GPS ANALYSIS OF RUNNING PERFORMANCE IN FEMALE FIELD SPORTS: A REVIEW OF THE LITERATURE

KEYWORDS

GPS; global positioning system; geographic information systems; soccer; field hockey; rugby; female sport; performance analysis.

ABSTRACT

The use of global positioning systems (GPS) in analyzing field sport performance is a recent development, particularly in soccer, rugby and field hockey. Research with GPS in female field sports has centered on match performance, fatigue, and training intensity. Of particular concern for GPS analysis is the need for standardized methods to determine the occurrence of high intensity running and sprinting. GPS analysis for female field sport athletes **can** assist in development of training plans and monitoring protocols in field sports. The aim of this article is to review studies published to provide useful information to inform coaches' S&C programming.

INTRODUCTION

Global positioning **systems (GPS)** have received increasing use in sport since the first use of GPS to track various physical activities in a single athlete. (15) The ability of GPS technology to track player movement simultaneously among multiple athletes is particularly useful in intermittent running sports like soccer, field hockey, and rugby, where motions like tackles and changes of direction occur frequently, and the most prevalent physical activity is running, with the majority of the research focus on the analysis of running categories in match analysis including distance travelled, maximal speed, and amount of high intensity running. While men's field sports have used GPS for some time, there is limited data available from women's field sports. The use of female-specific data can inform gender-specific training, and increase monitoring of potential injury risk in a population susceptible to running-based injury.

DISTANCE COVERED

Total distance is a global indicator of external physical load during match play. Distance covered during a time-specific match provides a bench mark for running performance expectations; however reported total distance is not always comparable because of differences in regulation times between sports and individual playing time due to substitutions. Instead, work rate or relative distance (distance/time, expressed in m/min) is used to compare total match effort between different sports and individual players. Table 1 summarizes total distance and work rates during matches from studies reporting match length and total distance travelled.

*****insert Table 1 near here*****

Among youth soccer players, Vescovi (24) reported a significant **difference ($p<0.001$)** in work rate from U15 players (86±3 min/min) to U16 and U17 players (100±1 and 100±3 m/min, respectively), indicating an increase in running ability in this age range. Recent studies using GPS reported work rates of 100 m/min or higher among elite adult players. Previous video-based motion analysis characterized professional women's soccer work rates from 110 – 116 m/min. (1,13) While high average work rates were still reported using GPS analysis (118 m/min), a wider range from 100 – 120 m/min could more effectively represent target work rates in elite female soccer.

Studies in field hockey reported similar work rates of 98 – 110 m/min (22) compared to age-matched NCAA soccer players (96 – 107 m/min). (21) Several studies of elite female rugby sevens describe similar work rates (91-117 m/min) (5,14,17,20) to elite field hockey and soccer, highlighting potential common fitness attributes among these field sports at similar participant age and competition level. Similar fitness standards in elite female field sports suggest that aerobic running programming may be generalized for intermittent field sports, with sport-specific focus centering on skill sets and positional differences.

Distance as an indicator of fatigue within a match

Total distance and work rate are useful performance parameters for monitoring fatigue between match periods. Though a reduction in distance or work rate might also be a result of contextual variables such as match result, opposition ranking, or player formation, (10,25) GPS analysis of substitutes in soccer demonstrate that substitutes into a match had higher work rates in the final 12 minutes of match play compared to players completing a full match, (21) suggesting fatigue is still a confounding variable of the reduction in work rate.

In soccer, fatigue during the second half and particularly in the last 15 minutes of play has been cited as a potential factor in injury risk during the same time period. (9) Barbero-Álvarez et al (2) reported an 8% reduction in distance for the second half in a friendly match with U13 players. In competitive youth matches, Vescovi (24) found a reduction of approximately 100-150 m (~3%) in total distance during the second half compared to the first half across all player positions (i.e. defenders, midfielders, and forwards). In elite women's soccer, Hewitt et al (10) reported a 4.8% decrease in the second half; in particular, distance travelled in the last two 15 minute periods of the game were significantly different to distance in the first 15 minute period. Vescovi and Frayne (22) reported similar work rate reduction patterns of 7-9% in female field hockey for all player positions, despite rolling substitutions.

Reduction in work rate in the second half of competition was reported in rugby sevens for both international- and national-level teams: national-level team average work rate decreased from 103 m/min in the first half to 88 m/min in the second half; international-level team average work rate decreased from 126 m/min to 104 m/min. (14) The one published study on women's rugby union demonstrated no reduction in second half distance, similar to results in men's rugby union. (18) Though the data do not demonstrate consistent percentage decrements, current published studies show decreases in work rate occur regardless of competition level or sport, with the exception of rugby union. Monitoring of fatigue during matches may impact substitution strategy and assist in fatigue-related injury prevention.

