmill protocol for the assessment of VO_{2max} (LTT), in which the average total test duration was just below 3 minutes (although it was preceded by a standardized 10-min warm-up supporting the adaptation of VO_2 kinetics), could also be potentially seen as a study limitation. Earlier, a test duration of at least 8 minutes was recommended for accurate VO_{2max} determination.[26] However, more recent studies (that employed an exhaustive incremental protocol similar to the one used in the current investigation) suggest that a test duration of 3 to 5 minutes might be sufficient to elicit real VO_{2max}.[3,15] Nonetheless, there is still the possibility that some of the players in this study did not reach their real VO_{2max} but instead only a VO_{2peak} during the LTT. Thus, this could mean that the magnitude of the underestimation we found through the YYIR1 and YYIR1-F1 compared with the LTT could be potentially larger than the one reported in this study.

Practical Applications

The most accurate way to assess VO_{2max} in female soccer players is through maximal laboratory treadmill testing. The YYIR1 is not an accurate test for the direct assessment (via portable spirometry) or indirect estimation of VO_{2max} (from a non-gender-specific formula, YYIR1-F1[9]) in female soccer players. Therefore, we do not recommend the use of the YYIR1 or YYIR1-F1 for either purpose.

Conclusions

In conclusion, although the direct and indirect VO_{2max} values were significantly related, the YYIR1 significantly underestimated VO_{2max} in female soccer players compared with LTT (the gold standard). The average VO_{2max} underestimation of the indirect method using YYIR1-F1[9] (non-gender-specific formula) was about twice as much than that of the direct assessment via portable spirometry in YYIR1 (17.8% vs 9.4%, respectively) with overall Bland-Altman 95% limits of agreement ranging from –31.8% to 1.4%. The lack of gender specificity of YYIR1-F1[9] might have been the reason for its larger error. The gender-specific estimation formula derived from the data of our study sample (YYIR1-F2) might be more appropriate to estimate VO_{2max} among female soccer players. However, this must be evaluated in future studies.

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Review

Women's football: Player characteristics and demands of the game

Vanessa Martínez-Lagunas [a,b,*], Margot Niessen [a], Ulrich Hartmann [a]

[a] Institute of Movement and Training Science, University of Leipzig, Leipzig, 04109, Germany
[b] Faculty of Kinesiology and Recreation Management, University of Manitoba, Winnipeg, R3T 2N2, Canada

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Abstract

The number of scientific investigations on women's football specific to the topics of player characteristics and demands of the game has considerably increased in recent years due to the increased popularity of the women's game worldwide, although they are not yet as numerous as in the case of men's football. To date, only two scientific publications have attempted to review the main findings of studies published in this area. However, one of them was published about 20 years ago, when women's football was still in its infancy and there were only a few studies to report on. The other review was more recent. Nonetheless, its main focus was on the game and training demands of senior elite female players. Thus, information on female footballers of lower competitive levels and younger age groups was not included. Consequently, an updated review is needed in this area. The present article therefore aims to provide an overview of a series of studies that have been published so far on the specific characteristics of female football players and the demands of match-play. Mean values reported in the literature for age (12–27 years), body height (155–174 cm), body mass (48–72 kg), percent body fat (13%–29%), maximal oxygen uptake (45.1–55.5 mL/kg/min), Yo-Yo Intermittent Recovery Test Level 1 (780–1379 m), maximum heart rate (189–202 bpm), 30 m sprint times (4.34–4.96 s), and counter-movement jump or vertical jump (28–50 cm) vary mostly according to the players' competitive level and positional role. There are also some special considerations that coaches and other practitioners should be aware of when working with female athletes such as the menstrual cycle, potential pregnancy and lactation, common injury risks (particularly knee and head injuries) and health concerns (e.g., female athlete triad, iron deficiency, and anemia) that may affect players' football performance, health or return to play. Reported mean values for total distance covered (4–13 km), distance covered at high-speed (0.2–1.7 km), average/peak heart rate (74%–87%/94%–99% HR_{max}), average/peak oxygen uptake (52%–77%/96%–98% VO_{2max}), and blood lactate (2.2–7.3 mmol/L) during women's football match-play vary according to the players' competitive level and positional role. Methodological differences may account for the discrepancy of the reported values as well. Finally, this review also aims to identify literature gaps that require further scientific research in women's football and to derive a few practical recommendations. The information presented in this report provides an objective point of reference about player characteristics and game demands at various levels of women's football, which can help coaches and sport scientists to design more effective training programs and science-based strategies for the further improvement of players' football performance, health, game standards, and positive image of this sport.

Keywords: Female soccer players; Match-play requirements; Physical and physiological profiles

1. Introduction

"The future of football is feminine", is the famous declaration of Joseph S. Blatter, current Fédération Internationale de Football Association (FIFA) president, that reflects the rising popularity of the women's game around the world and highlights the clear objective of FIFA to continue supporting its growth.[1] Currently, about 29 million women play football, which corresponds to nearly 10% of the total number of male and female footballers worldwide.[2,3] The number of registered female players (at the youth and senior level) grew by over 50% in 2006 compared to the previous FIFA Big Count in 2000.[3] Additionally, the number of international competitions,

* Corresponding author. Institute of Movement and Training Science, University of Leipzig, Leipzig, 04109, Germany.
E-mail address: lagunas@uni-leipzig.de (V. Martínez-Lagunas)
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professional and recreational leagues for female players of various age groups has considerably increased in recent years. This has given a large number of female footballers the opportunity to train and compete in professional environments, which at the same time has raised the performance expectations placed upon players and increased the need for specific scientific research that could help improve their performance.

Despite the increased popularity and professionalization of women's football around the world, there is still limited scientific research specific to female players compared to their male counterparts, especially in the areas of players' physical and physiological characteristics and game demands. For instance, in the case of men's football, there are numerous full-text peer-reviewed studies that have been published on these topics including players of several nationalities, competitive levels, age groups, and playing positions. Additionally, several comprehensive literature reviews have been published in order to discuss and summarize the findings of a large number of studies in this area.[4–12]

In women's football, on the other hand, only one journal review article dealing specifically with the applied physiology of female soccer (football) players was found in the present literature review.[13] This review article was published about 20 years ago, when women's football was still in its infancy and there were only a few published studies to report on. More recently, a book chapter with specific focus in reviewing the game and training demands of senior elite female football players has been published.[14] However, information on female football players of lower competitive levels and younger age groups was not included. The number of scientific publications specific to player characteristics and game demands in women's football has noticeably grown since then including information of players of several nationalities, competitive levels, age groups, and playing positions.[15–66] Consequently, an updated review is needed in this area.

Therefore, the purposes of the present literature review are: 1) to provide an overview of a series of studies that have been published so far on the specific characteristics of female footballers and the demands of match-play; 2) to identify areas/topics that require further scientific research in women's football; and 3) to derive a few practical recommendations from the information gathered in this review. Knowledge and understanding of this information can help coaches and sport scientists to design more effective training programs and science-based strategies for the further improvement of players' football performance, health, game standards, and positive image of the women's game.

2. Player characteristics

Several investigations specific to female football players of various nationalities, competitive levels, and positional roles have reported on their age, anthropometry, physiological, and physical attributes (Tables 1 and 2). However, they are still not nearly as numerous as in the case of scientific reports on male football players. Furthermore, several studies have highlighted the main physical and physiological differences that exists between the genders[67–69] and a few considerations that are characteristics only of females, and therefore, not present in their male counterparts, such as the menstrual cycle,[70–73] potential pregnancy and lactation,[70,74] injury risks,[75–79] and health concerns.[64,72] These reports also emphasized how these traits could affect players' football performance, health or their return to play. Hence, coaches of female players should be well educated on these topics.

2.1. Age and anthropometry

The age and body height of elite female football players competing at most recent FIFA Women's World Cup (Germany 2011) have been recently reported.[80] The average age for all 16 participating teams was approximately 25 years (range: 21–28 years). The average age of the top four most successful teams in this tournament (Japan, USA, Sweden, and France) was in the upper range of 26–28 years. The youngest and oldest players of this tournament were a midfielder (16 years) and a goalkeeper (38 years), respectively. In agreement with other reports on male football players,[11] female goalkeepers also seem to have longer careers than the field players. Some explanatory reasons for this may include that experience plays a crucial role for the goalkeeping position, that goalkeepers are less vulnerable to injuries, and that the game overall physical demands placed upon them are lower compared to those of the field players.[8,11] In terms of body height values reported from the FIFA Women's World Cup Germany 2011,[80] the average height of all teams was 168 cm. The tallest team was Germany (173 cm) and the shortest Japan (163 cm). The tallest individual player was 187 cm (a central defender) and the shortest 152 cm (a midfielder). Three of the four semi-finalists were among the tallest teams in the tournament (USA, Sweden, and France). However, world champion Japan was the shortest team of the tournament. Goalkeepers (mean height 172 cm and range 162–185 cm) were slightly taller than the field players.[49]

The mean values of age (12–27 years), body height (155–174 cm), body mass (48–72 kg), and percent body fat (13%–29%) reported in other publications for female players vary according to their nationality, competitive level, and positional role (Table 1). In the case of percent body fat, the type of measurement method used may also account for the discrepancies among the reported values. In men's football, it has been shown that there may be anthropometric predispositions for some positional roles (such as goalkeeping, central defense, and attack), with tall players having a certain competitive advantage and, therefore, being selected to play these roles.[7] A few studies also show that female goalkeepers tend to be taller and heavier than the field players[23,35,39,43,48,63,81] (Table 1). However, most of these studies have used a general categorization of playing positions (only goalkeepers, defenders, midfielders, and forwards). Thus, it is still unknown if there are anthropometrical differences among more specific positional roles (e.g., goalkeepers (GK), central and external defenders (CD, ED), central and external midfielders (CM, EM), and forwards (F)). Further

Table 1
Summary of studies reporting on age and anthropometric characteristics of female football players.

