applied sciences

MDPI

Review

Accuracy and Reliability of Local Positioning Systems for Measuring Sport Movement Patterns in Stadium-Scale: A Systematic Review

Markel Rico-González [1], Asier Los Arcos [2,*], Filipe M. Clemente [3,4,*], Daniel Rojas-Valverde [5] and José Pino-Ortega [6]

1 Departament of Physical Education and Sport, University of Basque Country, UPV-EHU, Lasarte 71, 01007 Vitoria-Gasteiz, Spain; markeluniv@gmail.com or mrico017@ikasle.ehu.eus
2 Society, Sports and Physical Exercise Research Group (GIKAFIT), Departament of Physical Education and Sport, Faculty of Education and Sport, University of Basque Country (UPV-EHU), 01007 Vitoria-Gasteiz, Spain
3 Escola Superior Desporto e Lazer, Instituto Politécnico de Viana do Castelo, Rua Escola Industrial e Comercial de NunÁlvares, 4900-347 Viana do Castelo, Portugal
4 Instituto de Telecomunicações, Delegação da Covilhã, 1049-001 Lisboa, Portugal
5 Centro de Investigación y Diagnóstico en Salud y Deporte (CIDISAD), Escuela deCiencias del Movimiento Humano y Calidad de Vida, Universidad Nacional, Heredia 86-3000, Costa Rica; drojasv@una.cr
6 Faculty of Sports Sciences, University of Murcia, 30720 San Javier, Spain; josepinoortega@um.es
* Correspondence: asier.losarcos@ehu.eus (A.L.A.); filipeclemente@esdl.ipvc.pt (F.M.C.)

Received: 30 July 2020; Accepted: 28 August 2020; Published: 29 August 2020

Abstract: The use of valid, accurate and reliable systems is decisive for ensuring the data collection and correct interpretation of the values. Several studies have reviewed these aspects on the measurement of movement patterns by high-definition cameras (VID) and Global Positioning Systems (GPS) but not by Local Positioning Systems (LPS). Thus, the aim of the review was to summarize the evidence about the validity and reliability of LPS technology to measure movement patterns at human level in outdoor and indoor stadium-scale. The authors systematically searched three electronic databases (PubMed, Web of Science and SPORTDiscus) to extract studies published before 21 October 2019. A Boolean search phrase was created to include sport (population; 8 keywords), search terms relevant to intervention technology (intervention technology; 6 keywords) and measure outcomes of the technology (outcomes; 7 keywords). From the 62 articles found, 16 were included in the qualitative synthesis. This systematic review revealed that the tested LPS systems proved to be valid and accurate in determining the position and estimating distances and speeds, although they were not valid or their accuracy decreased when measuring instantaneous speed, peak accelerations or decelerations or monitoring particular conditions (e.g., changes of direction, turns). Considering the variability levels, the included studies showed that LPS provide a reliable way to measure distance variables and athletes' average speed.

Keywords: local positioning system; electronic performance and tracking system; technology; game-analysis

1. Introduction

Electronic Performance and Tracking Systems (EPTS) are divided into Local Positioning Systems (LPS), multiple high-definition cameras (VID) and Global Positioning Systems (GPS) [1]. Moreover, LPS and GPS based sensors are included in a Wireless Body Sensor Network [2–4], which is a group of wearable sensor nodes and which can include other types of sensors (e.g., microelectromechanical sensors). These systems allow the quantification of kinematic [5,6], physiological [7], neuromuscular [5] and tactical variables [8–11] to optimize the training process and performance in competition [5,12–15]. GPS and VID have been widely used with a very similar frequency to track player movement patterns, but this cannot be interpreted as equality over time [1,16]. VID is a methodology for analyzing players' and teams´ performance based on multiple high-definition cameras placed around the field that track the players [12,13]. Until 2014, the use of this system was more common than other technologies to analyze soccer competition [12,16], although due to installation difficulties, VID was installed only in official match stadiums, making the assessment of the competition possible but rarely the monitoring of the training process [17,18]. It seems that the limitation to analyze team performance during the training process by VID was resolved using radio-frequency technologies (i.e., GPS and LPS) [19–21]. Recently, several federations of team sports such as soccer, Australian football or rugby allow the use of radio-based technologies during matches making their utilization more common. Thus, team sports technical staff will be able to assess team performance using the same technology (i.e., GPS or LPS) during competition and training. Since several studies have shown higher accuracy of LPS technologies compared to the rest of the available tools [18,22–24], it has been hypothesized that this system will be increasingly common in the future [19,20].

2. Local Positioning Systems

LPS, as a radio-frequency technology, is based on quite similar principles to those of GPS [19,21]. In this case, the satellite network is replaced by a set of antennae placed around the court, in order to alleviate any satellite reference problems by using time-based positioning techniques [19], in which the signal propagates from the transmitter (antenna) to the receiver carried by the players (device) [16,17,20]. The antennae continually send information to LPS receivers and the positioning is calculated with different algorithms classified into five categories based on estimating measurements: (1) time of arrival (TOA); (2) angle of arrival (AOA); (3) received signal strength (RSS); (4) time difference of arrival (TDOA); and, (5) hybrid algorithm [19]. At least three antennas that collect the information on three axes (i.e., x, y, z) are necessary to determine the positioning [19,20]. Several types of LPS have been used based on ultra-wide band (UWB) technology [17] or based on glass fiber technology [25].

Why Local Positioning Systems' Review?