Analysis of high-intensity running and sprinting

While work rate is a useful indicator of external work load, it does not indicate the amount of high-speed work performed during a match. High-intensity running (HIR) efforts can be critical to match results, (16) and the amount of HIR and the ability to repeat HIR are distinguishing performance attributes of elite players. (1) Sprinting is also a key component of performance in field sports. The ability to sprint faster and for longer distances are characteristics that distinguish top-class from lower-level players (13,14) and, as a component of HIR, are similarly critical to match results. (1) Maximal speeds during match play are reported in Table 2.

*****Insert Table 2 near here*****

HIR and sprinting have been researched in some depth in female field sports. Dwyer and Gabbett (7) proposed HIR velocity ranges and sprinting velocity thresholds for women's soccer and field hockey, based on normal curves of best fit from average distribution of speed from anonymized elite match data (HIR soccer: 12.2-19.1 km/hr, HIR field hockey: 13.3-19.1 km/hr, Sprinting both: ≥19.44 km/hr). However, the definitions of high-intensity running and sprinting in published research have still varied greatly. A summary of HIR and sprint thresholds and ranges used in GPS analysis of female field sports is in Table 3.

*****Insert Table 3 near here*****

Researchers argue that using velocity thresholds based on male data will underestimate high-intensity work of female athletes. (4,5) In one example, a study of NCAA soccer using a HIR threshold of >13.0 km/hr (similar to proposed HIR for female soccer players noted above) and sprinting threshold of >22.0 km/hr (higher than proposed sprinting threshold for females) reported 138.41±36.43 HIR efforts but only 4.31±3.51 sprints (mean±SD) per game. Not only does this underestimate work performed, but also underestimates the physiological cost of the work from both aerobic and anaerobic systems.

HIR and the ability to perform above this threshold is an important physiological component of intermittent field sports. As such, practitioners experimented with the use of high-intensity thresholds based on physiological tests. Clarke et al (5) tested 12 international rugby seven's players for maximal aerobic running capacity ($\dot{V}O_2max$ test). Researchers used speed at the second ventilatory threshold ($\dot{V}T_{2speed}$) to define high-intensity running. When individual thresholds based on $\dot{V}T_{2speed}$ were applied to match running data, distances travelled at high-intensity speeds were highly correlated with HIR capacity. This association declined using a group mean threshold of 12.6 km/hr (3.5 m/s). Because laboratory-based $\dot{V}O_2max$ tests are not always available, Bradley and Vescovi (4) have suggested using 80% of maximal aerobic velocity to estimate the second ventilatory threshold for individualized HIR thresholds. Maximal aerobic velocity can be determined through the use of a range of field-based fitness tests including a 5-minute time trial and the University of Montreal Track Test. (3) However, the use of a group mean threshold would allow for player comparison and comparison between age-matched sports, as the reported group mean threshold is similar to the HIR thresholds previously suggested for women's soccer and field hockey. (7)

Research has illustrated that players run a large percentage of matches below defined HIR thresholds. (5,21,22) A player's ability to run at low and moderate speeds for long periods can increase **overall** work rate, highlighting the importance of defining HIR threshold and suggesting that monitoring of player ability to perform sustained low-intensity work could be another component of performance analysis.

Sprinting and the ability to repeat sprinting efforts stress players anaerobically. However, anaerobic capacity varies greatly based on age and competition level. When studying the use of different sprint thresholds in professional women's soccer, Vescovi (23) found that 11% of sprints were in excess of 25.0 km/hr, though previous research in soccer and rugby shows that lower-standard players perform significantly less high-intensity work than international or top-class professional players (13,14). If this threshold were to be used for female players at sub-professional levels, the amount of sprinting during matches could be underestimated.

Positional differences

Another key use of GPS analysis is to assess positional differences within a sport. In field hockey and soccer, positions are generally categorized as forwards, midfielders, and defenders. In rugby, positions are broadly categorized as forwards and backs.

