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Validity and reliability of an eight antennae ultra-wideband local positioning system to measure performance in an indoor environment

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ABSTRACT

Validity and reliability have become crucial factors in tracking player load and positioning. One of the most important parameters to guarantee accurate measurements with radiofrequency systems is the number of reference nodes used to calculate player position. However, the accuracy of ultra-wideband (UWB) technology has only been analysed with 6 antennae. So, the purpose of the present study was to analyse the accuracy and inter-unit reliability of an UWB system with eight antennae. Three well-trained males covered 18 trajectories for the analysis of x- and y- coordinate accuracy assessment related to the positional variation among eight antennae UWB data and lines on a basketball court. This was achieved using geographical information system mapping software that calculated, for each interval and participant, the distance from the main axis of locomotion and the opposite side of the field every 0.5 s. The results showed that this is a valid system (Mean = 0.03 m; magnitude differences = 0.21% with real measures as reference; % CV <1% in all cases) for measuring locomotion and positioning. Besides, the inter-unit, test-retest and inter-subject analysis did not influence the reliability results. So, an eight antennae UWB system can be considered suitable for locomotion and positioning in an indoor environment.

Introduction

Electronic performance and tracking systems (EPTS) have been used to quantify training load (Rico-González, Pino-Ortega, Nakamura, Moura et al., 2020), to detect player´s positioning (Low et al., 2020; Rico-González, Pino-Ortega, Nakamura, Arruda-Moura et al., 2020; Rico-González, Pino-Ortega, Nakamura, Moura et al., 2020), and to assess their relationship with the changes in physical fitness performance (Jaspers et al., 2017), injury risk (Colby et al., 2014; Ehrmann et al., 2016) and neuromuscular fatigue (Garrett et al., 2019), to monitor rehabilitation programmes (Greig et al., 2019) and, to assess tactical positioning performance (Low et al., 2020;

Rico-González, Pino-Ortega, Nakamura, Moura et al., 2020, 2020). The quantification of the variables before mentioned has been increased in the last years because training load distribution is fundamental to ensure sufficient after-game recovery, prevent pre-match fatigue (Akenhead et al., 2016; Coutinho et al., 2015; Fessi et al., 2016; Jeong et al., 2011; Malone et al., 2015) and allow the prescription and managing of training workload precisely. Thus, EPTS has become fundamental in scientific research activity and this technology has been widely adopted by the teams´ technical staff (Serpiello et al., 2018). EPTS include optic-based systems (VID) and radio-frequency systems: Global Positioning Systems (GPS) and Local Positioning Systems (LPS).

The validity and reliability of EPTS have been classified as a fundamental topic in sport (Malone et al., 2017; Rico-González, Arcos et al., 2020). Several studies have assessed the validity and reliability of different technologies in different conditions and sports (Bastida-Castillo, Gómez-Carmona, De La Cruz Sánchez et al., 2019; Buchheit et al., 2014; Leser et al., 2014; Serpiello et al., 2018; Siegle et al., 2013). Malone et al. (2017) highlighted some considerations that should be followed when using GPS technology in the sport setting. One of these considerations is the number of satellites connected to each device. Specifically, to track positioning with GPS it is necessary to have a satellite network as a reference with a known position and devices to be detected in an unknown position (Malone et al., 2017; Rico-González, Arcos et al., 2020). Jackson et al. (2018) found that a higher number of connected satellites could improve the covered area and, subsequently, provide a higher quality of measurement. However, LPS seems to be the more accurate technology currently (Bastida-Castillo, Gómez-Carmona, De La Cruz Sánchez et al., 2019; Linke et al., 2018).