The accuracy and retest reliability are the two most important aspects of measurement [26]. Thus, the assessment of these two aspects on the measurement of player movement patterns is essential in any EPTS, mainly when it is used to plan, prescribe and monitor players' performance [27]. EPTS validation studies can be divided into three categories according to the examined parameter: (1) accuracy during static positioning (spatial coordinates), (2) accuracy during speed and acceleration movement and (3) accuracy during continuous data (e.g., small-sided games) [18]. To carry out a comprehensive accuracy assessment of EPTS, comparisons need to be made in three different categories because in each category different problems could occur and different accuracy demands have to be met [18]. While several studies have assessed the validity and reliability of GPS [5,14,27] and the VID [12] technologies to track player movement patterns with systematic reviews, to date, no study has carried out this type of analysis with respect to LPS technology. Thus, the aim of the review was to summarize the evidence about the validity and reliability of LPS technology to measure movement patterns in outdoor and indoor environments.

3. Materials and Methods

3.1. Design

The systematic review was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [28]. The protocol was not registered before the beginning of the project and did not require Institutional Review Board approval. The systematic electronic search was computed from three databases (PubMed, Web of Science and SPORTDiscus) to identify articles published before 22 October 2019. The authors were not blinded to journal names or manuscript authors. We created a Boolean phrase to include population (team sport, soccer, football, futsal, basketball, rugby, handball, hockey), terms relevant to the intervention technology (UWB, ultra-wide band, LPS, local positioning system*, LPM, local position measurement*) and measured outcomes (agreement, accurate, accuracy, precision, reproducibility, reliability, validity). Groups of keywords (population, technology and outcomes) were connected with OR within each group and using AND to combine the three groups.

3.2. Selection of Studies

One of the authors (MRG) downloaded the main data from the articles (title, authors, date and database) to an Excel spreadsheet (Microsoft Excel, Microsoft, Redmond, WA, USA) and removed the duplicate records. Then, the referred authors (MRG, JPO, ALA) screened search results independently against inclusion/exclusion criteria. The authors were not blinded to the title or authors of the publications. Any disagreements on the final inclusion-exclusion status were resolved through discussion in both the screening and excluding phases, and the final decision was through agreement among the authors.

Abstract and conference papers from annual meetings were not included because of rigor in outcome measures. If we had any questions about the application of the inclusion-exclusion criteria, we requested further information from the authors. The additional information provided by the authors was considered during the screening process. Lack of additional information led to the article being excluded. Documents from all languages were included unless the translation could not be made.

4. Results

4.1. Identification and Selection of Studies

A total of 62 documents were initially retrieved from SPORTDiscus (*n* = 11), PubMed (*n* = 16) and Web of Science (*n* = 35), of which 25 were duplicates. A total of 37 articles were screened. Next, the full texts and abstracts of the remaining articles were evaluated and 21 were removed because they did not report validity and reliability of LPS in team sports. Finally, 16 studies were included in the qualitative synthesis (Figure 1).

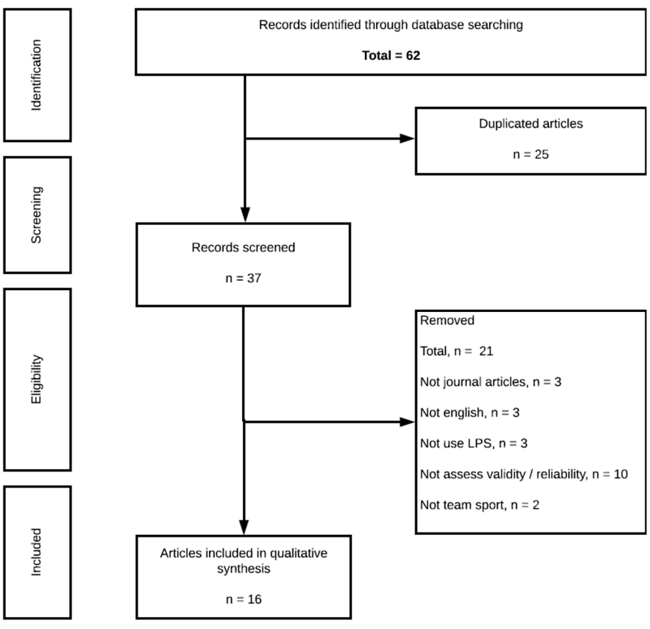

Figure 1. Flow diagram of the study.

4.2. Assessment of Methodological Quality

The quality of the included studies was individually assessed based on the information provided in the method section using the Rico-González et al., [21] checklist for the use of LPS technologies. Among the articles included in this systematic review (*n* = 16), 5 provided 29% of the required criteria, 3 provided 33%, 2 provided 38%, 2 provided 43%, 2 provided 48% and another 2 provided 52%. (Appendix A).

4.3. Study Characteristics

Among the 16 included articles, 1 article aimed to find interchangeability between EPTS systems [29]. The rest (*n* = 15) were developed to assess the validity or accuracy of LPS systems, and among them, five articles evaluated reliability [17,23,30–32] (Appendix B).

Despite the fact that LPS was developed to track players' positioning in indoor environments, the majority of the studies included in this systematic review were carried out outdoors (*n* = 9) during soccer training tasks [18,22–24,29,31,33–35]. Most of the studies carried out in indoor environments (*n* = 6) were performed during basketball bouts [17,30,36], while 1 was performed on ice hockey [37], 1 with handball players [38] and 1 was not specified [39]. In addition, 1 article was carried out in both environments [32] (Appendix B).