Study	Country	Level/*n* *Position/n*	Age (year)	BH (cm)	BM (kg)	BF (%)
Almagià Flores et al.[45]	Chile	U-20 WNT/26	18.1 ± 0.7	159.2 ± 5.0	59.7 ± 6.4	29.1 ± 2.3[b]
		Uni team/17	21.5 ± 1.9	162.6 ± 5.0	62.1 ± 8.8	28.4 ± 4.1[b]
Andersson et al.[51]	Sweden	1D/21	24.3 ± 4.9	170.0 ± 0.02	62.9 ± 4.9	
Andersson et al.[52]	Sweden/Norway	1D/17				
		Active group/8	22.6 ± 4.2	167.1 ± 5.7	63.3 ± 7.1	
		Passive group/9	21.6 ± 2.6	167.2 ± 4.7	65.0 ± 4.6	
Andersson et al.[53]	Sweden/Denmark	1D/17	27.0 ± 1.0	168.2 ± 1.5	61.0 ± 1.4	
Barbero-Álvarez et al.[54]	Spain	Youth players/12	12.1 ± 0.9	155 ± 6	48.4 ± 9.2	
Bunc and Psotta[28]	Czech Republic	1D/14	25.3 ± 4.8	165.0 ± 0.1	64.5 ± 9.9	14.9 ± 5.7[a]
Can et al.[29]	Turkey	1D/17	20.7 ± 2.1	162.4 ± 5.8	56.6 ± 5.0	19.8 ± 0.7[b]
Colquhoun and Chad[19]	Australia	National and state level/10	24.4 ± 4.5	158.1 ± 5.7	55.4 ± 6.5	20.8 ± 4.7[c]
Cook[93]	England	1D/8	22.0 ± 2.6	162.4 ± 0.1	61.2 ± 4.1	
David[48]	Canada	WNT/22	24.6	166.2	61.2	21.9[b]
		GK/2	*24.5*	*174.0*	*72.4*	*29.2*[b]
		D/6	*24.0*	*167.5*	*60.1*	*21.4*[b]
		M/9	*24.7*	*164.7*	*59.5*	*20.5*[b]
		F/5	*25.4*	*164.1*	*61.0*	*22.2*[b]
Davis and Brewer[15]	England	WNT/14				
		Pre-training	24.5 ± 3.6	166.0 ± 6.1	60.8 ± 5.2	21.5 ± 3.6
		Post-training	25.4 ± 3.7	166.0 ± 6.5	59.6 ± 5.2	21.1 ± 2.7
		(after 12 months)				
Dillern et al.[44]	Norway	3D/32	17.4 ± 2.4			
		GK/3		*164.7 ± 0.1*	*65.6 ± 5.1*	
		D/11		*167.8 ± 0.0*	*61.5 ± 4.9*	
		M/8		*164.4 ± 0.1*	*56.0 ± 6.3*	
		F/10		*168.0 ± 0.1*	*58.0 ± 7.0*	
Gabbett and Mulvey[55]	Australia	WNT/13	21.0 ± 2.0			
Gómez López and Barriopedro Moro[32]	Spain	Senior club team/7	22.6 ± 3.9	164.0 ± 0.6	59.5 ± 8.1	
		U-17 club team/15	16.6 ± 1.2	160.0 ± 0.6	57.7 ± 9.6	
Gómez López et al.[33]	Spain	U-17 club team/11	16.6 ± 1.2	160.0 ± 0.1	57.7 ± 9.6	16.8–17.4
Green et al.[101]	USA	Uni level/39	20.1 ± 1.5	165.6 ± 6.0	62.8 ± 7.3	
Haugen et al.[63]	Norway	WNT/76	22.8 ± 3.5	169.0 ± 5.5	63.2 ± 5.5	
		1D/53	21.1 ± 3.5	167.0 ± 5.0	60.6 ± 5.9	
		2D/28	20.9 ± 3.4	–	61.6 ± 8.6	
		JNT/11	17.1 ± 1.1	168.0 ± 5.3	61.2 ± 4.9	
		Juniors/17	17.5 ± 1.7	168.0 ± 7.1	62.7 ± 8.3	
		GK/11	*21.6 ± 5.2*	*174.0 ± 4.1*	*66.9 ± 4.4*	
		D/34	*22.3 ± 3.4*	*169.0 ± 5.2*	*63.1 ± 4.9*	
		M/32	*22.3 ± 4.3*	*169.0 ± 5.9*	*62.9 ± 5.6*	
		F/21	*21.4 ± 3.7*	*168.0 ± 5.2*	*62.9 ± 6.1*	
Haugen et al.[81]	Norway	WNT/85	23.5 ± 3.6		63.7 ± 5.2	
		1D/47	21.2 ± 3.6		62.4 ± 6.6	
		2D/29	22.3 ± 4.8		–	
		Junior elite/33	18.1 ± 2.9		61.7 ± 5.9	
		GK/17	*21.4 ± 4.7*		*67.3 ± 4.6*	
		D/63	*21.6 ± 4.1*		*61.9 ± 5.7*	
		M/62	*21.6 ± 4.3*		*61.5 ± 4.6*	
		F/52	*21.9 ± 3.8*		*64.1 ± 6.7*	
Hewitt et al.[57]	Australia	WNT/15	23.5 ± 2.5	170.0 ± 0.5	64.9 ± 4.6	
		D/6	*24.3 ± 1.0*	*169.0 ± 0.2*	*63.2 ± 0.8*	
		M/5	*23.4 ± 3.8*	*170.7 ± 0.3*	*63.1 ± 2.7*	
		F/4	*22.9 ± 0.8*	*171.7 ± 0.8*	*71.1 ± 1.7*	
Ingebrigtsen et al.[43]	Norway	1D & 2D/29	20.8 ± 3.7	166.0 ± 5.0	60.7 ± 6.6	
		GK/3		*168.7 ± 7.5*	*59.5 ± 7.2*	
		D/10		*168.6 ± 5.3*	*62.5 ± 7.3*	
		M/8		*165.3 ± 4.0*	*61.3 ± 7.3*	
		F/8		*163.6 ± 4.2*	*58.4 ± 5.2*	
Jensen and Larsson[102]	Denmark	WNT/10	23.0	169.0	63.2	Pre: 22.3 Post: 20.1

Table 1 (*continued*)

Study	Country	Level/n *Position/n*	Age (year)	BH (cm)	BM (kg)	BF (%)
Krustrup et al.[46]	Denmark	1D/14	24.0	167.0	58.5	14.6
		D/5	*24 ± 4*	*168 ± 0.07*	*60.7 ± 6.3*	*15.4 ± 3.7*
		M/5	*23 ± 5*	*165 ± 0.04*	*56.0 ± 5.9*	*12.5 ± 2.2*
		F/4	*25 ± 4*	*166 ± 0.04*	*58.7 ± 3.8*	*16.1 ± 2.4*
Krustrup et al.[98]	Denmark	1D/23	23.0	169.0	60.1	18.5
Manson et al.[103]	New Zealand	WNT/15	23.3 ± 4.9	168.0 ± 7.8	64.1 ± 5.4	
		U-20 WNT/18	17.8 ± 0.7	167.0 ± 7.2	62.2 ± 7.2	
		U-17 WNT/18	15.6 ± 1.0	164.0 ± 5.2	58.0 ± 5.5	
Martinez and Coyle[37]	USA	Uni NCAA 1D/10	19.2 ± 0.9	166.0 ± 0.5	63.9 ± 6.8	
Martínez-Lagunas et al.[58]	Germany	2D/11	22.0 ± 4.0	166.2 ± 8.8	63.0 ± 8.1	
		4D/13	22.3 ± 2.7	165.3 ± 5.7	63.0 ± 6.0	
Martínez-Lagunas et al.[59]	Germany	2D/7	23.3 ± 3.6	164.7 ± 7.5	58.1 ± 4.5	
Martínez-Lagunas et al.[60]	Germany	2D&4D/10	21.3 ± 2.9	163.0 ± 7.2	60.0 ± 4.6	
Martínez-Lagunas and Hartmann[65]	Germany	2D/18	21.5 ± 3.4	165.6 ± 7.5	63.3 ± 7.4	
McCurdy et al.[104]	USA	Uni NCAA 1D/15	20.0 ± 1.0	165.0 ± 2.0	61.7 ± 7.7	
Milanovic et al.[40]	Serbia	WNT/22	23.9 ± 4.5	168.8 ± 7.2	61.4 ± 6.0	25.9
Miles et al.[92]	England	Novice players/10	20.6 ± 0.9		63.2 ± 5.8	
Portela Sarazola[47]	Germany	U-17 State team/18	15.2 ± 1.1	165.4 ± 7.0	57.7 ± 8.1	
Rhodes and Mosher[16]	Canada	Uni team/12	20.3	164.8	59.5	19.7 ± 4.0
Sjökvist et al.[105]	USA	Uni NCAA 1D/14	20.0 ± 2.0	168.0 ± 4.0	61.9 ± 6.5	20.9 ± 3.4[b]
Sporiš et al.[39]	Croatia	1D/24	18.1 ± 0.9	165.6 ± 5.8	58.6 ± 9.0	13.6 ± 4.2
		GK/3	*19.1*	*172.5*	*64.4*	*13.7*
		D/5	*18.5*	*165.8*	*56.3*	*16.8*
		M/12	*18.3*	*164.0*	*56.0*	*12.6*
		F/5	*17.4*	*165.0*	*63.6*	*14.3*
Tamer et al.[21]	Turkey	1D/22				18.3 ± 1.7[b]
Todd et al.[23]	England	All/120	22.6 ± 5.9	163.4 ± 5.9	61.8 ± 6.7	24.4 ± 3.9[b]
		INT/25	22.3 ± 4.3	162.8 ± 5.9	61.2 ± 5.2	22.9 ± 3.4[b]
		PL/44	23.4 ± 5.9	163.3 ± 5.5	62.1 ± 6.4	23.9 ± 4.2[b]
		RL/51	21.3 ± 6.6	163.9 ± 6.3	61.6 ± 7.1	25.5 ± 3.5[b]
		GK/9		*168.5 ± 4.3*	*68.9 ± 5.5*	*23.5 ± 1.7*[b]
		D/45		*165.2 ± 5.6*	*62.7 ± 6.6*	*22.3 ± 2.3*[b]
		M/44		*161.6 ± 5.0*	*59.5 ± 5.0*	*22.5 ± 2.0*[b]
		F/22		*162.5 ± 6.8*	*60.9 ± 7.3*	*23.0 ± 0.6*[b]
Tumilty and Darby[17]	Australia	WNT/20	23.1 ± 3.4	164.5 ± 6.1	58.5 ± 5.7	
Vescovi et al.[35]	USA	Uni NCAA 1D/64	19.8 ± 1.2	168.4 ± 5.9	64.8 ± 5.9	
		GK/8				
		D/21	*19.6 ± 1.1*	*170.3 ± 5.7*	*66.4 ± 1.9*	
		M/18	*19.9 ± 1.1*	*169.9 ± 4.3*	*67.0 ± 6.7*	
		F/17	*20.0 ± 1.3*	*165.9 ± 6.3*	*61.3 ± 4.7*	
			19.5 ± 1.1	*168.3 ± 6.6*	*64.5 ± 5.8*	
Vescovi et al.[36]	USA	Youth players/78	12.6 ± 0.5			
		HS players/223				
		Uni NCAA 1D/113	15.3 ± 1.0			
			19.4 ± 1.1			
Vescovi[62]	USA	Professional league tryout/140	23.9 ± 2.8	167.6 ± 6.1	62.5 ± 6.7	
Vescovi and McGuigan[34]	USA	HS players/83	15.1 ± 1.6	163.00 ± 0.07	54.6 ± 7.9	
		Uni NCAA 1D/51	19.9 ± 0.9	168.00 ± 0.06	64.8 ± 5.9	
Wells and Reilly[24]	England	Uni players/49	19.0 ± 3.4	164.00 ± 0.09	60.7 ± 5.0	
		CD/11		*167.00 ± 0.01*	*62.6 ± 2.0*	*22.8 ± 1.4*[a]
		ED/10		*162.00 ± 0.03*	*59.9 ± 2.5*	*24.2 ± 1.4*[a]
		M/17		*164.00 ± 0.04*	*59.0 ± 2.8*	*23.1 ± 1.4*[a]
		F/11		*165.00 ± 0.02*	*61.7 ± 2.7*	*24.9 ± 1.1*[a]
Withers et al.[106]	Australia	Representative team/11	22.1 ± 4.1	164.9 ± 5.6	61.2 ± 8.6	22.0 ± 6.8[b]