One article on international soccer players (10) reported midfielders covering significantly more total distance than defenders, and midfielders covering significantly more distance at high-intensity velocities than both defenders and forwards. Both midfielders and forwards covered significantly more distance at sprinting velocities (>19 km/hr). A study evaluating sprinting in professional women's soccer matches (23) found that forwards completed more sprints per match (43±10) than defenders and midfielders (36±12 and 31±11, respectively). In NCAA soccer, (21) defenders covered less total distance than forwards and midfielders. Forwards and defenders both covered more distance at sprint speeds than midfielders. In youth soccer, (24) midfielders were found to cover more total distance than defenders, primarily due to more work performed at speeds lower than the HIR threshold. Forwards recorded more distance at sprint speeds and greater peak speeds than midfielders.

In field hockey, positional differences in the women's game are less clear. In one study on elite field hockey, (22) forwards had significantly less playing time than defenders, though total distance between all positions was similar. Defenders performed more low-intensity running and had a lower work rate than forwards and midfielders. Based on mean distance travelled, midfielders ran more during match play, though forwards recorded longer distances at sprint speeds and on average reached higher peak speeds. Gabbett (8) found that on average midfielders cover greater total distances during match play, and also covered longer distances at high-intensity velocities (HIR > 18 km/hr). Another study (11) reported defenders covering greater total distances and forwards covering the least, with no differences in mean sprint or high-intensity distance between positions. In a study focusing on sprint performance in field hockey matches, players had similar peak speeds, though forwards recorded higher peak speeds during some matches.

Positional differences were not evaluated in the literature on female rugby sevens. However, in rugby union (comprising teams of fifteen players), backs covered significantly more total distance than forwards. Backs also performed more work at higher intensities than forwards (5.4% v 1.4% of total time) (18) which results are in agreement with elite male rugby union data. (6)

Differences in running performance indicators between positions in sport have implications for position-specific training, though these may vary by competition level. In soccer and field hockey, midfielders generally run the length of the pitch, switching between defense and offense, so it would seem logical that midfielders cover a greater total distance. Forwards in soccer and field hockey tend to sprint faster and more often than other positions. Defenders might not demonstrate high total distance or high sprint distances due to opposition movement. Rugby backs are expected to run and pass the ball and to score, and so make frequent runs across the pitch accumulating high total distance. Forwards tend to run shorter distances than forwards, instead having a larger strength component for scrums and set pieces. Data from GPS analysis can assist in developing sprint training over sport-specific distances, HIR and repeated sprinting, and aerobic training specific to positions in order to reflect match demands.

TRAINING

GPS allows for tracking and analyzing movement patterns during training, where training often occurs away from stadium structures and large numbers of sessions make video analysis time-consuming. Only four peer-reviewed GPS analysis studies have evaluated training sessions in female field sports (2 soccer, 2 field hockey).

Gabbett (8) analyzed training sessions of small-sided games and competition performance of an elite women's field hockey team. More low-intensity work occurred during small-sided games compared to competition (~60% of training time v ~35% competition time), and less moderate (10.8 – 18 km/hr) and high-intensity work (>18 km/hr). Another study analyzed small-sided training games in field hockey, assessing the effect of team ranking on training status. (25) In this study, work rate and team ranking were highly correlated (Pearson's r = 0.95, adjusted R^2 = 0.87) with the highest training work rate (~84 m/min) performed by the topranked team, however high-intensity running did not have the same relationship with team ranking. Future research might investigate the effect of training work rate on team ranking.

Mara et al (12) used GPS to assess training in an elite female soccer team across an entire season. Training session times were not provided, though assuming analyzed sessions were of a similar length throughout the season, a decrease in work rate is inferred through the decrease in total distance from preseason to late season (6646±111 to 4604±110 m, respectively). This is consistent with expected decreases in training demand due to match scheduling, however acceleration and sprint performance also decreased throughout the season as monitored through periodic performance tests. Further understanding of training demands and physical performance indicators and the interaction of these variables throughout a competitive season would help inform coaches on effective periodization strategies specific to the female game.

Tan et al (19) studied the relationship of training demands and hemolysis relating to potential iron store depletion in professional female soccer field players (n = 7) and goalkeepers (n = 3). Training effected a similar hemolytic response in field players and goalkeepers, despite GPS analysis showing field players covering significantly ($P < 0.05$) more distance and spending more time at higher speeds than goalkeepers. This would suggest that hemolysis occurs due to goalkeeper-specific training demands such as plyometrics, acceleration within the box, tackles, and frequent landing on the ground to save goals that might be quantified through accelerometry in further studies. This study also found that the work rate of field players in training was significantly less than match work rate (74.5±8.8 and 105.6±9.2 m/min, respectively) which is consistent with differences in work rate between training and match play in field hockey. (25)

Although small-sided games are meant to replicate match situations, these studies illustrate a possible lack of adaptation from training to appropriately prepare for match play, as training efforts do not replicate the physiological demands of matches. GPS analysis could be useful for monitoring training and informing coaching and training staff if training goals are being met.