LPS has been used based on different technologies. Four studies used UWB technology with 6 antennae around the field and, in general, 18 Hz [17,23,24,36]. Local Position Measurement (LPM) was used in 10 studies in which between 11 and 19 antennae were used as a reference and, overall, at 45 data points per second (*n* = 6) [18,22,29–31,33–35,38,39]. The rest used Wireless Ad hoc System for Positioning (WASP) technology [32] with 12 antennae and 10 Hz, and other radio-based systems at 10 Hz and an unspecified number of antennae [37] (Appendix B).

All articles assessed the precision of LPS technology on the measurement of kinematic variables such as time-motion at different intensities during linear and nonlinear locomotion. The precision was assessed comparing the LPS with a criterion measurement device (considered as a gold standard in each article). Among them, tape measurement (*n* = 4), timing gates (*n* = 5), trundle wheel (*n* = 1), VICON optic-system (*n* = 4), Laser measurement (LAVEG) (*n* = 1) and Geographic Information System (GIS) (*n* = 1) were used as comparison methods. Moreover, one article analyzed the accuracy of UWB to measure collective tactical behavior variables (i.e., surface area), comparing its validity using GIS [24] (Appendix B).

5. Discussion

The use of valid, accurate and reliable systems is decisive for ensuring the data collection and correct interpretation of the values. Accuracy and validity can be defined as how close a measurement is to the exact or true value that is intended to be measured; thus, are really important factors to be considered in using location-based systems. Reliability can be understood as the capacity of an instrument or a measure to be repeatable or reproducible on repeated occasions [26]. With such an idea in mind, the purpose of the present systematic review was to summarize the evidence about the validity and reliability of LPS technology to measure movement patterns in outdoor and indoor environments. In the 16 included articles, the major topics that prevail were about validity, reliability and accuracy levels of the LPS technology. One article also tested interchangeability. This section will be organized according to the articles that tested the validity, reliability and accuracy of the LPS system to simplify and organize the discussion.

5.1. Accuracy and Validity of LPS Systems

One of the first LPM systems (45-Hz; 19 antennae) to be tested [33] revealed that, in static conditions, the average positional error was 1 cm, while in dynamic conditions the LPM underestimated distances for almost all courses varying from 0 (sprinting straight) to 29 cm (combined course while walking).

Using a similar frequency (45-Hz of the Inmotio) and smaller number of antennae (N = 12), a mean absolute error of all position estimations was found of 0.234 m [22]. The LPS of Catapult ClearSky T6 was tested by two studies [38,39] in indoor conditions, despite using different methodological approaches considering that in the study by Serpiello et al. [39] there were 18 antennae and a 10-Hz sampling frequency while in the study by Luteberget et al. [38] there were 16 antennae and a 20-Hz sampling frequency. In both studies [38,39], the LPS was compared with retroreflective-marker-based systems (VICON and Qualisys). In the study by Serpiello et al. [39], the comparisons in linear locomotor activities revealed mean differences between ClearSky and Vicon with bias between 0.2 and 2.3%. The mean differences between systems in the total distance, mean and peak speed and mean and peak accelerations ranged from 0.2 to 12%; however, for the case of mean and peak decelerations differences reached 84% [39]. In the other study testing ClearSky vs. Qualisys conducted by Luteberget et al. [38], mean differences were found for all position estimations of 0.21 m (in optimal conditions) and 1.79 m (in suboptimal conditions). For comparisons of distances, the mean differences were 0.31 m (for optimal conditions) and 11.42 m (for the suboptimal conditions) while instantaneous speed had mean differences between 34.8 and 39.2% in optimal conditions and 74.4 and 90.8% in suboptimal conditions [38]. Summarizing the evidence of both studies relative to ClearSky, validity is acceptable for measuring position, distance, speed and acceleration, although instantaneous speed and decelerations are not accurate enough due to large differences obtained in comparison to gold-standard methods.

In addition, testing a LPS (Kineson One, version 1.0) using 12 antennae and a 20 Hz sampling rate, the study conducted by Hoppe et al. [31] revealed typical error of estimation (TEE) for criterion variables within a circuit between 0.1 and 1.9. In the same study, the LPS system was also compared with a 10- and 18-Hz GPS system [31]. Overall, better validity values of LPS were found for determining distances covered and sprint mechanical properties, although the LPS system presented more outliers due to measurement errors compared to the 10-Hz GPS [31]. The NBN23 LPS system (Nothing But Net model) was also tested for its validity [30]. The system consisted of 12 antennae and frequencies between 9 and 50-Hz. The mean absolute error for distance variables varied between 0.10 m (in walking) and 0.18 m (in running), suggesting good values of validity [30]. For the case of time variables, mean absolute error varied between 0.2 s (at walking) and 0.14s (at walking). Time presented moderate to very high correlations [30]. The NBN23 LPS system revealed validity for monitoring distance and running time, although intensity affects the accuracy of the system [30]. Validation of an LPM system using glass fiber technology was also conducted using 19 antennae and 45 Hz [33]. Comparing average course speed to the average actual course speed, correlations were found (r = 0.71 to 0.97). Despite that, a systematic error of LPM was found in lower speed compared to actual speed [33]. Differences between LPM and actual speed were between −1.3 and 3.9% [33]. Finally, the TEE revealed a clear increasing tendency following the increase in the speed, thus TEE at low speed was more stable and less variable than in sprinting conditions [33]. Considering the values, it was possible to determine the validity of the system for measuring distance and speed [33]. A LPS using a Wireless Ad hoc System for Positioning (WASP) using 12 antennae and a sampling rate of 10-Hz was tested for its validity [32]. The results for mean error (%) varied between 1.26 (walking distance in a linear course) and 3.87% (sprinting distance in a nonlinear course). Results in indoor and outdoor conditions were consistent and revealed validity [32]. One of the included studies proposed to analyze the interchangeability of a multicamera, semiautomatic system, LPM (Inmotio) and GPS units [29]. Comparing the distance run at different speeds, the Inmotio tended to largely and moderately underestimate the distances run at 7.2 and 14.4 km/h^{-1}, respectively, while the multicamera system and the GPS tended to overestimate the distance run at all intensities [29]. In the study, the authors [29] proposed calibration equations for interchangeability of the systems, revealing that most of the calibration equations calculated were associated with small-to-moderate typical errors of the estimate.

