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Comparing accuracy between global positioning systems and ultra-wideband-based position tracking systems used for tactical analyses in soccer

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Abstract
Current studies have reported high accuracy in global positioning system (GPS) and recently developed ultra-wideband (UWB)-based tracking systems for monitoring time – motion patterns. The accuracy and reliability of both systems may be different in tactical analysis application, an aspect that has never been studied previously. The aims of the present study were: (i) to determine and compare the accuracy of GPS and UWB technologies in soccer players' positions (ii) to compare the tactical application of both systems. Following institutional ethical approval and familiarisation, 14 well-trained soccer players performed tests around five courses: (a) field perimeter, (b) halfway line, (c) centre circle, (d) perimeter of the penalty area, and (e) semicircle penalty area. Also, a small-sided game was played monitored with WIMUPRO™ to determine real and practical differences in accuracy of both systems in tactical analysis. For the GPS, the mean absolute error ($N = 9445$) of "x" and "y" coordinates was 41.23 ± 17.31 cm and 47.6 ± 8.97 cm, respectively. For UWB, it was 9.57 ± 2.66 cm and 7.15 ± 2.62 cm. The results of the "x" and "y" accuracy comparison were significantly lower in all cases ($p < 0.05$) with an ES of 0.78 and 0.95, respectively. In a real practical application, the differences of both systems reached 8.31% in typical tactical variables (ES = 0.11). In contrast to GPS-10Hz, UWB WIMUPRO™-20 Hz has been demonstrated to be an acceptable technology to estimate the position of players on the pitch with high accuracy and be a useful, automatic, and portable instrument for tactical analysis measurement.

KEYWORDS: *Assessment, game analysis, Tactic, technology, team sport*

Highlights

- The accuracy reported by both systems suggest that while GPS-10Hz has substantial limitations, UWB-20Hz has been recommended as accurate technology for estimating position of players on the pitch.
- Significance differences reported in tactical analysis between both systems suggest that the error of using one system or another can mean a difference of more than 8% 3. Test-retest reliability and inter-unit reliability were good for the two systems assessed. However, for use in research, UWB is recommended.

Introduction

In recent years, the increasing need for, and interest in, performance analysis in sport has led to new techniques of match analysis. Despite the ongoing development of these innovative technologies, they are most frequently used for notational and time – motion analysis. The first refers to the process of recording all players' actions and critical events during competitive performance (Travassos, Davids, Araújo, & Esteves, 2013); the second refers to the type and intensity of the players' movements. Thus, it is a physical/physiological analysis to measure load (Carling, Bloomfield, Nelsen, & Reilly, 2008). Notational and time – motion analysis pursue the following main objectives (Buchheit & Simpson, 2016): (i) objective assessment of the demands of external load during training and competition, (ii) optimisation of load patterns, and (iii) consequent improvement of performance and injury prevention. Both types of analysis have been

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thoroughly studied in different sports, such as Australian football (Deutsch, Kearney, & Rehrer, 2007; Hausler, Halaki, & Orr, 2016), basketball (Ben Abdelkrim, El Fazaa, El Ati, & Tabka, 2007; Conte et al., 2015; McInnes, Carlson, Jones, & McKenna, 1995), hockey (Rhodes, Mason, Perrat, Smith, & Goosey-Tolfrey, 2014; Spencer et al., 2004), and soccer (Gabbett & Mulvey, 2008). However, it should be borne in mind that the reasons for its expression in competitive performance must be constantly based upon on a tactical/strategic purpose; so the player stands or positions himself in some place, with higher or lower movement intensity, at a certain moment, in relation to the game configuration (Carling et al., 2008; Garganta, 2009; Sampaio & Maçãs, 2012). In this sense, several studies showed a significant influence of team tactics on physiological and kinematic demands during elite soccer (Bush, Barnes, Archer, Hogg, & Bradley, 2015; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007) but more in-depth analyses are missing, and at present it is unclear how to combine information about a player's physiology from training and competitions with tactical behaviour (Castellano, Alvarez-Pastor, & Bradley, 2014). Despite the fact that tactical analysis can be useful for understanding the behaviour of players' synchronous movement on the field, few studies have been made from this perspective of game analysis. The dynamics of the distance to their own goal (Silva et al., 2016), centroids of a team, surface area (Frencken & Lemmink, 2008), player distance from the centroid of the team (Sampaio & Maçãs, 2012), and team positioning and distribution on the pitch (Voronoi diagrams; Fonseca, Milho, Travassos, & Araújo, 2012; Lopes, Fonseca, Lese, & Baca, 2015) are some of the tactical analysis variables that have been addressed by research. However, an adequate tracking system with high accuracy must be used to study sport tactics.