Note: Data are expressed as mean ± SD, unless otherwise indicated.

Abbreviations: 1D = first division; 2D = second division; 3D = third division; 4D = fourth division; BH = body height; BM = body mass; BF = body fat; INT = international; PL = Premier League; RL = Regional League; Uni = university; HS = high school; NCAA = National Collegiate Athletic Association; U = under; WNT = Women's National Team; JNT = Junior National Team; GK = goalkeeper(s); CD = central defender(s); ED = external defender(s); F = forward(s); M = midfielder(s); D = defender(s).

[a] Measured by bioelectrical impedance (BIA).

[b] Measured by skinfold thickness.

[c] Measured by hydrostatic weighting.

Table 2
Summary of studies reporting on physiological and physical attributes of female football players.

Study	Country	Level/*n* *Position/n*	VO_{2max} (mL/kg/min)	YYIR1 (m)	HR_{max} (bpm)	30-m sprint (s)	CMJ[c]/VJ[d] (cm)
Andersson et al.[52]	Sweden/Norway	1D/17					
		Active group/8	55.4 ± 3.6		198 ± 6		30.5 ± 1.2[c]
		Passive group/9	53.8 ± 2.3		199 ± 6		29.8 ± 1.2[c]
Arecheta et al.[107]	Spain	1D/10	45.1 ± 6.3[a]		189 ± 14		
Bunc and Psotta[28]	Czech Republic	PL/14	53.9 ± 5.7[a]		193 ± 8		
Can et al.[29]	Turkey	1D/17					35.4 ± 7.1[d]
Colquhoun and Chad[19]	Australia	INT & State level/10	47.9 ± 8.0[a]		202 ± 17		
David[48]	Canada	WNT/22					
		GK/2	*48.7*[b]				
		D/6	*52.7*[b]				
		M/9	*52.6*[b]				
		F/5	*48.9*[b]				
Davis and Brewer[15]	England	WNT/14					
		Pre-training	48.4 ± 4.7[b]				
		Post-training (after 12 months)	52.2 ± 5.1[b]				
Dillern et al.[44]	Norway	3D/32					
		GK/3	*48.7 ± 4.6*[a]				
		D/11	*52.1 ± 3.6*[a]				
		M/8	*53.8 ± 5.5*[a]				
		F/10	*53.0 ± 5.0*[a]				
Evangelista et al.[18]	Italy	1D/12	49.8 ± 8.3[a]				
Gabbett and Mulvey[55]	Australia	1D/13	51.4 ± 5.4				
Gómez López et al.[33]	Spain	U-17 club team/11				4.89–4.96	29.9–30.3
Green et al.[101]	USA	Uni level/39	44.2 ± 3.3[a]				
Haugen et al.[81]	Norway	WNT/85				4.35[e]	30.7 ± 4.1
		1D/47				4.43[e]	28.1 ± 4.1
		2D/29				4.58[e]	–
		Junior elite/33				4.44[e]	28.5 ± 4.1
		GK/17				*4.48*[e]	*30.0 ± 4.8*
		D/63				*4.40*[e]	*29.6 ± 4.0*
		M/62				*4.44*[e]	*28.4 ± 3.9*
		F/52				*4.34*[e]	*30.5 ± 4.5*
Hewitt et al.[57]	Australia	WNT/15	54.8 ± 3.5[b]				
Ingebrigtsen et al.[43]	Norway	1D & 2D/29					
		GK/3	*50.7 ± 5.0*[a]				
		D/10	*51.9 ± 5.1*[a]				
		M/8	*55.4 ± 5.7*[a]				
		F/8	*52.9 ± 3.2*[a]				
Krustrup et al.[46]	Denmark	1D/14	49.4[a]	1379			
Krustrup et al.[98]	Denmark	1D/23	52.3 ± 1.3[a]			4.86 ± 0.06	35.0 ± 1.0[c]
Martinez and Coyle[37]	USA	Uni team/10	47.8 ± 3.5[a]	1120 ± 297			
			51.0 ± 4.9[b]				
Martínez-Lagunas and Hartmann[65]	Germany	2D/18	55.0 ± 5.3[a]				
			45.2 ± 3.4[b]				
Martínez-Lagunas et al.[58]	Germany	All/24	53.6 ± 5.3[a]	985 ± 372			
		2D/11	54.6 ± 5.1[a]	1102 ± 316			
		4D/13	52.7 ± 5.4[a]	886 ± 399			
Milanovic et al.[40]	Serbia	WNT/22					
		GK/2		*780 ± 85*			
		Outfield/20		*880 –930*			
Miles et al.[92]	England	Novice players/10	42.4 ± 4.3[a]		200 ± 11		
Mujika et al.[42]	Spain	Senior/17		1224 ± 255			
		Junior/17		826 ± 160			
Portela and Sarazola[47]	Germany	U-17 State team/16		941 ± 259	194 ± 10	4.64 ± 0.19	35.2 ± 3.5[c]
		D/6		*816 ± 196*		*4.67 ± 0.20*	*34.2 ± 2.1*[c]
		M/5		*1160 ± 181*		*4.74 ± 0.11*	*32.9 ± 3.4*[c]
		F/4		*900 ± 322*		*4.48 ± 0.20*	*38.8 ± 2.9*[c]
Sjökvist et al.[108]	USA	Uni NCAA 1D/14	53.9 ± 5.7	1097 ± 100	195 ± 4		48.8 ± 7.9[c]

Table 2 (*continued*)

Study	Country	Level/*n* *Position/n*	VO_{2max} (mL/kg/min)	YYIR1 (m)	HR_{max} (bpm)	30-m sprint (s)	CMJ[c]/VJ[d] (cm)
Todd et al.[23]	England	INT/25	46.8 ± 5.1[b]			4.62 ± 0.25	47.8 ± 6.4[d]
		PL/44	45.0 ± 6.0[b]			4.64 ± 0.25	49.0 ± 6.4[d]
		RL/51	43.9 ± 5.0[b]			4.70 ± 0.25	46.5 ± 4.8[d]
		Total/120	44.8 ± 5.8[b]			–	47.6 ± 5.8[d]
		GK/9	*40.5 ± 6.1*[b]			*4.84 ± 0.36*	*49.8 ± 7.0*[d]
		D/45	*45.3 ± 5.2*[b]			*4.64 ± 0.23*	*47.6 ± 4.7*[d]
		M/44	*45.0 ± 5.5*[b]			*4.69 ± 0.21*	*46.6 ± 6.1*[d]
		F/22	*46.2 ± 5.6*[b]			*4.58 ± 0.20*	*49.2 ± 6.9*[d]
Vescovi et al.[35]	USA	Uni NCAA 1D/64	48.7 ± 5.2[b]				41.9 ± 5.6[c]
		GK/8	*47.1 ± 5.6*[b]				*40.9 ± 4.4*[c]
		D/21	*47.6 ± 5.3*[b]				*40.8 ± 6.1*[c]
		M/18	*50.5 ± 4.6*[b]				*42.7 ± 5.7*[c]
		F/17	*49.4 ± 5.4*[b]				*42.7 ± 5.5*[c]
Vescovi et al.[36]	USA	Youth players/78					37.4 ± 4.8[c]
		HS players/223					38.7 ± 5.0[c]
		Uni NCAA 1D/113					42.0 ± 5.0[c]
Vescovi and McGuigan[34]	USA	HS players/83					39.6 ± 4.7[c]
		Uni NCAA 1D/51					40.9 ± 5.5[c]
Wells and Reilly[24]	England	Uni players/49					
		CD/11	*43.7 ± 3.0*[b]			*4.81 ± 0.18*	*35.4 ± 2.7*[d]
		ED/10	*45.7 ± 2.3*[b]			*4.86 ± 0.19*	*34.6 ± 3.6*[d]
		M/17	*48.0 ± 1.8*[b]			*4.84 ± 0.17*	*35.0 ± 3.5*[d]
		F/11	*46.3 ± 1.7*[b]			*4.80 ± 0.25*	*35.2 ± 3.6*[d]

Note: Data are expressed as mean ± SD, unless otherwise indicated.

Abbreviations: 1D = first division; 2D = second division; 3D = third division; 4D = fourth division; WNT = Women's National Team; INT = international; PL = Premier League; RL = Regional League; Uni. = university; HS = high school; NCAA = National Collegiate Athletic Association; U = under; GK = goalkeeper(s); CD = central defender(s); ED = external defender(s); F = forward(s); M = midfielder(s); D = defender(s); VO_{2max} = maximal oxygen uptake; HR_{max} = maximum heart rate; YYIR1 = Yo-Yo intermittent recovery test level; CMJ = counter-movement jump; VJ = vertical jump.

[a] Measured in a laboratory setting.