LPS, as a radio-frequency technology, is based on quite similar principles to those of GPS (Rico-González, Arcos et al., 2020). In this case, the satellite network is replaced by a set of antennae placed around the court. However, to our knowledge, no study assesses if the number of antennae around the court could influence the coverage area and subsequently, the accuracy of the system. In this way, Ogris et al. (2012) found that the accuracy of the LPS system offered less precision on the margins of the observation field. Among LPS technologies, ultra-wideband (UWB) has become the most promising one for positioning and tracking (Alarifi et al., 2016). To date, several studies have assessed the validity and reliability of UWB technology (Rico-González, Arcos, Clemente et al., 2020). However, in all of them, the antenna set was composed of 6 nodes around the court as a reference system.

Although athlete tracking technology is continually improving due to developments in hardware, software and data processing (Malone et al., 2017), there are no studies which have assessed if the number of UWB antennae (i.e. reference nodes) should be considered by manufacturers, researchers or technical staffs in order to carry out high-quality measurements. This variable would provide highly accurate reports to give to the coaches and, subsequently, help them in training design with higher accuracy. Thus, the purpose of the present study was to assess the validity and inter-unit reliability of UWB technology with an eight-antennae set. We hypothesised that a higher number of antennae could improve the covered area and, subsequently, provide a high-quality measurement.

Method

Participants

Three healthy well-trained males (age: 26.3 ± 4.5 years, mass: 74.2 ± 6. 7kg, height: 1.83 ± 0.06 m) volunteered to participate in the current investigation. The participants did not present any physical limitations or musculoskeletal injuries that could affect testing. Subject height was measured using a stadiometer (SECA, Hamburg, Germany), and body mass was obtained using a body composition monitor (TANITA BC-601, Tokyo, Japan). The study was conducted according to the Declaration of Helsinki and was approved by the Bioethics Commission of the University of Murcia (ID: 2061/2018). Participants were informed of the risks and provided informed written consent.

Equipment

The study methodology was written following the protocol by Rico-González, Arcos, Clemente et al. (2020) in order to guarantee a precise description of the use of technology, scoring 21 points out of 23 (91.3%). The rest of the items cannot be explained as the authors did have not this information.

Technology specification

Positional data on a court were recorded with a time-motion tracking system using six inertial measurement units (IMU; WIMU PRO[TM], RealTrack Systems, Almeria, Spain). Each device had its own internal microprocessor, 2 GB flash memory, and a high-speed USB interface, to record, store and upload data. The devices were powered by an internal battery with 4 h of life, weighed 70 g in total, and measured 81x45x16 mm. Each device contains, among other sensors, a 10 Hz GPS and 33 Hz UWB. This equipment and its measurements are valid and reliable using GPS (Muñoz-López et al., 2017) and UWB systems (Bastida Castillo et al., 2018). S PRO[TM] software (RealTrack Systems, Almeria, Spain) was used to analyse and export the data on the x- and y- position coordinates (Bastida-Castillo, Gómez-Carmona, De la Cruz-sánchez et al., 2019).

This UWB system was designed to alleviate any satellite reference problems by using time-based positioning techniques (Alarifi et al., 2016), in which the signal propagates from the transmitter (antenna) to the receiver (device). The transmitter in an UWB system is a set of antennae that transmit the radiofrequency signal almost under the same principle as the GPS system (Rico-González, Arcos et al., 2020). The UWB system occupies a very large frequency band, at least 0.5 GHz, as opposed to more traditional radio communications that operate on much smaller frequency bands. On the other hand, since UWB is only allowed to transmit at very low power, its signal emits little noise and can coexist with other services without influencing them (Bastida-Castillo, Gómez-Carmona, De la Cruz-sánchez et al., 2019).

System installation

The UWB system is composed of two sub-systems: (1) the reference system and (2) the devices tracked (carried by the players). The first one is composed of antennae that are transmitters and receivers of the radio-frequency signals. The antennae nodes compute the position of the devices that are in the play area, while the device receives that

calculation (Bastida-Castillo, Gómez-Carmona, De la Cruz-sánchez et al., 2019). In this study, the reference system was composed of eight antennae placed around the field and devices that were attached to the players (two each player) in a pocket in appropriate tight-fitting garments placed between the scapulae at the T2-T4 level to avoid unwanted movements and before in-field exercises following previous study protocols (Reche-Soto et al., 2019).