CONCLUSIONS AND PRACTICAL RECOMMENDATIONS

Understanding the requirements of field sport competition is a crucial factor in an effective training program if specific training adaptations are to have an optimal transfer to performance and reduce fatigue and subsequent injury. By understanding average work rates during performance (see Table 1), coaches are able to assess an athlete's current level of fitness in relation to the required competition demands. Subsequently, it is expected that on average, female soccer may have greater running demands than other female field sports including field hockey and rugby. The usefulness of designing training based on competition demands may be limited due to the reliance on averaged performance results. Match running demands may therefore be underestimated due to the impact of long active rest periods (walking) on the average work rate calculation. To more accurately reflect match demands, periods of active rest may be removed from the performance duration and work rate determined from periods with a significant physiological demand. Further, it may be possible to convert this newly calculated work rate to m/s to estimate the level of maximal aerobic velocity required to sustain performance without a rapid onset of fatigue. This combined with the use of GPS to monitor training allows for the creation of drills which replicate a similar intensity to competition.

Furthermore, the understanding of a performance profile (considering HIR and sprinting efforts) can reduce the impact of averaged data and improve training program specificity. However, as presented in Table 3, there is a lack of agreement on the methods used to determine HIR thresholds and sprints within female field sports with some methods informed from the respective male field sport and from adult data, despite youth participants, a result of limited data in female field sports. While the specific velocities utilized in analysis are expected to be different between sports, as well as individualized between athletes, it is important that a standard definition is used in order to allow inter-study comparisons. However, regardless of these limitations, HIR, sprinting data and work rate should still be utilized to inform training especially with consideration of positional and age-specific differences as demonstrated in soccer and rugby union.

It is evident that female performance attributes vary considerably to male counterparts, highlighting the need for more female-specific data. A greater abundance of data combined with more specific determination methods will allow coaches and training staff to develop appropriate practices to enhance competition preparation in female field sports.

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Table 1

Table 1 - Reported match work rate and total distance per sport

References	Year	*n*	Competition level	Total distance (m)	Work rate (m/min)
Soccer					
Tan et al.	2012	7	Elite	8533±2449	105.6±9.2
Vescovi	2012	79	Elite	9997±928	111*
Hewitt et al.	2014	15	Elite	9631±175	107*
McCormack et al.	2014	10	Elite	8953.9±1035.4	100*
Vescovi and Favero	2014	113	Elite	4413 - 5540 m***	102*
McCormack et al.	2015	10	Elite	N/A	118*
Vescovi	2014	11	Elite Youth, U15	6961±238	86±3
		63	Elite Youth, U16	8024±101	100±1
		15	Elite Youth, U17	8558±223	100±3
Barbero-Alvarez et al.	2008	12	Youth, U13	3977.8±324.7****	79.3±7.5
Field Hockey					
Gabbett	2010	14	Elite	6154 - 6931 (mean, position)	94*
Macutkiewicz and Sunderland	2011	25	Elite	5541±1144	115*
Vescovi and Frayne	2015	68	Elite	6062 - 6765 m (mean, position)	106*
Vescovi	2014	44	High-level, U17 and U21	5541 (SD not reported)	79*
Rugby 7s					
Suarez-Arrones et al.	2012	12	Elite	1556.2±189.3	111*
Clarke et al.	2014	22	Elite	1204*	86±7
Portillo et al.	2014	21	Elite - National	1363.4±221.8	97*
		29	Elite - International	1642.2±171.2	117*
Clarke et al.	2015	12	Elite	916 m (14 min) - 1660 m (Final, 20 min)	105±4.9**
Vescovi and Goodale	2015	13	Elite - Development	1252 ± 135	91 ± 11
		16	Elite - International	1468 ± 88	95 ± 5
Rugby Union					
Suarez-Arrones et al.	2014	8	Elite	5820±512	68*