In soccer, global positioning systems (GPS) and, more recently, ultra-wideband (UWB) technology have become standard tools for movement-pattern analysis during matches and training sessions. Although it is accepted that 10 Hz GPS is currently the most suitable for monitoring time – motion analyses (Aughey, 2011; Cummins, Orr, O'Connor, & West, 2013; Leser, Schleindlhuber, Lyons, & Baca, 2014; Rhodes et al., 2014), it has been demonstrated that both systems (GPS and UWB) are similar in accuracy and reliability for this application (Bastida Castillo, Gómez Carmona, De la Cruz Sánchez, & Pino Ortega, 2018). But, in this sense, the accuracy and reliability of both systems may be different in tactical analysis application, an aspect that has never been studied previously. Additionally, there is still a lack of research into the more recently developed UWB technology, which might also allow measurements during competitive matches in stadiums; the GPS technology, on the other hand, has obvious limitations (Álvarez, 2008; Aughey, 2011; Cummins et al., 2013). In sport science, UWB-based position tracking systems have only been assessed for accuracy and intra-unit reliability for time – motion analysis in indoor conditions in basketball (Leser et al., 2014) and wheelchair court sports (Rhodes et al., 2014). It is necessary to ascertain their accuracy in a valid protocol, which evaluates player position on the field under soccer conditions. The main aim of this study was to determine and compare the accuracy of GPS and UWB technologies in soccer players' positions. A secondary aim was to compare both for their tactical application.

Method

Participants

Fourteen well-trained soccer players (age: 24.43 ± 4.45 years, mass: 72.34 ± 5.65 kg, height 1.81 ± 0.56 m) volunteered to participate in the current study. All participants had to meet the following requirements: (i) 2 *years* of soccer playing experience and (ii) no physical limitations or musculoskeletal injuries that could affect testing. Subject height was measured using a measuring rod (SECA, Hamburg, Germany). Body mass and body composition were obtained using an eight-electrode segmental body-composition monitor (Model BC-601, TANITA, Tokyo, Japan). The study, conducted according to the Declaration of Helsinki, was approved by the Bioethics Commission of the University of Murcia (2061/2018). Participants were informed of the risks and discomforts associated with maximal testing and provided written informed consent.

Procedures

The data acquisition in the current study was carried out on a soccer field measuring 64 × 100 m. The participants completed a total of five tasks with different types of courses to represent different directions and different distances: (a) perimeter of the field (T1) (goal lines and touchlines), (b) halfway line (T2), (c) centre circle (T3), (d) perimeter of the penalty area (T4), and (e) semicircle penalty area (T5) (Figure 1). The dimensions of the task layout were as follow: perimeter of the field: 100 m long, 64 m wide; halfway line: 64 m long; perimeter of the penalty area: 16.5 m long, 40.32 m wide; centre circle: 9.15 m radius;