[b] Estimated from a field test or formula.

[c] Measured as counter-movement jump.

[d] Measured as vertical jump.

[e] Sum of three 10 m segments is provided.

studies with larger sample sizes should investigate to what extent players' anthropometrical characteristics influence role selection in women's football.

2.2. *Physiological and physical attributes*

High-levels of physical fitness provide players with the physiological basis to cope with the physical demands of the game and allow them to use their technical and tactical abilities effectively, especially towards the end of a match when fatigue starts to arise.[82] The assessment of players' physical capacities (e.g., aerobic and anaerobic capacity, speed, strength, and power) may give an indication of the physical demands of a particular level of play because players have to adapt to the requirements of the game in order to be successful at that level of competition.[4,7] Moreover, it is believed that the physical demands of the game become more pronounced as the level of competition increases.[4] Thus, football players independent of their gender need to achieve a reasonable balance in developing these physiological and physical capacities that is appropriate to the level they compete at and their positional role.[9]

Scientific investigations on the physiological and physical attributes of female footballers have considerably increased in recent years due to the increased popularity of women's football worldwide. However, most of the published studies have been focused on adult elite female players of different nationalities, who were competing internationally with their respective national team or at the highest women's football division in their country. Therefore, information about the physiological and physical profiles of adult and youth female players competing at lower levels of the game is still missing. Furthermore, only a few studies have investigated positional differences specific to the physical condition of female football players.[23,24,35,39,40,43,44,47,63] The classification of the playing positions used in these studies has been limited to three (defenders, midfielders, and forwards) or four categories (adding the goalkeepers or the full-backs). However, the physical demands placed in the external and central positions during men's and women's match-play are considerably different.[83,84] Hence, a more detailed classification of playing position including at least six categories (GK, CD, ED, CM, EM, and F) may reveal significant differences in the fitness profiles of female football players that may be missed when only a general classification of playing positions is used. This information will allow coaches to develop individualized and position-specific physical training programs for their players, which have been proven to be more effective in improving players' physical capacities.[85,86] Additionally, the evaluation of players' physical performance can assist coaches in several aspects, such as in the identification of individual physical strengths and weaknesses, evaluation of the effectiveness of a specific training program, setting individual and team physical fitness standards, talent identification and development.[9,87]

Recent publications have reported on commonly used measures of physiological and physical attributes of female football players of various groups (Table 2). The mean values shown in this table for maximal oxygen uptake (VO_{2max}), performance in Yo-Yo Intermittent Recovery Test Level 1 (YYIR1), maximum heart rate (HR_{max}), 30 m sprint time, and counter-movement jump or vertical jump (CMJ/VJ) vary according to the players' nationality, competitive level, and positional role. On average, these players achieved VO_{2max} values that ranged from 45.1 to 55.5 mL/kg/min, YYIR1 scores of 780−1379 m, HR_{max} values of 189−202 bpm, 30 m sprint times of 4.34−4.96 s, and CMJ/VJ results of 28−50 cm (Table 2). The type of measurement methods used may also account for the discrepancies among the reported values.

2.3. Special considerations

Due to the worldwide increased popularity and participation numbers in women's football, many coaches that previously only coached male players are now coaching female players as well. When coaching female players these coaches try to use the same physical training loads they used with the men without considering the specific characteristics of female players commonly due to lack of knowledge in this area. Therefore, experienced and novice coaches who are now working in women's football need to be aware of the main physical and physiological differences that exist between the genders.

These differences start becoming more significant at the onset of puberty (~12−14 years of age) depending on individual and sex-specific maturation rates.[88] Before this time period the physical differences between men and women are small and females may have a slight advantage for a short period of time because they usually experience their growth spurt and sexual maturation on average 2 years earlier than males.[88] Once males enter into puberty and their testosterone levels start to increase, the gender physical differences lean to their favor. Thus, it is well known that in general females are lighter, shorter, have a lower muscle mass, and more essential sex-specific fat mass than their male counterparts due to inherent biological factors that result in lower absolute physical capacities (e.g., aerobic endurance, muscular strength, power, speed, and agility) for the average woman compared to the average man.[67−69] Consequently, coaches and trainers must select appropriate training loads and intensities based on the actual physical capacities of their female players, especially if they used to work only with male athletes before, respecting the principles of training such as progressive overload, adaptation and recovery, specificity, reversibility, and variation. If these recommendations are observed, the relative improvements (percent from maximum) and training adaptations that women get after participating in a well-designed physical training program could be comparable to those of their male counterparts engaging in a similar regime.[67,69]

There are also few other considerations that are characteristics of females only that may affect their athletic performance, health or return to sport participation. These include the menstrual cycle, potential pregnancy and lactation, common injury risks, and health concerns. These special considerations will be briefly described next with special emphasis on scientific reports specific to female footballers.

In terms of the menstrual cycle, there is scientific consensus that in most cases athletic performance shows little change over the different phases of the cycle, except in the small percentage of women that experience strong pre-menstrual discomfort or painful menses.[70] Nevertheless, there are scarce scientific reports specific to female football players in this area. Some authors have shown that the injury risk in female football players may be perhaps higher in certain phases of the menstrual cycle than in others.[71] However, there is still inconsistency in the results of this type of studies, and thus, further research is warranted. The use of contraceptive pills seems to alleviate some pre-menstrual symptoms such as irritability, discomfort, or pain in the breasts and abdomen and to reduce the risk of musculoskeletal injuries, although they may also cause some unwanted side effects.[71,89] In some cases players who travel, train, and compete regularly at a high-level may also want to delay their menstruation for better comfort and convenience during these activities by using long-acting contraceptive pills. Nonetheless, the long-term consequences on players' health and fertility of such permanent practice are still unknown, and therefore, it is currently not recommended. Furthermore, menstrual irregularities (i.e., infrequent or absent menses) in female football players may be linked to excessive energy expenditure due to intensive training combined with inadequate nutritional intake, competitive and personal stress, and low body fat, which may result in increased risk of low bone density or osteoporosis, stress fractures due to suppressed estrogen levels, reduced performance, and impaired fertility.[72] Thus, the absence of menses should not be perceived as a pleasant convenience, especially if the player has already experienced several months of missed periods without being pregnant. This should represent a red flag and the affected player should seek immediate medical help to avoid irreversible damage in her bone health and fertility.

Although female athletes may become pregnant at some point during their athletic career, scientific studies on the impact of pregnancy on exercise performance, impact of exercise upon pregnancy and lactation (breastfeeding), training recommendations/guidelines during pregnancy, and recommendations to return to sport after pregnancy for high-level athletes are still scarce. Most of the published literature on these topics refers to the average or sedentary female population[70,74] but to our knowledge no scientific reports are currently available specific to female football players. Several top level female footballers have successfully returned to compete at the highest level after childbirth. Thus, it will be meaningful to identify these players and investigate further the strategies they have used to succeed in this task. The information that can be gathered in this type of study will be very useful for other female players interested in combining their football career with establishing a family and having kids.

It is also well known that female football players have a higher risk to suffer from knee (e.g., anterior cruciate ligament (ACL) tear)[75] and head injuries (e.g., concussion)[76] than their male counterparts. Consequently, coaches and players should be well informed about the potential risks factors and prevention programs or recommendations that have been recently developed to reduce the incidence of these severe injuries.[77–79] Finally, health problems such as the female athlete triad (syndrome that includes three interrelated elements: low energy availability/eating disorders, menstrual dysfunction, and low body density/osteoporosis),[72] iron deficiency, and anemia[64] may also be common among female football players. These diseases can have severe consequences on the health, well-being, and athletic performance of the affected players. Therefore, more scientific research should be performed in order to develop specific strategies/recommendations to prevent, recognize, and treat these health issues among female footballers.

3. Demands of the game

Published reports on the physical and physiological demands of women's football are more limited than the available literature on female players' characteristics and by far scarcer than the related research specific to men's football. However, due to the increased popularity of the women's game, several investigations have been conducted recently in this area. These new studies provide significant information for better understanding the demands of the women's football game.

3.1. Physical demands

Football is a sport of intermittent nature that requires multiple and constant changes of direction running intensity, accelerations, and types of movements (running forwards, backwards, lateral movements, jumps, tackles, *etc.*). The specificity of training principle in sports science states that the most effective training is the one that resembles the demands of a sport/game as close as possible. Therefore, a broad understanding of the physical demands of women's football is essential for developing sport-specific conditioning programs for female football players.

Recent technological advances (e.g., computerized video-based time-motion analysis systems, semi-automatic multi-camera systems, and Global Positioning System (GPS)) now allow the simultaneous evaluation of the physical demands placed upon several or all players participating in a football match and can be completed in a relatively short period of time.[90] The pioneer work in this area started in the late 1970's in men's football with manual video-based notational analysis such as the one used in the classical study of Reilly and Thomas.[91] This latter method was very labor intensive, time consuming and restricted the analysis to a single player at a time. Since then many investigations employing a variety of measurement methods have been conducted relative to this topic in men's football and excellent reviews[5,6,11,12] have summarized their findings. In women's football, the oldest reports date back to the early 1990's.[13,92] More recent investigations are now available and summarized in Table 3, including the pioneer reports on the topic as well.[13,92] The mean values shown in this table for total distance covered (4−13 km) and distance covered at different speeds (e.g., 0.2−1.7 km covered at high speeds) vary according to the players' nationality, competitive level, positional role, and method of measurement employed in each study. This information provides a good point of reference for players, coaches, and sport scientists regarding the overall physical demands of women's football match-play.