* Work rate approximated from available data

** Omitting Cup Final match due to longer playing time

*** Distance travelled during 45 minute half

**** Distance travelled during 50 minute match

Table 2

Table 2 - Mean maximal speed and highest reported speed during match play

Reference	Year	Competitive level	*n*	Mean maximal speed (km/hr)	Highest reported speed (km/hr)
Soccer					
Vescovi	2012	Professional	79	21.8±2.3	26.5
McCormack et al	2014	Elite	10	27.5**	N/A
Vescovi	2014	Elite Youth, U15	11	24.3±0.5	25.3
		Elite Youth, U16	63	25.6±0.2	26.1
		Elite Youth, U17	15	25.6±0.5	26.6
Barbero-Alvarez et al	2008	Youth, U13	12	19.5***	
Field Hockey					
Vescovi and Frayne	2015	Elite	68	22.4*	25.6
Vescovi	2014	High-level, U17	24	24.2*	24.6****
		High-level, U21	20	24.6*	25.0****
Rugby Sevens					
Suarez-Arrones et al	2012	Elite	12	23.1*	28.3
Portillo et al	2014	Elite - National	21	21.5*	N/A
		Elite - International	29	24.6*	N/A
Vescovi and Goodale	2015	Elite - Development	13	26.0±1.5	26.8
		Elite - International	16	27.3±0.7	27.7
Rugby Union					
Suarez-Arrones et al	2014	Elite	8	22.9±2.8	27.9

*Average maximal speed approximated from reported data

** Reported as 7.64±0.49 m/s

*** SD not reported

**** Mean maximum speed from sprint speed zone >20.0 km/hr

Table 3 - Sprint and HIR definitions

Authors	Year	Level	HIR threshold or range (km/hr)	Sprint threshold or range (km/hr)	HIR and Sprint reference
Soccer					
Barbero-Alvarez et al	2008	Amateur Youth	13.1-18	>18.1	Male youth soccer (Castagna, 2003)
Vescovi	2014	High-level	15.6 - 20.0	>20.0	Adult female soccer (Dwyer & Gabbett 2012, Vescovi 2012)
Vescovi and Favero	2014	Elite/NCAA	15.6 - 20.0	>20.0	Adult female soccer (Dwyer & Gabbett 2012, Vescovi 2012)
McCormack et al	2015	Elite/NCAA	>13.0*	>22.0 *	No reference provided
Hewitt et al	2014	Elite	12 - 19	>19	Adult female soccer (Dwyer and Gabbett, 2012)
McCormack et al	2014	Elite/NCAA	>13.0	>22.0	No reference provided
Tan et al	2012	Elite	>16.0	N/A	Original - two speed zones, >75% maximum speed from group mean 20-m running times
Mara et al	2015	Elite	>12.2*	≥19.4 *	Adult female soccer (Dwyer and Gabbett, 2012)
Dwyer and Gabbett	2012	Elite	12.2 - 19.1*	≥19.4 *	Original - best fit curves based on velocity from match data
Field Hockey					
Macutkiewicz and Sunderland	2011	Elite	15.1 - 19.0	>19.0	Adult male soccer (Bangsbo, 1992); Adult female hockey (Lothian and Farrally, 1992)
Vescovi and Frayne	2015	Elite/NCAA	16.1 - 20.0	20.1 - 32.0	Adult female hockey (Dwyer and Gabbett, 2012) Adult female soccer (Vescovi 2012)
Vescovi	2014	High-level	N/A	>20.0	Adult female hockey (Dwyer and Gabbett, 2012) Adult female soccer (Vescovi 2012)
White and MacFarlane	2015	High-level	>18.0	N/A	No reference provided
Gabbett	2010	Elite	18 - 25.2 *	>25.2*	No reference provided
Dwyer and Gabbett	2012	Elite	13.3-19.1 *	≥19.4 *	Original - best fit curves based on velocity from match data
Rugby Sevens					
Suarez-Arrones et al	2012	Elite	18.1 - 20.0	>20.0	Adult male rugby union (Cunniffe et al 2009)

Clarke et al	2014	Elite	>18*	>21.6 *	No reference provided
Portillo et al	2014	Elite - International and National)	18.1 - 20.0	>20.0	Adult male rugby union (Cunniffe et al 2009)
Clarke et al	2015	Elite/International	>12.6 *	>18.0 *	Original - based on physiological threshold second ventilatory threshold
Vescovi and Goodale	2015	Elite - International and Developmental	16.1 - 20.0	20.1 - 32.0	Adult female field hockey (Dwyer and Gabbett, 2012); Adult female soccer (Vescovi, 2012; Bradley and Vescovi, 2015)
Rugby Union					
Suarez-Arrones et al	2014	Elite	18.1 - 20.0	>20.0	Adult male rugby union (Cunniffe et al 2009), Adult female rugby sevens (Suarez-Arrones et al 2012)

*Converted from m/s