An ultra-wide band (UWB) from RealTrack systems was tested in indoor conditions for its accuracy revealing mean absolute error of all position estimations of 5.2 cm (0.97%) for the x-position and 5.8 cm (0.94%) for the y-position [17]. Additionally, the estimation of errors was between 2.1 and 8.3 cm on the x-axis and 3.5 and 8.2 cm on the y-axis [17]. The results of the study [17], suggested acceptable accuracy levels of the UWB for monitoring the position of players. The same UWB (RealTrack systems) tested in outdoor conditions [24] revealed a mean absolute error of 41.23 and 47.6 cm for x-axis and y-axis, respectively. The findings confirmed the high accuracy and high transmission path of the UWB, mainly considering comparisons with GPS systems [24]. A third included study [23], testing the UWB from RealTrack systems showed a bias (%) of 0.55 to 5.85% for determining distance covered, and, moreover, a bias between −0.56 and 0.67 for determining mean velocity [23]. An additional comparison with GPS also revealed the better accuracy of UWB [23]. In brief, the studies [17,23] testing the accuracy of UWB of RealTrack systems showed a good accuracy of the system to determine players' positions, distances covered and mean velocities. An alternative brand of UWB (Ubisens Series 7000 compact tag) was also tested for its accuracy [36], also showing sufficient accuracy to test positions of players independently of the length of the recorded runs.

Summarizing the evidence about validity of LPS, all the tested systems (e.g., Catapult ClearSky T6; Kineson One; NBN23; WASP; LPM using glass fiber technology; Inmotio) revealed mean error below 5% measuring distances and average speeds, although not in measuring instantaneous speed and decelerations. It was clear that all studies confirmed good and acceptable accuracy of LPS systems to estimate the position and the distance and velocities achieved by players, although a decrease in accuracy occurs in some conditions (e.g., turns, changes of direction, sport-specific actions) and intensities (e.g., peak accelerations or decelerations).

5.2. Reliability

Commonly, reliability can be tested determining the within-subject variation, changes in the mean and retest correlation [26]. Reliability of the measures are critical for LPS systems, mainly to ensure the consistency and allow comparisons over time and in a repeated way (ref). The most common tests to be applied in reliability analysis are the coefficient of variation or typical error of measurement (TEM) and, in some cases, the intraclass correlation test (ICC) [27]. Following the suggestions of [27], reliability can be interpreted as good for variability lower than 5%, moderate between 5 and 10% and poor for 10% or above.

From the included studies of this systematic review, four of them [17,24,30,31] proposed to test the reliability levels of LPS systems. A 20-Hz LPS system (Kinexon One) using 12 antennae was tested by Hoppe et al. [31], revealing typical errors between 0.1 (criterion variable of 10m jogging with jump) and 1.7 (criterion variable of 129.6 m entire circuit). The LPS revealed good reliability for the entire distance covered, walking over 10 m with change of direction (COD), sprinting with CODs, sprinting over 30-m, sprinting over 5-20 m and theoretical maximal force and horizontal power [31]. However, in comparison to the GPS tested (10-Hz and 18-Hz), the LPS revealed greater noise at distances covered during standing, mainly caused by a shift in the zero-velocity line and increase in the velocity due to performed turning maneuvers [31]. Despite that, comparisons of reliability between the GPS and LPS was mainly favorable to LPS [31]. An UWB from RealTrack Systems was tested for its intra- and interunit reliability [17]. The intraunit reliability of UWB in mean velocity varied between 0.895 and 0.999 of ICC (95% of confidence interval) and the low and upper (for interunit variability) ranged between −0.09 and 0.42%. In the case of distance covered, the typical error of UWB varied between 0.94 and 4.87% and the lower and upper bias was between −2.65 and 2.06%. Thus, it was concluded that the UWB was reliable for distance covered and mean velocity [17]. Another study testing interunit reliability of UWB of the RealTrack system presented ICC values of 0.65 and 0.88 for x- and y-axis, respectively [17].

The NBN23 LPM system (Nothing But Net) was tested for its reliability. The coefficient of variations for walking, running and sprinting was 1.1–3.0%, 0.9–4.1% and 0.6–4.3%, respectively [30]. Comparisons between the LPM system and the taped measurement were also conducted, showing that the differences between the trials only varied for the 0–15 m at walking speed and interparticipant differences were found at 0–10 m in walking. Thus, results of the study showed that the NBN23 was reliable for monitoring distance and running time.