Overall, the studies mentioned above showed that male and female players cover similar total distances during a football match compared to their male counterparts. However, the main difference lies in the amount of distance covered at high-speeds (>15 km/h).[14,51] Male players typically cover significantly more distance at these speeds than female players mainly due to the inherent biological differences between the genders (e.g., in anthropometry and physical capacities). The amount of distance covered at high-speeds also seems to be quite sensitive to differentiate players of various competition levels both in men's and women's football. Players of higher competition levels usually cover a larger distance at these speeds than players competing at lower levels.[53,55,61] A few of these studies also revealed significant differences according to the players' positional role[53,61,93] and evidence of decreased players' physical performance either in terms of total distance covered or amount of high-intensity running in the second half compared to the first half of match-play, which may be the result of fatigue.[46,49,51,53,59,60,93]

The physical analysis of the 2011 FIFA Women's World in Germany[49] investigated all 32 matches disputed among 16 participating teams, including over 300 players and over 700 data sets. All measurements were made through a semi-automatic multi-camera system that allowed the simultaneous analysis of all players participating in each match. This report provides to date the largest international database about the physical demands of women's football matches disputed at the highest level of the game among 16 different nations from all continents. Additionally, it also includes some practical training recommendations based on the study findings. The average total duration of these World Cup matches (not including extra time) was 92−95 min, whereas the average actual playing time was only about 57.5 min (61%−63% of total match duration). Field players covered on average a total distance of 10.2 km, with 0.5% of maximum sprints (>25 km/h), 2.3% of optimum sprints (21.1−25 km/h), 3.9% of high-speed runs (18.1−21 km/h), 22.8% of moderate runs (12.1−18 km/h), and 70.5% of low-speed runs (<12 km/h). In contrast, goalkeepers covered a total average distance of 6 km, with 0.6%−0.7% of maximum and optimum sprints, <1% of high-speed runs, 5%−6% of moderate runs, and 91%−92% of low-speed runs. This report

Table 3
Summary of studies reporting on physical demands of women's football.

Study	Country	Method/*n* matches	Level/*n* *Position/n*	Total distance (km)	Distance by category or speed zone (km (% total distance))
Andersson et al.[51]	Sweden	Video/10	ID/21	9.9	Movement category:
					HIR: 1.15
Andersson et al.[52]	Sweden/Norway	Video/2	ID/17		Movement category:
			Match 1		HIR: 1.09 ± 0.2
			Match 2		HIR: 1.11 ± 0.1
Andersson et al.[53]	Sweden/Denmark	Video/54	ID/17		Movement category:
			INT match	9.9 ± 1.8	HIR: 1.53 ± 0.1
			DOM match	9.7 ± 1.4	HIR: 1.33 ± 0.9
			D/9	*9.5*[a]	
			M/5	*10.3*[a]	
			F/3	*9.7*[a]	
Barbero-Álvarez et al.[54]	Spain	GPS (1 Hz)/1 (7 v 7 match)	Youth players/12	3.98 ± 0.32	Speed zones (km/h):
					0–0.4: 0.02 (0.5)
					0.5–3: 0.66 (17)
					3.1–8: 2.19 (55)
					8.1–13: 0.84 (21)
					13.1–18: 0.23 (6)
					>18.1: 0.02 (0.5)
Cook[93]	England	GPS (5 Hz)/8	ID/8	9.37 ± 0.92	Speed zones (km/h):
			CD	*8.65 ± 0.35*	*>16: 0.55 (6)*
			ED	*10.22 ± 0.56*	*>16: 0.94 (9)*
			CM	*10.05 ± 0.62*	*>16: 0.87 (9)*
			F	*8.58 ± 0.50*	*>16: 0.87 (10)*
FIFA[49]	16 different nations	Multi-camera system/32	WNT/336	10.22	Speed zones (km/h):
					Goalkeepers
			GK	*6.04*	<12: 5.59 (92.4)
					12.1–18: 0.41 (6.7)
					18.1–25: 0.05 (<0.1)
					>25: 0.002 (<0.1)
					Field players
			CD	*10.16*	<12: 7.20 (70.5)
			ED	*10.85*	12.1–18: 2.33 (22.8)
			CM	*11.35*	18.1–21: 0.40 (3.9)
			EM	*11.28*	21.1–25: 0.24 (2.3)
			F	*10.46*	>25: 0.06 (0.5)
Gabbett and Mulvey[55]	Australia	Video/12	WNT/13		Movement category:
					Sprinting: 0.82 ± 0.33 (8.5)
					Sprinting: 0.98 ± 0.32 (9.2)
					Sprinting: 1.18 ± 0.15 (12.3)
			D	*9.62 ± 1.20*	
			M	*10.67 ± 1.34*	
			F	*9.60 ± 0.36*	
Hewitt et al.[57]	Australia	GPS/4	WNT/15	9.14 ± 1.03	Speed zones (km/h):
					0–5: 2.40 ± 0.12 (26)
					5–8: 2.10 ± 0.11 (21)
					8–12: 2.33 ± 0.19 (26)
					12–16: 1.41 ± 0.16 (15)
					16–20: 0.62 ± 0.11 (7)
					>20: 0.28 ± 0.08 (3)
			D/6	*9.01*	
			M/5	*9.64*	
			F/4	*8.51*	
Krustrup et al.[46]	Denmark	Video/4	ID/14	10.30	Movement category:
					LIR: 9.00
					HIR: 1.31

Table 3 (*continued*)

Study	Country	Method/*n* matches	Level/*n* *Position/n*	Total distance (km)	Distance by category or speed zone (km (% total distance))
Martínez-Lagunas et al.[59]	Germany	GPS (1 Hz)/5	2D/7	9.65 ± 0.86	Speed zones (km/h): <12: 7.23 ± 1.24 (75) 12–16: 1.56 ± 0.35 (16) 16–20: 0.64 ± 0.16 (7) >20: 0.22 ± 0.07 (2)
			D/3	*9.42*	
			M/3	*10.30*	
			F/1	*8.38*	
Martínez-Lagunas et al.[60]	Germany	GPS (5 Hz)/1	2D&4D/10	7.23 ± 1.47	Speed zone (km/h): >16: 0.63 ± 0.36 (9)
Mohr et al.[61]	USA	Video/37	Pro players/34		Movement category:
			Top-class	10.33 ± 0.15	HIR: 1.68 ± 0.09
			High-level	10.44 ± 0.15	HIR: 1.33 ± 0.10
Portela Sarazola[47]	Germany	GPS (5 Hz)/3	U-17 State team/16	5.74–6.77	Speed zone (km/h): >16: 0.20–0.29
Scott and Drust[99]	England	Video	WNT/30	11.98 ± 1.33	Movement category: Walking: (26) Jogging: (45) Cruising: (13) Sprinting: (3) Other: (13)
			ED	*12.64 ± 0.42*	
			CD	*11.01 ± 1.40*	
			M	*12.97 ± 0.54*	
			F	*11.80 ± 1.28*	

Note: Data are expressed as mean ± SD, unless otherwise indicated.
Abbreviations: 1D = first division; 2D = second division; 4D = fourth division; WNT = Women's National Team; GK = goalkeeper(s); CD = central defender(s); ED = external defender(s); CM = central midfielder(s); EM = external midfielder(s); F = forward(s); M = midfielder(s); D = defender(s); GPS = Global Positioning System; INT = international; DOM = domestic; LIR = low-intensity running; HIR = high-intensity running; U = under.
[a] Average of values reported for international and domestic matches.

also revealed positional differences among the field players (*i.e.*, tendency of the central and external midfielders to cover larger total distances, the external midfielders the largest distance in high-speed runs, and the forwards the larger distance in maximal and optimal sprints compared to the other field players). Overall, there was an average 2.7% decrease in total distance covered by the field players in the 2nd half compared to the 1st half of match-play. The teams making it to the semi-finals (USA, Japan, Sweden, and France) also showed some of the best physical performances during the tournament. However, there were also other very fit teams that were knocked-out early from the tournament, which highlights the fact that a high physical capacity is not the only requirement to succeed in women's football. Other factors such as the technical, tactical, mental/psychological characteristics of the participating players/teams also play a crucial role. Nonetheless, a high-level of fitness does provide a competitive advantage by helping players to maintain high-intensity exercise longer and being more resistant to fatigue, especially towards the end of a game.[46,51]

Future studies should provide a more detailed analysis of accelerations, changes of direction, and other types of movements required during a women's football match because this information is still scarce. So far the main focus of the current published reports has been in total distance and distance covered at various running speeds. Further investigations of the physical game demands place upon other players' age groups and competition levels should be conducted in the future (e.g., comparison of U17, U20 and senior international *vs.* national competitions). A longitudinal study comparing the physical demands of women's football match-play at international and national competitions over several years may also provide meaningful information about the evolution of the women's game over time. Detailed classifications of playing positions (including detailed analysis of the goalkeeper position), fatigue development analysis during and after match-play and simultaneous analysis of physical, technical, and tactical game demands should also be considered in future research in this area.

3.2. *Physiological demands*

Investigations on the physiological demands of women's football match-play involving simultaneous measurements of heart rate (HR), oxygen consumption (VO_2), and blood lactate (La) are still scarce (Table 4) mainly due to the difficulty, high cost, and laborious procedures required to conduct this type of studies. Even in the case of men's football, they are also limited. To our knowledge, there is to date only one published study that has included simultaneous HR, VO_2, La, and GPS measurements during a women's football match.[60] This investigation consisted of a full 90 min competitive friendly match (11 *vs.* 11), in which continuous HR and VO_2 (via

Table 4
Summary of studies reporting on physiological demands of women's football.

Study	Country	Level/n *Position/n*	Average & peak HR (bpm (% HR_{max}))	Average & peak VO_2 (mL/kg/min (% VO_{2max}))	La (mmol/L)
Andersson et al.[52]	Sweden/Norway	1D/17	Match 1		
		Active group/8	163 ± 3 (82)		
		Passive group/9	161 ± 2 (81)		
			Match 2		
			171 ± 3 (86)		
			168 ± 2 (84)		
Andersson et al.[53]	Sweden/Denmark	1D/17			
		INT match	162 ± 6 (85) & 187 ± 2 (97)		
		DOM match	163 ± 5 (85) & 185 ± 2 (97)		
Gómez López and Barriopedro Moro[32]	Spain	Senior club team/7 U-17 club team/15	172 & 196		4.6–7.3
Krustrup et al.[46]	Denmark	1D/14	167 (87) & 193 (97)	37.6 (77)[b] & 47.4 (96)[b]	
Krustrup et al.[98]	Denmark	1D/23	168 ± 1 (86) & 194 ± (98)		2.7–5.1
Martínez-Lagunas et al.[59]	Germany	2D/7	169 ± 4 (87) & 192 ± 7 (99)		
Martínez-Lagunas et al.[60]	Germany	2D&4D/10	152 ± 10 (79) & 182 ± 8 (94)	28.3 ± 4.0 (52)[a] & 53.0 ± 3.8 (98)[a]	2.2 ± 0.8
Miles et al.[92]	England	Novice players/10			
		4 v 4 game – GK	*147 ± 17 (74)*	*(49.7)*[a]	*2.3 ± 0.7*
		4 v 4 game – Outfield	*171 ± 17 (86)*	*(73.6)*[a]	*4.0 ± 1.2*
Portela Sarazola[47]	Germany	U-17 State team/16	163 (84)		
Weber et al.[22]	Germany	1D			3.7
		3D			5.1