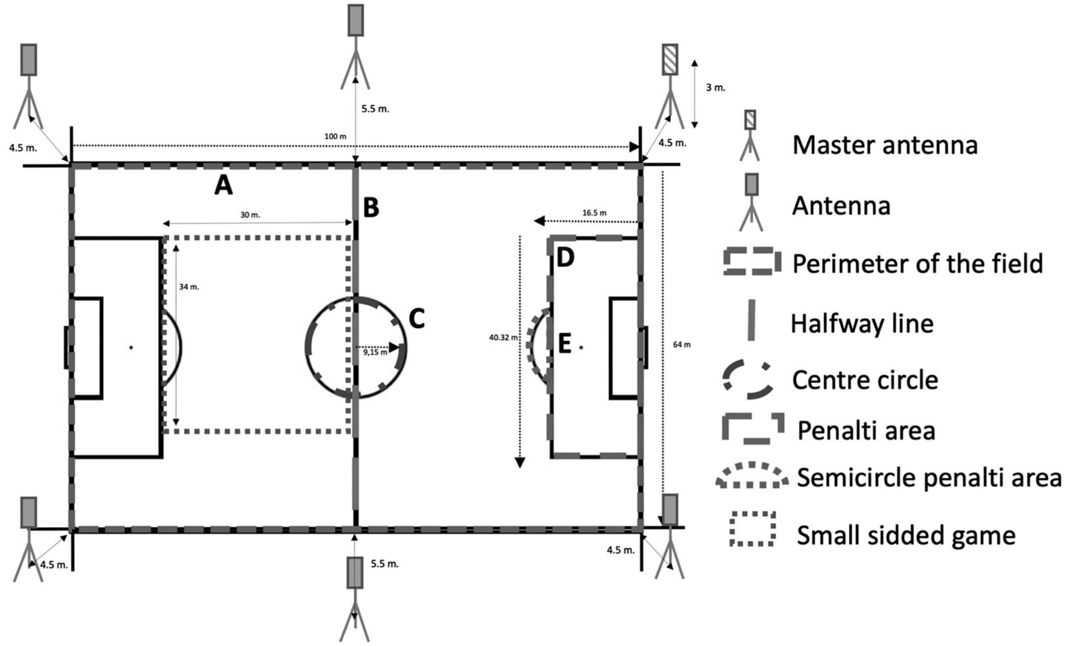

Figure 1. Different courses performed by the athletes in this research (a) perimeter of field course (goal lines and touchlines), (b) halfway line, (c) centre circle, (d) perimeter of the penalty area, and (e) semi-circular penalty area; antennae location; and the small sided game area.

semicircle penalty area: 9.15 m radius from penalty marker, as prescribed by the FIFA rules. The real distance was measured with a trundle wheel (Mini Rolfix, BMI, hersbruck, Germany). All the tasks started from a standing position. Each task was performed three times with an interval of at least 5′of rest between trials, obtaining a total of 210 trials for each type of tracking system. The participants made the different movements shown below according to two criteria: (i) to move only on the lines marked on the soccer pitch, and (ii) to carry out the movements reaching a speed of >15 km/h when the course allowed it. However, in the centre circle (c) and semicircle penalty area (e) it was not possible to reach 15 km/h due to the centrifugal force generated by the curvilinear trajectory. On a second day, a small sided game was performed with the same participants to monitor real soccer conditions (section below). Before beginning the protocols, the athletes performed a standardised 5′ warm-up at aerobic intensity (RPE 5/10) and a 5′-protocol composed of a simulation of the different movements that were to be performed later. Besides, all designed courses were practised during the warm-up. A 10-point Likert-type scale was employed, 0 being the minimum effort and 10 the maximum scale. The warm-up period and the rest of the tests were monitored in real time by S PRO™ software to verify that the devices were performing correctly and the participants achieved the necessary speed in each trial. When the participants finished this protocol, they performed 5′ of recovery running. The two days of data collection occurred in conditions that were considered good for gathering valid and reliable GPS data (no cloud cover, the satellite numbers for all units ranged from 8 to 14, and GPS horizontal dilution of precision (HDOP) was 0.95 ± 0.19 during all testing days).