The antennae were set up around the court following Luteberget et al. (2018) in optimal conditions (see Figure 1). The antennae with UWB technology were fixed 5 m from the perimeter line in the corners (n = 4) and 7 m from the middle line of the field (n = 2) and from behind the goals (n = 2) (Figure 1), forming an octagon for better signal emission and reception. All of the antennae were positioned at a height of 3 m and held by a tripod (Bastida-Castillo, Gómez-Carmona, De la Cruz-sánchez et al., 2019). Once installed, they were switched on one-by-one, with the master antenna turned on last. From that moment, it was necessary to respect a 5-minute protocol in which the antennae computing nodes calculate their positioning and the distance between them. Finally, unlike GPS sensors, UWB manufacturers provide a method that allows data time synchronisation. In this case, the master antenna manages the time using a common clock which allows data recording at the same time. Time position coordinates were calculated with a 33 Hz sampling rate (Bastida-Castillo, Gómez-Carmona, De la Cruz-sánchez et al., 2019) (Figure 1).
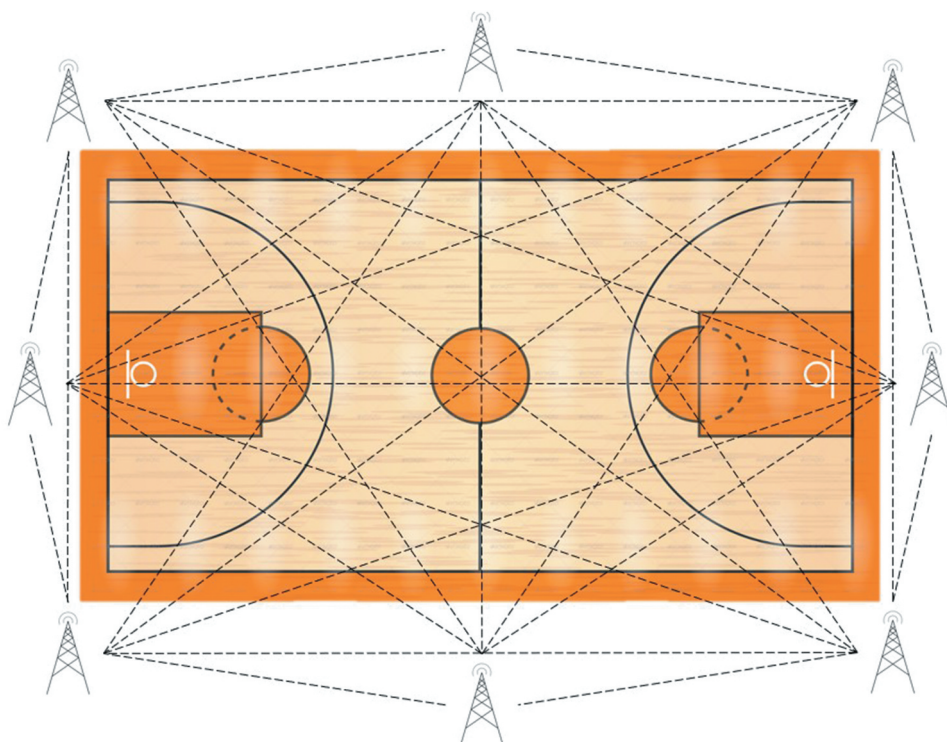

Figure 1. The ultra-wideband reference system disposition during the study.

Procedure

Data acquisition in the current study was carried out on a standard basketball court measuring 28 × 15 m. Following Alarifi et al. (2016) the conditions were maintained with low temperatures, humidity gradients, and slow air circulation to allow easier positioning. Moreover, as the UWB is still subject to interference caused by metallic materials (Alarifi et al., 2016), the protocol was followed in the place that was furthest from this kind of materials.