Summarizing the evidence regarding the reliability of LPS systems, it is possible to conclude that the three systems (Kinexon One, RealTrack Systems and NBN23) had coefficient of variations below 5% thus revealing reliability for measuring distances covered at different speeds and also for quantifying velocities achieved during the tasks.

6. Conclusions and Future Issues

This systematic review revealed that the tested LPS systems showed they were valid and accurate in determining the position and estimating distances and speeds, although not being valid or decreasing their accuracy when measuring instantaneous speed, peak accelerations or decelerations or monitoring particular conditions (e.g., changes of direction, turns). Considering the variability levels, the included studies showed that LPS provides a reliable way to measure distance variables and athletes' speeds. Further LPS developments could improve these systems for instantaneous speed, peak accelerations, decelerations, changes of direction or turns. Moreover, more standards for validation and reliability should be identified, aiming to define similar conditions that may allow sports scientists to easily identify the confidence thresholds for the systems.

Author Contributions: Conceptualization, M.R.-G., A.L.A., and J.P.-O.; project administration, J.P.-O.; supervision, M.R.-G., A.L.A., D.R.-V. and J.P.-O.; validation, D.R.-V. and J.P.-O.; visualization, F.M.C. and J.P.-O.; writing—original draft, M.R.-G., A.L.A. and F.M.C.; writing—review and editing, M.R.-G., A.L.A., F.M.-C., D.R.-V. and J.P.-O. All authors have read and agreed to the published version of the manuscript.

Funding: For the case of the F.M.C., this work is funded by FCT/MCTES through national funds and when applicable co-funded EU funds under the project UIDB/ EEA/50008/2020.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Quality assessment of the studies using Rico-González et al. [21] checklist for radio-frequency technologies.

Ref.	GC1	GC2	GC3	GC4	GC5	GC6	GC7	GC8	GC9	GC10	GC11	GC12	GC13	GC14	LPS1	LPS2	LPS3	LPS4	LPS5	LPS6	LPS7	LPS8	TS	%
Frencken, Lemmink and Delleman [33]	0	0	1	-	-	1	0	0	1	1	0	0	0	-	1	0	0	0	0	0	0	1	6	29
Ogris et al. [22]	0	0	1	-	-	2	0	1	1	0	0	1	0	-	0	0	0	0	0	1	0	1	8	38
Sathyan et al. [32]	0	0	1	-	-	1	1	0	1	1	0	1	0	-	1	0	0	0	1	1	0	1	10	48
Siegle et al. [34]	0	0	1	-	-	1	0	0	1	1	0	0	0	-	1	0	0	0	0	1	0	1	6	29
Stevens et al. [35]	0	0	1	-	-	1	0	0	1	1	1	1	0	-	0	0	0	1	0	0	0	0	7	33
Buchheit et al. [29]	0	0	1	-	-	2	0	0	1	1	1	1	0	-	0	0	0	1	0	0	0	0	8	38
Leser et al. [36]	0	0	1	-	-	2	0	0	1	1	1	1	0	-	1	1	0	0	0	0	1	1	11	52
Bastida Castillo et al. [23]	0	0	1	-	-	1	0	0	1	1	0	0	0	-	1	0	0	0	0	0	0	1	6	29
Linke et al. [18]	0	0	1	-	-	1	0	0	1	1	0	0	0	-	1	1	1	1	1	1	0	0	10	48
Hoppe et al. [31]	0	0	1	-	-	1	0	1	1	2	0	0	0	-	0	1	1	0	0	1	0	0	9	43
Serpiello et al. [39]	0	0	1	-	-	1	0	0	1	1	0	0	0	-	0	0	0	0	0	1	1	1	7	33
Luteberget et al. [38]	0	0	1	-	-	1	0	0	1	1	0	0	0	-	0	0	0	0	0	1	1	0	6	29
Bastida-Castillo et al. [17]	1	0	1	-	-	2	0	0	1	1	0	0	0	-	0	0	0	0	0	1	1	1	9	43
Link et al. [37]	0	0	1	-	-	1	0	0	1	1	1	0	0	-	1	0	0	0	0	0	0	0	6	29
[24]	1	0	1	-	-	2	0	-	1	1	0	0	0	1	1	0	0	0	0	1	1	1	11	52
Colino et al. ([30]	0	0	1	-	-	1	0	0	1	1	1	1	0	-	0	0	0	0	0	1	0	0	7	33

GC1: Was the process to avoid technology lock explained?; GC2: Was the data download moment mentioned?; GC3: Was the brand/model mentioned?; GC4: Were the variability and reliability of the model cited?; GC5: Was the model assessed for variability or reliability according to the variables used? (Multi-player vs. single player); GC6: How was the validation test performed?; GC7: Were data exclusion criteria mentioned?; GC8: Was a sensor fusion algorithm explained (only for velocity and acceleration)?; GC9: Was the raw data justified?; GC10: Was the raw data justified?; GC10: Was the software-derived data justified?; GC11: Was a data reduction method mentioned?; GC12: Were different Hz values used for each variable reported?; GC13: Was the time synchronization method explained (only for collective measures (i.e., tactical variables)?; LPS1: Was the technology mentioned (e.g., UWB, ultrasounds)?; LPS2: Was the temperature reported?; LPS3: Were humidity gradients reported?; LPS4: Was it mentioned whether there was slow air during the sessions?; LPS5: Was it mentioned whether there were any metallic materials around the antennas?; LPS6: Was the installation shape explained?; LPS7: Was the installation height reported?; LPS8: Was the measurement method reported?; TS: total score; %. percentage; "-": no applicable.