The UWB system was installed on the field as follows (Figure 1): (i) six antennae with UWB technology were fixed 4.5 m. from the perimeter line of the field, except for the ones located in the middle line of the field that were fixed at 5.5 m., in this way the antennae formed a hexagon for a better emission and reception of the signal. All of them were located at a height of 3 m. and held by a tripod; (ii) once installed, they were switched on one by one making sure that the master antenna was the last, and then a process of autocalibration of the antennae was carried out for 5′; (iii) in a last step, the tracking devices were switched on and a process of recognition and automatic communication with the antennae was carried out during 1′. Each participant was equipped with two lightweight (70 g) inertial devices, measuring $81 \times 45 \times 16$ mm. The two inertial devices were placed in a custom vest located on the back of the upper torso fitted tightly to the body, as is typically used in games. In the custom vest, the devices were placed in parallel (with a separation of 2 cm) and at the same height.

Data processing

To investigate the accuracy of the two tracking systems (UWB and GPS) for monitoring players' positions on the pitch, the data were transformed into the raw position data (x and y coordinates), using S PRO software (RealTrack Systems, Almeria, Spain). The reference system to compare the results was projected in the software using a desktop GIS mapping and data editing application that allows making all kinds of geometrical shapes such as polygons or circles with millimetre accuracy (Geographic information system). In this way, the routes executed with the real measurements as well as the data in x and y coordinates of the two devices carried by the participants were introduced. Of all the data entered, only those that corresponded to the execution of the routes were selected, according to registers obtained using ANT + technology at the beginning and end of the test (Bastida Castillo, Gómez Carmona, Pino Ortega, & de la Cruz Sánchez, 2017). In routes a), b) and d) a number was assigned to each edge of the projected rectangle, so in each test the software automatically calculated the distance of the participant's position with respect to the same side in which displacement occurs (y coordinate) and opposite side (x coordinate). In lanes c) and e) the centroid of the projected circle was assigned, so in each test the software automatically calculated the distance of the position of the participant from the indicated centroid (coordinate x). The calculation of the distance of the participant's position according to the reference element was made every 0.5 s, obtaining a total of 9,586 samples. The precision error was considered as the difference between the real distance and the distance reported by the tracking systems (see Figure 1).

Small-sided game

In order to determine real and practical accuracy differences of both systems (GPS and UWB) in a tactical analysis application, a small-sided game was played monitored with WIMUPRO™ (Figure 2). A total of three trials of 10' each were carried out, using a 5' rest interval between them. The same participants who defined the pitch for accuracy and reliability analyses were distributed into two teams (7 × 7) and equipped in the same way as in the previous protocol. The area of play (34 × 30 m) and the objectives of the small-sided game (ball possession) were clearly explained to the participants in order to match the situation to a real context. The surface area (Gis Area) and the area perimeter (Gis Length), variables of typical tactical analysis, were reported for monitoring both types of tracking technology (GPS and UWB). The surface area covered by the players was used in this study because it can provide useful information for player synchronisation and space – time organisation (Garganta, 2009). It seems relevant to discover concepts and methods that allow the assembly and organisational knowledge of game complexity and the teams' dynamic interactional properties (Kempe, Grunz, & Memmert, 2015). The accuracy difference of both systems was reported as the difference in Gis Length and Gis Area between them.

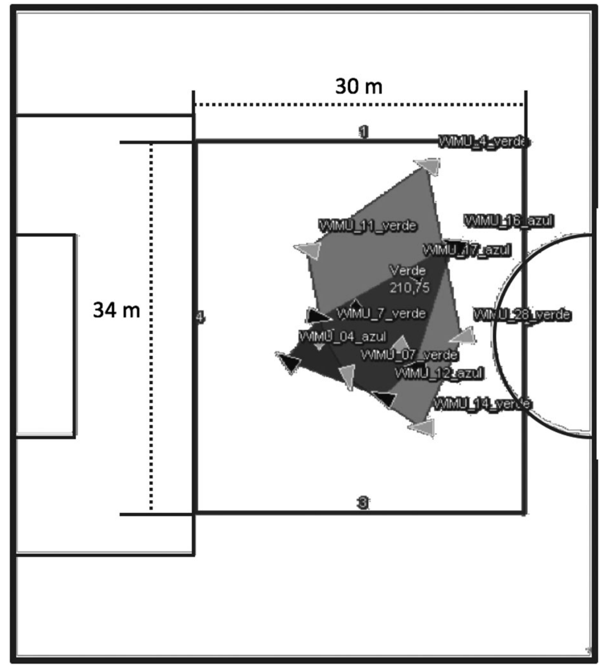

Figure 2. Area of player analysis in a typical small-sided game 7 × 7.