Note: Data are expressed as mean ± SD, unless otherwise indicated.
Abbreviations: 1D = first division; 2D = second division; 3D = third division; 4D = fourth division; GPS = Global Positioning System; VO_2 = oxygen consumption; VO_{2max} = maximal oxygen uptake; HR = heart rate; HR_{max} = maximum heart rate; La = blood lactate; INT = international; DOM = domestic; U = under.
[a] Measured by portable spirometry
[b] Estimated from HR-VO_2 relationship.

portable spirometry) and La assessment (every 15 min) was conducted simultaneously on 10 outfield players during the duration of the match (Fig. 1). Similar to other authors,[46,59,94] Martínez-Lagunas et al.[60] found a significant reduction in the players' physical and physiological performance in the 2nd compared to the 1st half and a large individual variability of the results (mostly due to the players' positional role). However, the results of this latter study (Table 4) are lower than published data on VO_2 average values reported for male footballers collected via portable spirometry (57%–77% VO_{2max})[94,95] or by using Douglas bags (47%–60% VO_{2max})[96] during friendly games; average La values (2.4–10.0 mmol/L)[6,97] reported for male players during match-play; average HR (81%–87% HR_{max}),[46,53,59] La (2.7–5.1 mmol/L),[22,98] and GPS (e.g., 9.1–9.6 km of total distance covered)[57,59] or computerized video-based (10.2–12.0 km of total distance covered)[46,49,53,55,61,99] physical data of female football players during competitive matches. The HR and VO_2 results from Martínez-Lagunas et al.[60] are also lower than the average reported values based on indirect estimation via the HR-VO_2 relationship (approximately 80%–90% of HR_{max} corresponding to ~70%–77% VO_{2max}), which may tend to overestimate actual VO_2.[46,53,97,100] Possible reasons for the discrepancy of results may include gender, players' characteristics and competitive level, game conditions, methodological differences, and movement impairment due to the measuring equipment. Further studies using a larger sample size (players and games) should be conducted in order to verify these results. Moreover, competitive level and positional role differences should also be evaluated in more detail in the future.

4. Conclusions, future directions, and practical recommendations

The present literature review aimed 1) to provide an overview of a series of studies that have been published so far on the specific characteristics of female footballers and the demands of match-play; 2) to identify areas/topics that require further scientific research in women's football; and 3) to derive a few practical recommendations from the information gathered in this review. Published studies on the specific characteristics of female football players have reported the following mean values for age (12–27 years), body height (155–174 cm), body mass (48–72 kg), percent body fat (13%–29%), VO_{2max} (45.1–55.5 mL/kg/min), YYIR1 (780–1379 m), HR_{max} (189–202 bpm), 30 m sprint times (4.34–4.96 s), and counter-movement jump or vertical jump (28–50 cm) that vary mainly according to the players' competitive level and positional role. There are also some special considerations that coaches and other practitioners should be aware of when working with female athletes such as the menstrual cycle, potential pregnancy and lactation, common injury risks (particularly knee and head injuries) and health concerns (e.g., female athlete triad, iron deficiency, and anemia) that may affect players' football performance, health

Fig. 1. Portable spirometry measurements during a women's football match.

or return to play. In terms of the demands of the game, reported mean values for total distance covered (4−13 km), distance covered at high-speed (0.2−1.7 km), average/peak HR (74%−87%/94%−99% HR_{max}), average/peak VO_2 (52%−77%/96%−98% VO_{2max}), and La (2.2−7.3 mmol/L) during women's football match-play also vary according to the players' competitive level and positional role. Methodological differences may account for the discrepancy of the reported values as well.

Due to the increased popularity and participation numbers of women's football worldwide, there is a high demand of scientific research specific to female players of various age groups, nationalities, competitive levels, and positional roles (including detailed analysis of the goalkeeping demands and more specific field player classifications). To date, most investigations in the areas of player characteristics and demands of the game are of a descriptive nature. Therefore, there is a need for more experimental studies that evaluate the effectiveness of certain training and recovery interventions (e.g., 1 *vs.* 2 competitive matches per week) on players' characteristics (e.g., anthropometry, physiological, and physical capacities) and on their football performance during match-play. The latter is not only in terms of physical/physiological aspects but also regarding technical, tactical, and mental/psychological elements because football performance is influenced by all these factors, and thus, all should be taken into account. There is also considerable scope for further research specific to female players in topics such as the effects of the menstrual cycle and contraceptive pills use, potential pregnancy and lactation, common injury risks (particularly knee and head injuries), and health concerns (e.g., female athlete triad, iron deficiency, and anemia) on football performance and return to play. Finally, more studies are needed to quantify the physiological demands placed upon female footballers during match-play and training sessions in terms of on-field VO_2, HR, and La concentrations.

Practical recommendations that can be derived from the present review include:

- The physical capacities of players should be tested regularly through objective and standardized performance assessment in order to identify their strengths and weaknesses. This can also be useful for evaluating the effectiveness of a specific training program, setting individual and team fitness standards, and talent identification/development.
- Based on this information physical training should be individualized according to the players' current fitness levels, positional role, and level of competition. This will help players to cope more efficiently with the demands of the game.
- Coaches and practitioners working with female players should be aware of their specific characteristics and understand gender differences especially if they used to work only with male athletes before. An open approach and knowledge on menstruation and pregnancy including their potential impact on football performance is needed.
- The long-term consequences of using long-acting contraceptive pills to manipulate the players' menstrual cycle according to their competition and training schedules are still unknown, and therefore, this practice is currently not recommended.
- Due to the higher risk of female players to suffer from knee and head injuries compared to their male counterparts, coaches should implement an injury prevention program for their female players on a regular basis (e.g., FIFA 11+ injury prevention program).
- Health problems such as the female athlete triad (low energy availability/eating disorders, menstrual dysfunction, and low body density/osteoporosis), iron deficiency, and anemia may affect some female footballers. Thus, coaches should be knowledgeable about their common symptoms and consequences in order to identify the affected players early and refer them as soon as possible to a physician.
- Coaches and practitioners working with female players should be educated on the topics mentioned above through women's football specific courses.

- The information presented in this report provides an objective point of reference about player characteristics and game demands at various levels of women's football, which can help coaches and sport scientists to design more effective training programs and science-based strategies for the further improvement of players' football performance, health, game standards, and positive image of this sport.

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PUBLICATION 4 (P-IV)[33]

10 GPS performance analysis of women's soccer competitive matches of the second and fourth German leagues

V. Martínez-Lagunas, M. Niessen and U. Hartmann

Institute of Movement and Training Science, University of Leipzig, Leipzig, Germany

Introduction

Recent applications of Global Positioning System (GPS) in sport have facilitated the simultaneous evaluation of physical performance of multiple athletes during competition and/or training. The use of GPS technology for this purpose is less labor intensive and less time consuming than the pioneer method of video-based notational analysis that was used several years ago. While this pioneer method was highly accurate, it restricted the analysis to a single athlete at a time (Carling et al., 2008). Moreover, GPS technology is more affordable and practical than the semi-automatic multi-camera systems that have also been developed in the last few years. Recently, several validation studies have been conducted on the application of GPS technology for field sports including Australian football, cricket, field hockey, rugby union and league, and soccer (Aughey, 2011; Hohmann et al., 2013; Petersen et al., 2009; Randers et al., 2010; Vickery et al., 2014). Overall, it has been shown that GPS technology has acceptable validity and reliability for estimating longer distances covered at low intensities, but requires further refinement to assess short, multi-directional high-velocity movements that are common in team sports (Aughey, 2011; Hohmann et al., 2013; Petersen et al., 2009; Vickery et al., 2014). Furthermore, a soccer-specific study demonstrated that GPS devices are suitable to describe activity profiles and fatigue development during match-play when compared to other types of match analysis systems, although caution is advised when comparing absolute distance values among them due to the existence of large between-systems differences including GPS units of different sampling frequencies (Randers et al., 2010).

Although the popularity of women's soccer has considerably increased in the last few years, scientific research on the physical demands of the women's game at different competitive levels is still limited. So far most studies have been focused on the highest competitive levels, such as the national team (Andersson et al., 2010; Gabbett & Mulvey, 2008; Hewitt et al., 2009; Hewitt et al., 2014; Mohr et al., 2008; Scott & Drust, 2007), and first division level (Andersson et al., 2010; Bradley et al., 2014; Cook, 2012; Krustrup et al., 2005; Mohr et al., 2008; Vescovi & Favero, 2014). However, there is scarce information about lower levels of the women's game (Martínez-Lagunas et al., 2010). In most countries, their various women's soccer leagues are organized within a promotion and relegation system, in which lower divisions usually serve as a preparation platform before the most talented players reach the highest level of the game. Consequently, it is crucial to investigate the physical demands of women's soccer at various competitive levels in order to develop more specific and effective conditioning programs for female soccer players based on their level of play and positional role. Therefore, the aim of the present study was to compare the physical demands of women's soccer competitive matches of the second and fourth German leagues using GPS technology.

Methods

Subjects

Twenty-two outfield female soccer players from a local club who were competing in the second (2L) and fourth (4L) German national leagues took part in this study. Eight players competed only in the 2L, eight players only in the 4L, and the remaining six players participated in both leagues as they played up or down based on coaching decisions. The data of the six players who played games in both leagues were included for analysis in each league. Therefore, the total number of players considered for each league was 14 (8+6). The overall players' age, body height, body mas, and maximal heart rate (mean±SD) independent of competitive league were 23.0±3.9 (range: 17–36) yrs, 163.1±6.6 (152.1–176.5) cm, 60.2±5.4 (50.0–73.4) kg, and 190±8 (167–204) bpm, respectively. Further players' characteristics according to their competitive league appear in Table 10.1. Players' maximal heart rate (HR_{max}) was determined prior to the start of study begin as the peak value reached in a 5-s period, during the last part of a common soccer-specific field test (Yo-Yo Intermittent Recovery Test Level 1) that has been shown to be a practical and valid tool for this purpose (Bangsbo et al., 2008; Krustrup et al., 2003; Martínez-Lagunas & Hartmann, 2014).