Appendix B

Table A2. Studies that assess validity or reliability of LPS.

Article	Aim	Sport	LPS Device (Technology)	Algorithm	Ant	Hz	Criterion Measure	Task (Length in Meters)	Speed Threshold (km/h^{-1})	Results	Conclusions
								LPM (lmp04.59)			
Frencken, Lemmink, and Delleman [33]	Accuracy /validity	Soccer (Outdoor)	LPM system (glass fiber technology). With cable [40]	Time difference	19	1000/22 = 45.45	Tape measure and timing gate	*Static condition; Walking* and *sprinting:* Straight (500), 45° turn (1000), 90° turn (1000), combined (2500)	-	*Distance* Walking = Straight, mean: 1 ± 2, 95% CI = 0 to 2; 45° turn, mean: −8 ± 6, 95% CI = −10 to −0.6; 90° turn, mean: −16 ± 10, 95% CI = −20 to −12; combined, mean: −29 ± 27, 95% CI = −40 to −19 Sprinting = Straight, mean: 0 ± 3, 95% CI = −1 to 1; 45° turn, mean: −6 ± 9, 95% CI = −9 to −2; 90° turn, mean: −16 ± 20, 95% CI = −24 to −9; combined, mean: −2 ± 42, 95% CI = −14 to 18; *Speed* Walking = Straight, mean: 5.3 ± 0.3, 95% CI = −0.2 to −0.1; 45° turn, mean: 5.6 ± 0.2 95% CI = −0.2 to −0.0; 90° turn, mean: −5.4 ± 0.3, 95% CI = −0.2 to −0.1; combined, mean: 5.1 ± 0.3, 95% CI = −0.1 to −0.1; Sprinting = Straight, mean: 16.0 ± 1.2, 95% CI = −0.8 to −0.5; 45° turn, mean: 16.9 ± 0.8, 95% CI = −0.7 to −0.4; 90° turn, mean: −14.6 ± 0.8, 95% CI = −0.5 to −0.2; combined, mean: 15.1 ± 0.5, 95% CI = −0.3 to −0.1.	Typical error > with increased speed but not with turning angle.

Table A2. *Cont.*

Article	Aim	Sport	LPS Device (Technology)	Algorithm	Ant	Hz	Criterion Measure	Task (Length in Meters)	Speed Threshold (km/h^{-1})	Results	Conclusions
Ogris et al. [22]	Accuracy	Soccer (Outdoor)	LPM [40]	TOF	12	1000/22 = 45.45	VICON	*Walking, jogging, low, moderate, high-speed, and sprinting* = Straight (500), 45° turn (1000), 90° turn (1000) and SSG (3 vs 3)	Walk: 2–6; Jog: 6.1–11; Low: 11.1–14; Moderate: 14.1–19; High-speed: >19; As fast as possible	Absolute error: 0.234 ± 0.207 cm; RMSE: 0.2133 (x axe) and 0.234 (y axe).	LPS less reliable with high dynamics movements and instantaneous velocities.
Siegle et al. [34]	Accuracy	Soccer (Outdoor)	Laser measurement device (LAVEG)	TDOA	11	1000/22 = 45.45	Laser measurement (LAVEG)	*Linear movement* = Low speed (25 m); *m*edium speed (25 m); high speed (25 m); Acceleration, stop (at 12.5 m), acceleration; Acceleration, stop (at 12.5 m), turn and acceleration.	-	Mean RMSE = 24 cm; *Low speed* = RMED: 22 cm; *Run-stop-run* = RMED: 51 cm	In linear measurement, LPS was more precise than image-based systems.
NBN23 (Nothing But Net, Valencia, Spain)											
Colino et al. [30]	Validity/ reliability	Basketball (indoor)	NBN23 (Nothing But Net, Valencia, Spain)	-	12	9, 17, 33, 50 Cut-off frequency	Timing gates	*Specific courses* = (1) three displacements were made at a comfortable walking speed. Displacements 4 to 6 were performed running at gentle pace; (2) three displacements were performed sprinting at maximum speed.	-	*Distance (all speeds/<0.08 s running time)* Maximal absolute error = < 18 cm Product-moment correlations = range: 0.60–0.99 ICC varied between high (0.75–0.90) and extremely high (>0.99) for most measures. Coefficients of variation remained almost invariable as speed increased (walking: 2.16; running: 2.52; sprinting: 2.20).	The running time errors could be too large for performance tests that require acute precision.