Equipment

Position-tracking system. The 10-Hz GPS and 20-Hz UWB chipsets are integrated in the same inertial measurement unit (IMU) device. The GPS-based position-tracking system uses the emission of radio signals in a synchronised way by satellites in orbit around the earth. The time of arrival of the signal to a chipset is translated into distance by trigonometry, allowing the position to be estimated. In order to estimate the position, the system requires at least three satellites. In the present study, during the test, the GPS system was connected to an average of 13.9 satellites. Thus, if all nodes have a common clock, the receiving node can determine the time of arrival (TOA) of the incoming signal and directly calculate its distance from the transmitter; thus, multiplying the estimated TOA by the speed of light makes it possible to draw a circle with the reference node at its centre and a radius equal to the estimated range. By collecting at least three measurements (triangulation) and intersecting the defined circles, it is possible to determine the position of the node with high precision.

The UWB system uses the same procedures as the GPS-based one to estimate position replacing the satellite reference system with a local reference system with antennae. It was adjusted to the reference field before the start of the investigation. It consisted of following the course of the perimeter of the field walking with one of the devices carried high in one hand, recognising this as the reference system. The point used to create the coordinate system was two each second making a total of 322 points. The layout of the field is projected in the S PRO™ software (RealTrack Systems, Almeria, Spain), which will later be the reference field in the system. This reference system was close to the real measures of the field (100 × 64 m).

Statistical analysis

The distance issue of the two axis coordinates to the reference line was automatically calculated and downloaded in excel format using S PRO specialised software. The accuracy of position data was calculated as the differences and percentage of differences of "*x*" and "*y*" position coordinates regarding their reference line on the field (Bastida-Castillo et al., 2018). To compare differences in accuracy between the two tracking systems, an independent-samples T-test was performed. The effect size (ES) was calculated to quantify the magnitude of the differences as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), or large (0.80 and above) (Field, 2009). The significance level was determined at $p < 0.05$. The Wilconxon test was performed to compare differences in tactical variables during small sided games between GPS and UWB, Inter-unit reliability was determined using Hopkins's reliability spreadsheet (Hopkins, Marshall, Batterham, & Hanin, 2009) to calculate the percentage typical error of measurement (% TEM). This involved comparing the reported values for the two units that each participant carried. These tests assisted with understanding the degree of error and the amount of variation between the units. Percentage of coefficient of variation (CV) was performed to determined test-retest reliability. The magnitudes of %TEMs used included poor (>10%), moderate (5–10%), or good (<5%; Hopkins, spreadsheet). The strength of the CV (<10%) was quantified in accordance with Atkinson and Nevill (1998).

Results

The mean absolute error ($N = 9586$) of the "*x*" and "*y*" position coordinates was 41.23 ± 17.31 cm and 47.6 ± 8.97 cm, respectively, for GPS, and 9.57 ± 2.66 cm and 7.15 ± 2.62 cm for UWB. Table 1 summarises the mean ± SD differences of the estimates of "*x*" and "*y*" coordinates for all designed travel tests, their percentages of difference, and *T*-student comparison between both systems with the ES of differences. The results of "*x*" and "*y*" accuracy comparison were significantly lower in all cases ($p < 0.05$) in UWB with an ES of 0.78 and 0.95, respectively.

The CV (test-retest reliability) was between 2.54% and 3.48% for GPS and between 0.54% and 1% for UWB. The %TEM (inter-unit reliability) was between 1.98 and 2.12 for GPS and between 1.12 and 1.19 for UWB.