Table 10.1 Further player characteristics according to their competitive league

League	*Age (yrs)*	*Body height (cm)*	*Body mass (kg)*	*HR_{max} (bpm)*
2L	22.5±3.0 (17–29)	164.0±7.7 (152.1–176.5)	60.8±6.4 (50.0–73.4)	192±7 (180–204)
4L	23.4±4.2 (18–36)	162.9±6.4 (153.8–174.5)	60.6±6.5 (50.0–73.4)	189±9 (167–204)

Results presented as mean±SD, (range).
2L: second German national league, 4L: fourth German national league, HR_{max}: maximal heart rate, n = 14 players for each league (eight players competing only in the 2L or 4L + six players participating in both). No significant differences were observed between 2L and 4L.

This investigation conformed to the standards set by the Declaration of Helsinki's ethical principles for research involving humans. All participating players completed a medical screening questionnaire and signed a written informed consent form after receiving verbal and written explanation of the study procedures and its potential risks. All athletes were in good health and free of injuries at the time of testing.

Match analysis

Players' physical match performance was monitored by means of a GPS device with a sampling frequency of 5 Hz (SPI-Pro, GPSports Systems, Canberra, Australia). The validity and reliability of this GPS model has been reported elsewhere (Hohmann et al., 2013; Petersen et al., 2009). Additionally, players' heart rate (HR) was continuously monitored every 5 s during match-play by means of the Polar Team² System, Polar Electro Oy, Kempele, Finland. A total of ten competitive matches were evaluated in this study (five matches for each competitive league). The participating players were monitored during one to five matches in each league and only the data sets of the players who completed the whole match (90 minutes) were used for data analysis. Therefore, a total of 34 and 26 complete data sets were considered for data analysis in the 2L and 4L, respectively. Additionally, these data sets were classified further according to the positional role that the coaching staff assigned to the players in each match considering only the data sets of the players who played the whole match in that particular position. Thus, our positional analysis included 17, 13, and four complete data sets of defenders, midfielders and forwards in the 2L; and 12, ten, and four in the 4L, respectively. The variables evaluated were total distance, distance covered at different speed zones, speed, and HR. Six arbitrary speed zones based on the work of Hewitt et al. (2009) were used: strolling (0–5 km/h), walking (5–8 km/h), low-speed running (8–12 km/h), moderate-speed running (12–16 km/h), high-speed running (16–20 km/h), and sprinting (>20 km/h). These speed zones are similar to those used in other reports on female soccer players (Bradley & Vescovi, 2015; Martínez-Lagunas et al., 2010; Vescovi & Favero, 2014).

Statistical analysis

Descriptive statistics are presented as mean±SD unless otherwise indicated. Student's *t-test* was used to assess differences according to competitive league and game period (first vs. second half) within each league. Additionally, one-way ANOVA with LSD *post-hoc* tests was used to assess differences according to playing position within each league. Data were analyzed using Team AMS V2.1_R1_2010_P5 (GPSports Systems, Canberra, Australia), Excel 2010 (Microsoft Corp, Redmond, WA, USA), and IBM SPSS Statistics Version 21 (IBM Corp, Armonk, NY, USA). Significance level was set at $p < 0.05$.

Results

Total distance covered (TDC) was 12 percent higher in the 2L matches compared to the 4L matches (or 15 percent higher when only the six players who played games in both leagues were considered) ($p < 0.05$) and no significant reduction in TDC was identified in the second compared to the first half of match-play for either league ($p > 0.05$) (Table 10.2). Average HR was higher in the 2L matches (89 percent HR_{max}) compared to the 4L matches (87 percent HR_{max}) and it was also higher in the first half compared to the second half of match-play within both leagues ($p < 0.05$) (Table 10.2). There were no statistical differences in peak HR (highest value attained in 5-s periods) during the 2L and 4L matches (both reached 99–100 percent HR_{max}) ($p > 0.05$). The attained average peak speed was 5 percent higher ($p < 0.05$) in the 2L (26.5±1.8 km/h) than in the 4L (25.2±2.2 km/h).

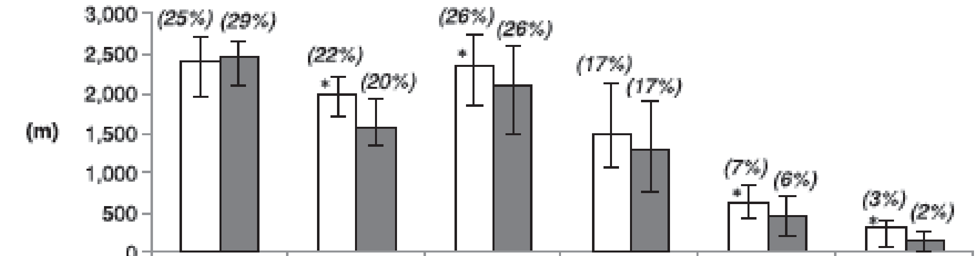
Absolute distance covered at the following speed zones 5–8 (18 percent, indicates percent difference), 8–12 (12 percent), 16–20 (23 percent), and >20 (44 percent) km/h was higher in the 2L matches than in the 4L matches ($p < 0.05$) (Figure 10.1). Players covered about 30 percent more distance at speeds above 16 km/h (high-speed running and sprinting) in the 2L matches than in the 4L matches (this percentage difference was the same when only the six players who played games in both leagues were considered). No statistical differences were found at 0–5 or 12–16 km/h between the two leagues ($p > 0.05$) (Figure 10.1). No significant reduction in distance covered at >16 km/h was identified in the second vs. first half for either league ($p > 0.05$).

In terms of playing position, defenders (D) covered less total distance ($p < 0.05$) than midfielders (M) and forwards (F) in both leagues (2L: D 8715±694 m, M 9966±684 m, F 9803±577 m; and 4L: D 7224±1188 m, M 9437±719 m, F 8191±1032 m). Additionally, forwards covered significantly less total distance than midfielders in the 4L ($p < 0.05$).

Table 10.2 Total distance covered and average heart rate by competitive league

Variable	*2L (n=34)*	*4L (n=26)*
TDC	(m)	(m)
First half	4,735±498*	4,277±706
Second half	4,587±438*	3,947±732
Full game	**9,322±903***	**8,224±1415**
HR	**(bpm)**	**(bpm)**
First half	173±7 (90% HR_{max})*#	168±10 (88% HR_{max})#
Second half	169±+6 (88% HR_{max})*	162±10 (86% HR_{max})
Full game	**171±6 (89% HR_{max})***	**165±9 (87% HR_{max})**

Results presented as mean±SD.
*Significantly higher than 4L, #higher than second half ($p < 0.05$).
2L: second German national league, 4L: fourth German national league, TDC: total distance covered, HR: average heart rate, HR_{max}: maximal heart rate, n: number of complete data sets analyzed for each league.



	0–5 km/h	5–8 km/h	8–12 km/h	12–16 km/h	16–20 km/h	20+ km/h
□ 2L (n=34)	2,361	2,040	2,384	1,576	671	290
■ 4L (n=26)	2,393	1,672	2,098	1,384	515	162

Distance covered (m) at different speed zones (km/h)

Figure 10.1 Distance covered (m) at different speed zones (km/h)

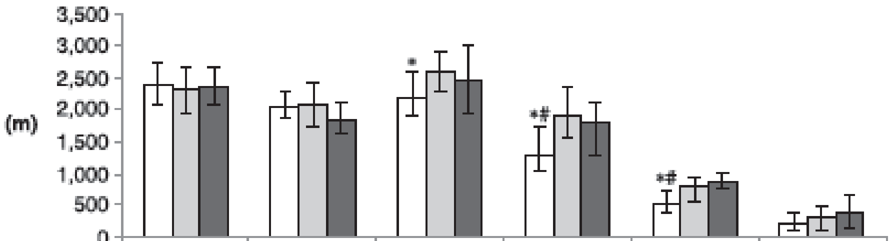
In the 2L, defenders covered less distance at 8–12 (15 percent, indicates percent difference), 12–16 (32 percent), and 16–20 (32 percent) km/h than midfielders and also less distance at 12–16 (28 percent), 16–20 (41 percent) km/h than forwards ($p < 0.05$). No significant positional differences in distance covered were identified at 0–5, 5–8, and > 20 km/h ($p > 0.05$) (Figure 10.2A). In the 4L, defenders covered less distance at 5–8 (16 percent), 8–12 (35 percent), 12–16 (45 percent), and 16–20 (44 percent) km/h than midfielders and also significantly less distance at 5–8 (22 percent) km/h than forwards ($p < 0.05$). Furthermore, forwards covered significantly less distance at 8–12 (28 percent), 12–16 (34 percent) km/h than midfielders. No significant positional differences in distance covered were identified at 0–5 and > 20 km/h ($p > 0.05$) (Figure 10.2B).

Discussion and conclusion

Due to the current literature gap on lower levels of the women's game, the primary aim of this investigation was to compare the physical demands of women's soccer competitive matches of the second and fourth German leagues using GPS technology. We analyzed total distance, distance covered at different speed zones according to Hewitt et al. (2009), speed, and heart rate. Additionally, we also evaluated positional differences. Our data showed that the physical demands of the 2L games were significantly higher (including higher TDC, distance covered at various speeds, average peak speed, and average HR) than those of the 4L games and that several positional differences exist in both leagues.