The three participants completed a lineal trajectory along the halfway line of the basketball court on six different days. The distance was covered twice: once in each direction (expressed as going and coming back in the results section and onwards). So, a total of 72 trajectories (Mean velocity: 20.91 ± 0.82 km/h; Mean time to cover half-line: 2.41 ± 0.11 seconds) was monitored with two devices in each participant. This resulted in a total of 11,424 samples (2 devices in 72 trajectories at a sampling frequency of 33 Hz) which were used for the statistical analysis in the present study.

The participants covered the trajectories according to two criteria: (1) to move only along the halfway line marked on the basketball court, and (ii) to reach a speed of > 21 km/h. 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 movements that were to be performed later. A 10 points Likert-type scale was employed, 0 being the minimum effort and 10 the maximum scale (Bastida-Castillo, Gómez-Carmona, De la Cruz-sánchez et al., 2019). The warm-up period and the rest of the test were monitored in real-time by S PRO^{TM} software to verify that the devices were performing correctly and the participants had achieved the necessary speed in each trial. Two trials were deleted because they did not reach the minimum speed.

Data processing and reference system

Different positioning measurement methods have been applied to report data from RF signals between the antennae and devices. The high amount of positioning algorithms can be classified into five main categories based on estimated measurements (Alarifi et al., 2016). Typically, with the time difference of arrival (TDOA) only one transmitter is necessary (i.e. antenna master) that requires multiple receivers to share the data and cooperate to determine the location of the transmitters. This cooperation needs significant bandwidth in comparison with other algorithms. TDOA, together with the time of arrival (TOA), offers higher accuracy relative to other algorithms because of the high time resolution of the UWB signals. So, in this study, the TDOA algorithm was used to estimate positioning.

To investigate the precision of the UWB system for monitoring players´ positions on the court, the data were transformed into raw position data (x and y coordinates) using specific software (SPRO^{TM}, RealTrack Systems, Almeria, Spain). The data were downloaded after the session. This is consistent with other research in which the data monitored in real-time were significantly inaccurate relative to the post-session data (Aughey & Falloon, 2010). Unlike other validity and reliability studies in which optic-based systems have been used as the gold standard (Linke et al., 2018; Ogris et al., 2012), a geographical information system (GIS) was proposed as the reference

system in this study (Bastida-Castillo, Gómez-Carmona, De la Cruz-sánchez et al., 2019), which does not require any instrument additionally than a WIMU PRO^{TM} inertial device with SPRO^{TM} software included. The reference system to compare the results was projected in the software using the GIS mapping application. GIS allows representation of geometrical shapes, such as polygons or circles, with millimetre accuracy. In this way, the routes selected with their real measurements (measured by trundle wheel; reliability: ICC = 0.99; accuracy: Bias<0.5 cm) were introduced on the previously created template. And then, the x and y coordinate data of the UWB system were introduced and compared. The distance error of each axis was reported.

Of all the data entered, only those that corresponded to the execution of the routes were selected, according to recordings obtained using ANT+ technology and photocells at the beginning and end of each test. Specifically, photocells (ChronoJump, Spain) include a connection that carries a communication signal to the software to start a timer when the light beam is interrupted. In this experiment, an ANT + transmitter was connected to the output of the communication signal via RCA cable (standard communication cable). The ANT+ transmitter emits a wireless signal that the inertial devices receive through ANT+ and register a mark in the timeline of WIMU PRO^{TM} when they receive a signal. This process was evaluated previously, obtaining very satisfactory results in reliability (ICC = 1.00; r = 1.00) and validity assessment (Bias = 0.6 ± 1.8 milliseconds; 95%LOA = −2.9 to 4.1 milliseconds) (Bastida Castillo et al., 2017) (see more information in the previous study).