The results of the Wilconxon test show significant differences ($p < 0.05$) in Gis Area and Gis Length in small-sided games of both systems. The difference represents 2.56% (ES = 0.09) in Gis Length attack to 8.31% (ES = 0.11) in Gis Area defence. Test retest reliability (%CV) was between 1.89% and 2.24% for GPS and between 0.4% and 0.95% for UWB. The inter-unit reliability (%TEM) was between 1.54% and 1.99% for GPS and between 1% and 1.15%.

Table 1 *T*-student for bias (in cm) comparison between GPS and UWB of "*x*" and "*y*" coordinates Figure 3.

Discussion

To our knowledge, the present study is the first to investigate the accuracy of GPS and UWB-based tracking systems for measuring players' positions in soccer tactical analysis applications. In addition, this study offers the possibility to compare the accuracy of both systems through the inclusion of both technologies in the same inertial device. Despite betting on a new player-tracking method (UWB) with the obvious limitations of GPS technology, previous studies determined sufficient accuracy of both systems for time – motion analysis applications, and no significant differences between them were examined (Bastida-Castillo et al., 2018). Nevertheless, it has been discussed that for tactical analyses, the estimation error of position should be below the natural sway of the body's centre of gravity (15–20 cm) in the observed movements (Leser, Baca, & Ogris, 2011). Assuming the above, the present results prove sufficient accuracy of the UWB tracking system to perform tactical analysis in soccer (<10 cm) in contrast with GPS (>40 cm). The significant difference ($p < 0.05$) between systems in all designed travel indicates the real advantage of UWB over GPS (ES = 0.78–0.95). The same trend was observed in

Table 1. *T*-student for bias (in cm) comparison between GPS and UWB of "*x*" and "*y*" coordinates.

		GPS				UWB					
Designed travel	Device	"*x*" difference	% difference	"*y*" difference	% difference	"*x*" difference	% difference	ES	"*y*" difference	% difference	ES
T1	1	71.48 ± 21.95	4.97%	69.63 ± 21.7	4.91%	4.36 ± 3.14*	0.09%	0.91	7.87 ± 3.35*	0.16%	0.89
	2	54.21 ± 54.85	6.05%	55.37 ± 28.84	4.84%	12.42 ± 3.8*	0.25%	0.47	3.11 ± 2.7*	0.06%	0.78
T2	1	38.68 ± 44.6	1.64%	29.61 ± 29.65	1.04%	10.43 ± 2.73*	0.37%	0.40	5.42 ± 4.13*	0.19%	0.49
	2	54.12 ± 35.58	0.96%	41.75 ± 20.25	0.73%	13.47 ± 5.91*	0.48%	0.62	6.83 ± 5.68*	0.24%	0.76
T3	1	29.08 ± 21.24	3.18%	–	–	10.82 ± 9.87*	1.18%	0.48	–	–	–
	2	32.89 ± 23.39	3.59%	–	–	10.8 ± 9.45*	1.18%	0.52	–	–	–
T4	1	48.09 ± 36.57	1.19%	44.64 ± 25.28	1.17%	7.29 ± 4.45*	0.18%	0.61	9.85 ± 4.44*	0.25%	0.69
	2	45.37 ± 28.46	1.13%	44.64 ± 27.2	1.17%	9.81 ± 3.95*	0.25%	0.65	9.85 ± 3.64*	0.25%	0.66
T5	1	16.69 ± 19.57	1.82%	–	–	7.7 ± 7.25*	0.84%	0.29	–	–	–
	2	21.76 ± 19.17	2.38%	–	–	8.62 ± 6.95*	0.94%	0.41	–	–	–
Total		41.23 ± 17.31	2.69 ± 1.74%	47.6 ± 8.97	2.31 ± 1.99%	9.57 ± 2.66*	0.58 ± 0.42%	0.78	7.15 ± 2.62*	0.19 ± 0.07%	0.95
95%LoA (L to U)		24.66–59.28	0.95–4.43	36.44–54.4	0.31–4.30	6.9–12.24	0.15–1	–	4.53–9.78	0.12–0.26	–

T1 = perimeter of the field; T2 = halfway line; T3 = centre circle; T4 = perimeter of penalty area; T5 = semicircle penalty area; * = Significance difference $p < 0.05$; difference expressed as mean ± standard deviation; ES = effect size; LoA = limits of agreement.