Table A2. *Cont.*

Article	Aim	Sport	LPS Device (Technology)	Algorithm	Ant	Hz	Criterion Measure	Task (Length in Meters)	Speed Threshold (km/h^{-1})	Results	Conclusions
						WASP, Wireless					
Sathyan et al. [32]	Validity/ reliability	Athletes from basketball, netball, rugby and soccer (Outdoor and indoor)	WASP. Wireless	Least squares algorithm	12	10	Tape measure	*Static condition; Walking, jogging, running* and *sprinting* = Outdoor linear course (30 m); indoor linear course (28 m); outdoor nonlinear course (27.6 m); indoor nonlinear course (27.6 m)	-	*Static* = mean 90th percentile error = 18 cm; indoor mean standard deviation = 11.9 ± 4.85 cm; outdoor mean standard deviation: 12.1 ± 5.17 cm; *Dynamic* = indoor 90th-percentile relative position errors: 28 cm; outdoor 90th-percentile relative position errors: 18 cm; *Linear course* = indoor mean error: 2.2%; outdoor mean error: 1.3%; *Nonlinear course* = indoor mean error: 2.7%; outdoor mean error: 3.2%	LPS showed consistent accuracy in both indoor and outdoor venues.
						Inmotio					
Stevens et al. [35]	Accuracy	Soccer (Outdoor)	version 05.30R, Inmotiotec GmbH, Regau, Austria	-	11	1000/22 = 45.45	VICON	Jog = submaximal and maximal: Straight, 180° change of direction, 90° change of direction	-	*Distance and speed* = LPM underestimated distance and average speed by 2 to 7% for movements involving a 180° change of direction (differences within 2% across all movements and intensities); Acceleration/deceleration = absolute bias; 0.01 ± 0.36 m/s^2; 95% limits of agreement = 0.02 ± 0.38 m/s^2; Peak acceleration (0.48 ± 1.27 m/s^2) and peak deceleration (0.32 ± 1.17 m/s^2) was overestimated.	LPS´s accuracy depends on movement intensity and type of movement. LPS had limited accuracy for peak acceleration and deceleration.

Table A2. *Cont.*

Article	Aim	Sport	LPS Device (Technology)	Algorithm	Ant	Hz	Criterion Measure	Task (Length in Meters)	Speed Threshold (km/h^{-1})	Results	Conclusions
Buchheit et al. [29]	Inter change-ability of different tracking technol-ogies	Soccer (outdoor)	Inmotio Object tracking v2.6.9.545, Amsterdam, the Netherlands	-	11	45	Timing gates	*Runs* on an oval 200 m course during training and *friendly match*: 200 m course at low, high and sprint; Standardized sprint during training and friendly match = 40 m sprint, L-shaped sprint, Zig-zag shaped sprint, distance into speed zones and number of accelerations: distance into speed zones during the runs; Peak speed and acceleration and sprint times	Los intensity: 7.2; High intensity: 14.4; sprint: 19.8 km—h^{-1}	Differences between systems in total distance = trivial-small; Differences between systems for high intensity running distance = slightly-to-moderately greater when tracked with Prozone, and accelerations, small-to-very largely greater with LPM.	Interchangeability of the different tracking systems is possible with the provided equations, but care is required given their moderate typical error of the estimate.
Linke et al. [18]	Accuracy	Soccer (outdoor)	Inmotio Object Tracking BV, Amsterdam, Netherlands	-	11	1000/22 = 45.45	VICON	*Sport specific courses* = 15 m sprint into 5 m acceleration, 20 m sprint into 10 m backward running into 10 m forward running, 505 agility tests, two rapid 90° turns, (5 and 6) curved runs toward and away from the camera, 20 m shuttle run test wit 180° changes of direction for 2 min and *SSG* (possession 5 vs 5 for 2 min).	Standing: < 1; low speed: ≥ 1 to < 6; Moderate speed: ≥6 to < 15; Elevated speed: ≥15 to < 20; High speed: ≥20 to < 25; Very high speed: ≥ 25; High acceleration thresholds were set at ≥ 3 m-s^{-2}; High deceleration thresholds were set at ≤ 3 m-s^{-2}	*Position* = Mean: 23 ± 7 cm; *Instantaneous speed* = error: 0.25 ± 0.06 m-s^{-1}; *Instant acceleration* = error: 0.68±0.14 m-s^{-2}; *SSG* = error range = 4.0%.	The magnitude of the error increased as the speed of the tracking object increased.
KINEXON ONE (Munich, Germany)											
Hoppe et al. [31]	Validity and reliability	Soccer	KINEXON ONE, version 1.0, Munich, Germany	-	12	18/20	-	*Specific circuits* = walking, jogging and sprinting sections that were performed either in straight-lines or with changes of direction.	-	*Distance covered* UWB 18 Hz = TEE: 1.6–8.0%; CV: 1.1–5.1% UWB 20 Hz, TEE: 1.0–6.0%; CV: 0.7–5.0% *Sprint* UWB 18 Hz, TEE: 4.5–14.3%; CV: 3.1–7.5% UWB 20 Hz, TEE: 2.1–9.2%; CV: 1.6–7.3% Relative loss of data sets due to measurement error UWB 18 Hz = 20.0% UWB 20 Hz = 15.8%	Overall, 20 Hz LPS had superior validity and reliability than 18 Hz LPS and 10 Hz GPS.