Statistical analysis

Data are presented as mean values ± SD. A Shapiro-Wilk test was performed for the evaluation of normality (assumption) for statistical distribution. The reliability analysis was expressed as a percentage of the coefficient of variation (%CV). Inter-unit reliability was defined as the difference in using one device or another. Test-retest reliability indicates the difference in making the measures on one day or another. And inter-subject reliability shows the variation in data measured in one participant or another. The accuracy analysis was assessed as the mean difference between device data and real measures (as the criterion reference), the mean difference was relativised as the percentage of differences. The accuracy analysis was presented as the percentage of the coefficient of variation (% CV). Statistical analysis was performed using SPSS (Statistics 20.0) for Mac OS Mojave.

Results

The mean difference was less than 0.04 m and into the 95% of cases (n = 5712 samples) was between 0.01 and 0.07 m respect to the real measure as the reference. The magnitude of the differences was expressed as 0.21% in comparison with the real measures. %CV was less than 1% in all cases (Table 1).

The reliability results are shown in Table 2. Remarkably, %CV was less than 1% in all cases (going, coming back, and total samples). Besides, inter-unit, test-retest and inter-subject analysis did not influence the reliability results (Table 2).

Table 1. Accuracy analysis as mean difference, percentage of difference and percentage of coefficient of variation with real measures as reference.

	Mean ± SD (m)	Mean Difference (m)	Difference (%)	CV (%)
Going	14.03 ± 0.03	0.03 ± 0.03	0.21%	< 1%
Coming back	14.02 ± 0.02	0.03 ± 0.03	0.27%	< 1%
Only Device 1	14.03 ± 0.03	0.03 ± 0.04	0.21%	< 1%
Only Device 2	14.02 ± 0.07	0.03 ± 0.07	0.23%	< 1%
Total	14.03 ± 0.03	0.03 ± 0.02	0.21%	< 1%

Table 2. Percentage of coefficient of variation as inter-unit, test-retest and inter-subject reliability in relation to going, coming back and total.

	Device 1 (M± SD, m)	Device 2 (M± SD, m)	CV (%)
Inter-unit			
Going	14.03 ± 0.02	14.04 ± 0.02	< 1%
Coming back	14.03 ± 0.03	14.02 ± 0.03	< 1%
Total	14.03 ± 0.03	14.03 ± 0.06	< 1%
	Test (M± SD, m)	Retest (M± SD, m)	CV (%)
Test-retest			
Going	14.04 ± 0.02	14.06 ± 0.02	< 1%
Coming back	14.03 ± 0.06	14.04 ± 0.04	< 1%
Total	14.04 ± 0.04	14.04 ± 0.04	< 1%
	Participant 1 (M± SD, m)	Participant 2 (M± SD, m) Participant 3 (M± SD, m)	CV (%)
Inter-Participants			
Going	14.06 ± 0.03	14.05 ± 0.04 14.05 ± 0.06	< 1%
Coming back	14.01 ± 0.03	14.02 ± 0.05 14.03 ± 0.02	< 1%
Total	14.03 ± 0.03	14.03 ± 0.02 14.03 ± 0.04	< 1%

Discussion and implications

To our knowledge, this is the first study to assess the accuracy and inter-unit reliability of an eight antennae UWB system for monitoring the positions of players. The main findings were: (1) the eight antennae UWB system is a valid system (Mean = 0.03 m; magnitude differences = 0.21% with real measures as reference; %CV <1% in all cases) to measure locomotion and positioning in an indoor environment, and (2) inter-unit, test-retest and inter-subject analysis did not influence the reliability results.

Several studies have assessed the accuracy and reliability of LPS systems (Bastida Castillo et al., 2018; Bastida-Castillo, Gómez-Carmona, De la Cruz-sánchez et al., 2019; Buchheit et al., 2014; Frencken et al., 2010; Linke et al., 2018; Luteberget et al., 2018; Ogris et al., 2012; Sathyan et al., 2012; Siegle et al., 2013; Stevens et al., 2014). Some of them (Bastida Castillo et al., 2018; Bastida-Castillo, Gómez-Carmona, De la Cruz-sánchez et al., 2019; Linke et al., 2018) compared EPTS technologies. Linke et al. (2018) showed higher validity for measuring an athlete's position with LPS (23 ± 7 cm) than both VID (56 ± 16 cm) and GPS (96 ± 49 cm). However, among LPS technologies, UWB seems to be the most promising technology for the future. It showed higher accuracy and inter-unit reliability than GPS and VID in some studies (Bastida Castillo et al., 2018; Bastida-Castillo, Gómez-Carmona, De la Cruz-sánchez et al., 2019). Specifically, Bastida Castillo et al. (2018) demonstrated the better accuracy