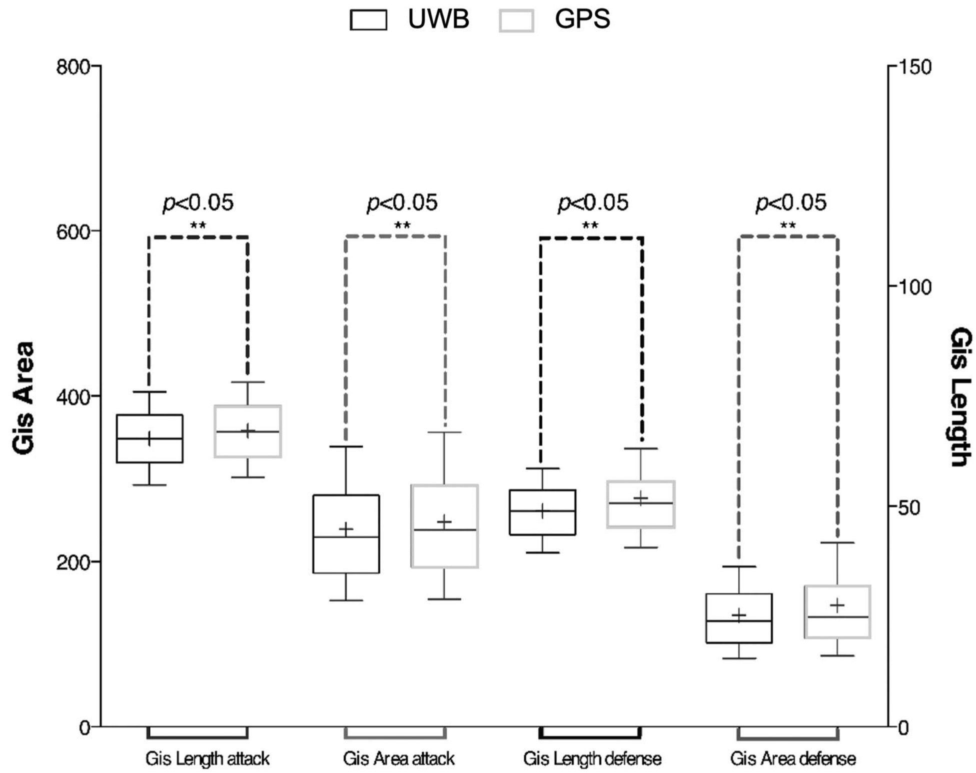

Figure 3. Box and whiskers plot with differences (m) of both systems (UWB and GPS) in Gis Length and Gis Area variables analysed in a small-sided game.

reliability, in both GPS and UWB good results were reported in test-retest (%CV) and inter-unit reliability (%TEM) (GPS: %CV = 2.89% ± 0.44 and %TEM = 2,06 ± 0.1; UWB: %CV = 0.68% ± 0.2 and %TEM = 1.15 ± 0.08).

In a small sided game, the results demonstrate differences of 2.56% to 8.31% in usual tactical analysis variables using one system or another. Good test-retest and inter-unit reliability were reported for both systems, but better results were observed for the UWB-based system. The difference that the results showed was not of great magnitude. This phenomenon could be due to the short duration of the trials (10´), taking into account the accumulation of error over a prolonged period of time (Bastida-Castillo et al., 2018; Cummins et al., 2013; Rhodes et al., 2014). However, the difference reported was significant between both systems and represents an important error that can be from a couple of metres to 21 metres. In this sense, we recommend the use of UWB-based tracking systems to monitor this kind of analysis, as they are more precise than GPS-based systems.