In this study the average TDC during the 2L and 4L games was 9.3 km and 8.2 km, respectively. These findings fall within the lower ranges of expected values that have been reported in previous studies, which vary depending on the players' level of play: 9.1–12.0 m for female national team soccer players (Andersson et al., 2010; Gabbett & Mulvey, 2008; Hewitt et al., 2009; Hewitt et al., 2014; Mohr et al., 2008; Scott & Drust, 2007), 9.4–10.7 km for female first division

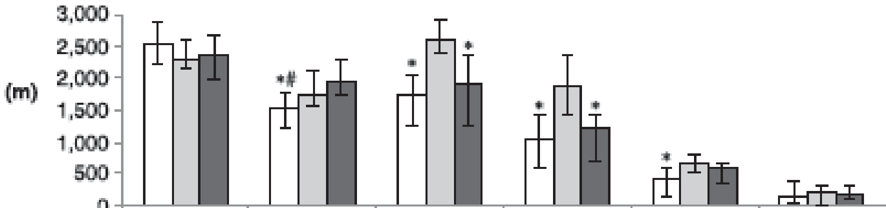
a) 2L



	0–5 km/h	5–8 km/h	8–12 km/h	12–16 km/h	16–20 km/h	20+ km/h
□ Defenders (n=17)	2,408	2,042	2,199	1,285	532	250
□ Midfielders (n=13)	2,300	2,094	2,601	1,889	781	303
■ Forwards (n=4)	2,363	1,859	2,465	1,794	905	417

Distance covered (m) at different speed zones (km/h)

b) 4L



	0–5 km/h	5–8 km/h	8–12 km/h	12–16 km/h	16–20 km/h	20+ km/h
□ Defenders (n=12)	2,483	1,498	1,716	1,027	368	132
□ Midfielders (n=10)	2,291	1,778	2,637	1,872	657	201
■ Forward (n=4)	2,378	1,928	1,896	1,237	599	153

Distance covered (m) at different speed zones (km/h)

Figure 10.2 Distance covered at six different speed zones according to Hewitt et al. (2009) by playing position A) in the 2L and B) in the 4L

n = number of complete data sets included for analysis in each playing position.
*Significantly lower than midfielder, #lower than forward ($p < 0.05$).
2L: second German national league, 4L: fourth German national league.

soccer players (Andersson et al., 2010; Bradley et al., 2014; Cook, 2012; Krustrup et al., 2005; Mohr et al., 2008; Vescovi & Favero, 2014), and 9.7 m for female second division players (Martínez-Lagunas et al., 2010). Although previous studies did not find a significant difference in the TDC during match-play when comparing female players of different performance levels (e.g. national team vs. first division) (Andersson et al., 2010; Mohr et al., 2008), our study findings did show a significant difference in TDC during the 2L and 4L games (2L > 4L, both when all players and when only the six players who played matches in both leagues were considered). This is probably due to the fact that the separation between the 2L and the 4L evaluated in the present study is larger compared to the national team and first division levels investigated in previous research (Andersson et al., 2010; Mohr et al., 2008). Similar to other scientists investigating international female matches (Scott & Drust, 2007) and domestic first division games (Andersson et al., 2010; Mohr et al., 2008), we found no significant reduction in TDC in the second compared to the first half during the 2L or 4L games. However, other researchers have demonstrated a significant decrease (up to 10 percent) in TDC between game halves (Bradley et al., 2014; Cook, 2012; Gabbett & Mulvey, 2008; Martínez-Lagunas et al., 2010). Thus, comparisons among studies should be viewed with caution because players' fitness characteristics, methodology used, game tactics, and environmental conditions may be responsible for the differences in study results.

Soccer is an intermittent sport combining periods of high- and low-intensity activities and there is no exact or single measure of physical performance during match-play (Bradley et al., 2014), although it has been suggested that the distance covered at high-intensity may be an important determinant of physical match performance due to its positive relation with players' fitness status (Bangsbo et al., 2008; Krustrup et al., 2003; Krustrup et al., 2005) and its ability to distinguish players of different competitive levels and positional roles in both men's and women's soccer (Andersson et al., 2010; Bangsbo et al., 2008; Krustrup et al., 2003; Mohr et al., 2008). Therefore, we analyzed distance covered at six different speed zones based on the work of Hewitt et al. (2009). The generic speed zones or thresholds used in the present study adhere to the current recommendations given by Bradley and Vescovi (2015) in order to standardize the definition of high-speed running (15–16 km/h) and sprinting (20 km/h) of women's soccer matches with ≥ U20 players and are similar to those used in other studies on female soccer players (Martínez-Lagunas et al., 2010; Vescovi & Favero, 2014). Like other authors (Andersson et al., 2010; Mohr et al., 2008), we found that the distance covered at the higher intensities (> 16 km/h) was significantly greater (30 percent) in the superior level of play compared to the lower level (2L > 4L, both when all players and when only the six players who played matches in both leagues were considered). This shows that these latter players were able to adapt well to the higher physical demands of the 2L matches. Overall, all players covered 23 percent higher distance at high-speed running (16–20 km/h) and 44 percent higher distance at sprinting speed (> 20 km/h) in the 2L compared to the 4L. The absolute distance values covered at high-intensity running (> 16 km/h) in the 2L (960.8 m) and 4L (676.6 m) in this study are comparable to the values reported in previous studies that also used GPS technology and the same arbitrary speed thresholds for the analysis of Australian international games (900 m) (Hewitt et al., 2009) and German second league games (860 m) (Martínez-Lagunas et al., 2010). Nevertheless, the differences in these values become larger when compared to studies that used video-based technology and/or different thresholds to define distance covered at high-intensity running (1,300–2,407 m) (Andersson et al., 2010; Hewitt et al., 2014; Krustrup et al., 2005; Mohr et al., 2008).

In the present study, we found further significant differences in absolute distance covered at 5–8 m/h (walking) and 8–12 km/h (low-speed running) between the leagues (2L > 4L), but no significant difference at 0–5 km/h (strolling) and 12–16 km/h (moderate-speed running). However, in terms of relative percentage values from the TDC by league, the differences were smaller and the percentages found in this study (~73–75 percent for low-speed running, walking, and strolling, ~17 percent for moderate-speed running, ~6–7 percent for high-speed running, and ~2–3 percent for sprinting) are also similar to those reported by other authors (Hewitt et al., 2009; Martínez-Lagunas et al., 2010). Moreover, no significant reduction in distance covered at high-intensity running was found in the second half compared to the first half of match-play in either league, although other researchers have reported a significant decrease in this variable between the game halves during international and first division female soccer matches (Mohr et al., 2008). Furthermore, our study results showed that the attained average peak speed was about 5 percent higher in the 2L than in the 4L matches, which supports further the higher physical demands of the 2L compared to the 4L matches. To date, no other studies have compared this variable between different levels of play in women's soccer.

Prior to the start of the current study, each player's HR_{max} was determined as the peak value attained in a 5-s period towards the end of a common soccer-specific field test that has been described elsewhere and has been shown to be a practical and valid tool for this purpose (Bangsbo et al., 2008; Krustrup et al., 2003; Martínez-Lagunas & Hartmann, 2014). Thus, the average and peak HR values attained during the games could be expressed as percentages of HR_{max}. Average HR values during match-play for the 2L and 4L were 171 and 165 bpm corresponding to 89 percent and 87 percent HR_{max}, respectively. These values are similar to those reported in previous studies (Andersson et al., 2010; Krustrup et al., 2005; Martínez-Lagunas et al., 2010). However, we did find a significant difference in the average HR values attained during the 2L and 4L games (2L > 4L), while Andersson et al. (2010) did not show such a difference between the international and domestic women's soccer games that they evaluated. When looking at each playing position, we found that defenders covered significantly less total distance than midfielders and forwards in both leagues and that forwards also ran less total distance than midfielders in the 4L. These findings are in line with those of previous research showing similar results regarding positional differences in women's soccer (Andersson et al., 2010; Cook, 2012; Gabbett & Mulvey, 2008; Hewitt et al., 2009; Hewitt et al., 2014; Mohr et al., 2008; Scott & Drust, 2007). In all these studies, the conclusion or tendency is that midfielders cover the greater total distance compared to defenders and forwards. Additionally, in the present study midfielders were also found to run more distance at low-, medium-, and high-intensity speeds than defenders in both leagues. Other authors also support the finding that midfielders have greater running at high intensity compared to defenders (Andersson et al., 2010; Hewitt et al., 2014; Mohr et al., 2008). In this study we did not find significant differences in sprint distance among the playing positions, although other reports support some positional differences in this category (Cook, 2012; Hewitt et al., 2014; Mohr et al., 2008). Studies that have compared the physical demands placed on central or external defenders and midfielders in men's soccer have identified further positional differences. For example, Di Salvo et al. (2007) found superior TDC for the central midfielders followed by external midfielders, external defenders, forwards and central defenders. On the other hand, Bradley et al. (2009) reported superior distance covered at high- and very high-intensity running for the external midfielders compared to all other positions, as well as higher sprinting distance compared to central defenders, central midfielders, and attackers. Therefore, future research in women's soccer should include the analysis of more specific field player classifications (i.e. at least five sub-categories: central defenders, external defenders, central midfielders, external midfielders, and forwards, instead of only three of them: defenders, midfielders, and forwards, which is the common practice in the current literature). Additionally, the evaluation of the specific physical demands placed on female goalkeepers at various competitive levels should also be included in future investigations because there is currently very scarce information relative to this playing position.

We acknowledge that a few limitations are associated with the current study. For instance, we analyzed a relatively low number of players, matches, and complete data sets. Although we were able to detect significant differences between the two competitive levels, the low number of complete data sets available for the comparison of positional differences may be a limiting factor, especially in the case of the forward category, in which there were only four complete data sets available for analysis. Thus, the generalization of our study findings to other groups of female players should be made with caution. Gregson et al. (2010) showed that there is a high match-to-match variation (CV of 16–31 percent) in the amount of high-speed activities that elite male players perform during match-play and suggested that large sample sizes ($n \geq 80$) are required to detect real systematic changes in this area. Nevertheless, the opportunities to collect physical performance data during women's soccer matches of various competitive levels are still scarce, especially at lower competitive levels. The number of players, matches, and complete data sets used in the present study compare favorably to those of similar published studies on women's soccer (Andersson et al., 2010; Gabbett & Mulvey, 2008; Hewitt et al., 2014; Mohr et al., 2008). Furthermore, comparisons among study findings using different types of match analysis systems should be performed with caution because large absolute between-system differences exist when comparing video-based time-motion analysis, semi-automatic multi-camera, and GPS systems (Randers et al., 2010). Additionally, the current limitations of using GPS technology for the analysis of athletes' physical performance during training and match-play should be taken into account. Particularly that there is a tendency for the GPS devices to underestimate distance and speed measures with lower accuracy and reliability in the case of high-intensity efforts as well as low level of interunit reliability (Vickery et al., 2014). Finally, differences in the speed zones or thresholds used in the current literature to define the various locomotor activities should be considered when comparing study results (Bradley & Vescovi, 2015).

In conclusion, the physical demands of 2L competitive matches are higher than those of 4L matches, especially in terms of TDC (12 percent, indicates percent difference), distance covered at > 16 km/h (30 percent), and average peak speed (5 percent difference) resulting in a higher average HR (2 percent).

Furthermore, positional differences exist in terms of total distance covered and distance covered at various speeds (e.g. 8–12, 12–16, and 16–20 km/h) in both leagues. These physical demands are significantly lower for defenders than for midfielders and forwards. Midfielders tend to face the highest physical demands during match-play in both leagues. Thus, players' physical preparation should meet the specific demands of their competitive level and positional role.

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