of UWB (bias: 0.57–5.85%), test-retest reliability (%TEM: 1.19), and inter-unit reliability (bias: 0.18) in determining distance covered than the GPS technology (bias: 0.69–6.05%; %TEM: 1.47; bias: 0.25) overall. In another study, the same authors (Bastida-Castillo, Gómez-Carmona, De La Cruz Sánchez et al., 2019) showed the mean absolute error found for the GPS (N = 9445) of 'x' and 'y' coordinates was 41.23 ± 17.31 cm and 47.60 ± 8.97 cm, respectively, while for UWB, it was 9.57 ± 2.66 cm and 7.15 ± 2.62 cm. Considering that the positioning should be less than the natural balance of the centre of gravity of the human body (between 15 and 20 cm) in an observed movement (Leser et al., 2011), the results of these studies carried out with UWB and the results of the present study showed that this technology with six or eight antennae set is valid for training locomotion and positioning.

However, there is a need to compare the results of the six antennae UWB and eight antennae UWB. All of the studies that assessed the accuracy of wireless UWB used a set of six antennae (Bastida Castillo et al., 2018; Bastida-Castillo, Gómez-Carmona, De La Cruz Sánchez et al., 2019; Bastida-Castillo, Gómez-Carmona, De la Cruz-sánchez et al., 2019; Leser et al., 2014). Bastida-Castillo et al. (2019) measured positioning in soccer showing 9.57 ± 2.66 cm and 7.15 ± 2.62 cm of mean absolute error. However, studies carried out in an indoor environment suggest higher accuracy. For example, the same authors in another study (Bastida-Castillo, Gómez-Carmona, De la Cruz-sánchez et al., 2019) observed the movements over basketball court lines (i.e. indoor) with a 6 antennae UWB wireless system. They found a mean absolute error of all estimations for the x-position of 5.2 ± 3.1 cm and the y-position of 5.8 ± 2.3 cm. In this study, the results showed that the precision error of eight antennae UWB was less than 0.04 m and, into the 95% of the cases (n = 2340 samples) was between 0.01 and 0.07 m in comparison with the real measure as the reference. So, although these results showed a slight suggestion that eight antennae could record more accurate data, the researchers should develop further studies in which six antennae UWB and eight antennae UWB are compared under the same conditions.

Limitations

The effect of using more devices with the same bandwidth could affect the results. However, a previous study did not report any problems in UWB tracking system accuracy with 28 devices turned on (Bastida Castillo et al., 2018).

The results of the present study reflect the accuracy and reliability of an eight antennae UWB system in an indoor environment. However, further studies are needed to corroborate if this number of antennae shows higher quality measurements than a six antennae UWB system.

Results of the accuracy analysis were represented as the difference between the real measure and the raw data of devices' positioning during the trials. Therefore, they were shown in metres and relativised by percentages. Additionally, following the data reported previously by several authors, the accuracy results were complemented with the coefficient of variation. However, since it assesses the results in terms of mean or median in this context, further studies could assess its relevance considering the effects on levels of variability and quantitative error.

Conclusions

UWB seems to be the most promising technology for the future. However, athlete tracking technology is continually improving thanks to developments in microprocessors, data processing, and software. In this way, even though six antennae UWB has been assessed in several studies, new studies should suggest further developments. In this study, an eight antennae UWB system showed its suitable accuracy and inter-unit reliability in an indoor environment.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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