For accuracy analysis of tracking system, only the gold standard (motion-capture system) comparison was performed, until the publication of an alternative method described in Bastida-Castillo et al. (2018), which tries to justify the great cost in time and money of the first method. This arose from the need to evaluate a radio-frequency tracking system in the location in which it will be used, because the same tracking system can report with varying degrees of precision, depending on where it is going to be used and owing to the different structures (distance from the court to the walls, marker position, etc.) that different courts present. So, a comparison of the accuracy results of the current WIMUPRO™ with other studies testing similar systems is very difficult because of the lack of standardised methods. Nevertheless, previous studies on GPS 10 Hz show a mean error ranging from 1.0% to 29% (Bastida-Castillo et al., 2018; Beato, Bartolini, Ghia, & Zamparo, 2016; Castellano et al., 2011; Johnston, Watsford, Kelly, Pine, & Spurrs, 2014). Previous studies only measure time-motion variables when investigating the accuracy of the GPS-based tracking system, not the exact position of players, which is evaluated in the current study. The results of the current study showed a mean difference in distance from the reference of between 0.31% and 4.30%, which is lower than previously reported. On the other hand, only two previous studies reported the position error of LPS in dynamic tasks, with a mean error of 0.21 m. in indoor conditions (Luteberget, Spencer, & Gilgien, 2018) and 0.23 m. in outdoor conditions (Ogris et al., 2012). Although the

Table 2. Advantages and disadvantages of GPS-based and UWB-based tracking systems.

ADVANTAGES		DISADVANTAGES	
GPS	UWB	GPS	UWB
High numbers of measurements possible		Satellite signal line of sight in stadium	Fixed installation
Operator not needed	High accuracy	Accuracy limited for players' positioning	Installation cost
Short installation time	High transmission path		Installation time
High reliability			

current study was performed in outdoor conditions, the result of the present model of LPS with UWB-based technology slightly outperforms these results (mean error ranging 0.04 m. to 0.12 m).

Table 2 Advantages and disadvantages of GPS-based and UWB-based tracking systems.

Conclusion

In summary, although previous studies determined the sufficient accuracy of GPS (>10 Hz) for time – motion analysis, the present results prove that it has obvious limitations in determining the accurate position of players. On the other hand, UWB WIMUPRO™ 20 Hz has been demonstrated to be an accurate technology for estimating the position of players on the pitch. It provides new ways to study game complexity and dynamic interaction properties that could improve research into the analysis of tactical performance in team sports. Even so, both systems have a series of advantages and disadvantages in their use (Table 2), that depending on the objective (for example only time-motion analyses not needing LPS accuracy) will make one system or another more appropriate.

Study Limits

In the current study the raw positional data was examined. Nevertheless, not all systems provide unfiltered raw positioning data for the analyst. The current study reports insight into the raw positional data and the error in the acquisition technology, without the possible influence of the manufacturer's software. Thus, it could be used as a more stable measure of accuracy than software-derived metrics.

The effect of field conditions is also especially important in indoor settings, when the distances to the walls are small or there are obstacles that can interfere with the signal such as markers, baskets, etc. Although, to a lesser extent, this is also a factor that influences the fields in outdoor conditions. This has been observed in several studies (Bastida-Castillo et al., 2018; Luteberget et al., 2018), so it cannot be assumed that the current results would be true for all types of fields, especially larger stadiums. In this sense, future research should include the inclination of reference antennae in the vertical direction of the playing field as well as the optimisation of the geometry of their positions in relation to the playing field. If needed, the accuracy of this type of systems in any field could be evaluated using the methodology described in this study with appropriate software.

Disclosure statement

The last author of this article participates in the research and the sports development of the inertial device mentioned. To guarantee the objectivity of the results, the data from the inertial devices were obtained and analyzed by two independent researchers not related to the inertial device development.

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