Table A2. *Cont.*

Article	Aim	Sport	LPS Device (Technology)	Algorithm	Ant	Hz	Criterion Measure	Task (Length in Meters)	Speed Threshold (km/h^{-1})	Results	Conclusions
Inmotio and Kinexon											
Link et al. [37]	Accuracy	Ice hockey (Indoor)	Radio 1: Inmotiotec GmbH, Regau, Austria. Radio 2: Kinexon GmbH, Munich, Germany.	-	-	Radio 1: 100, Radio 2: 15 Aligned to 100	Timing gates	*Specific courses* = Linear sprint (40 m), Shuttle run (five shuttle sprints (15.5 m) and four shuttle turns.	-	*Linear Sprint 11* MAERadio1 = 1; MAERadio2 = 1; ICCRadio1 = 0.98; ICCRadio2 = 0.99 *Shuttle Total* MAERadio1 = 2; MAERadio2 = 2, ICCRadio1 = 1.0; ICCRadio2 = 1.0 *Similar results were found for the turning subsection of the shuttle run* CURadio1 = 0.5; CURadio2 = 0.5	Limitations occur when testing changes/differences in performance over very short distances like an 11 m sprint, or when intermediate times are taken immediately after considerable changes of direction or speed.
Realtrack Systems (Almería, Spain). UWB											
Leser et al. [36]	Accuracy	Basketball (Indoor)	UWB	TDOA/AOA	6	4.17 ± 0.01 per tag	Trundle wheel	*Runs* in the center of the playing field and at the borders; *Matches* (5 vs. 5 + 1 player (without ball contact) leading a trundle wheel)	-	*Runs* = difference with trundle wheel: 8.25 ± 4.07%; 95% LoA: 0.27–16.22%); *Match* = mean difference = 3.45 ± 1.99%; 95% limits of agreement = −0.46–7.35%.	LPS had enough accuracy for time-motion analysis.
Bastida Castillo et al. [23]	Accuracy /interunit reliability	Soccer (outdoor)	UWB	TOA x the speed of light	6	18	Timing gates and real distance	*Linear*, *circula*r and *zig-zag* course	Walking: <6; run: >16	*Distance covered* = bias: 0.57–5.85%; Test–retest reliability %TEM: 1.19; Interunit reliability bias: 0.18 *Velocity* = bias: 0.09; ICC: 0.979; bias: 0.01	In static conditions and over prolonged periods of time UWB is more accurate than GPS. GPS accuracy was slightly more affected by the speed and type of displacement than UWB technology. Intra- and interunit reliability was acceptable for both systems analyzed.
Bastida-Castillo et al. [17]	Accuracy/ interunit reliability	Basketbal (Indoor)	UWB	TOA	6	18	Fixed reference lines of basketball court	*Positional data; Dynamics* = Perimeter markings of court; Middle line court.; Exterior perimeter of the painted lines; Center circle 6.75 m line.		MAE of all estimations for the x-position of 5.2 ± 3.1 cm and for the y-position of 5.8 ± 2.3 cm. Interunit reliability and ICC = 0.65 (x coordinate) and 0.85 (y coordinate).	Position estimations are very precise and acceptable for tactical analyses. The error of the position estimations does not change significantly across different courses. The use of different devices does not significantly affect the measurement error.

Table A2. *Cont.*

Article	Aim	Sport	LPS Device (Technology)	Algorithm	Ant	Hz	Criterion Measure	Task (Length in Meters)	Speed Threshold (km/h^{-1})	Results	Conclusions
Bastida-Castillo et al. [24]	Accuracy	Soccer	UWB	TOA x the speed of light	6	20	GIS	*Specific courses* = Field perimeter; Halfway line; Centre circle; Perimeter of the penalty area; Semicircle penalty area; *SSG* (7 vs 7).	-	MAE = 9.57 ± 2.66 cm (x coordinate) and 7.15±2.62 cm (y coordinate). *SSG* For tactical variables, differences between UWB and GPS reached 8.31% (ES=0.11).	UWB-20Hz has been recommended as accurate technology for estimating position of players on the pitch, while GPS-10Hz has substantial limitations Significance differences reported in tactical analysis between GPS and LPS that the error of using one system or another can mean a difference of more than 8%. Test-retest reliability and interunit reliability were good for the two systems assessed.
Catapult											
Serpiello et al. [39]	Validity	Indoor	LPS (Catapult ClearSky T6, Catapult Sports, Australia)	Hybrid algorithm TDOA, Two-Way Ranging and AOA	18	10	VICON	*Specific courses* = a maximal change of direction at 45° either left or right over a total distance of approximately 5.5 m; A self-paced walk over a linear course of 12 m; A self-paced jog over a linear course of 12 m; A maximal acceleration over a linear course of 12 m.	-	The mean differences for distance, mean/peak speed, and mean/peak accelerations in the linear drills were in the range of 0.2–12%, with typical errors between 1.2 and 9.3%. Mean and peak deceleration had larger differences and errors between systems.	LPS had acceptable validity to assess movements.

Table A2. *Cont.*

Article	Aim	Sport	LPS Device (Technology)	Algorithm	Ant	Hz	Criterion Measure	Task (Length in Meters)	Speed Threshold (km/h^{-1})	Results	Conclusions
Luteberget et al. [38]	Validity	Handball (Indoor)	Catapult ClearSky T6, Catapult Sports, Australia	-	16	20	Qualisy infra-red camera system	Specific courses = A straight-line sprint and deceleration to a stop; Two diagonal movements, forward and back to the left and the right, with the paths separated by an angle of ~75°; A straight-line sprint, a 90° turn, and then deceleration to a stop; A zig-zag (angle of turns ≈ 60°) course executed with sideways movements, and a 360° turn; Five continuous laps of the same course as in task 4, without the 360° turn.		Mean difference = 21 ± 13 cm in the optimal setup, and 179 ± 761 cm in the suboptimal setup. *Distance* Average difference = < 2% for all tasks in the optimal condition, while it was < 30% in the suboptimal condition. Instantaneous speed Differences = ≥ 35% in the optimal and ≥74% suboptimal condition The differences between the LPS and reference system in instantaneous speed were speed dependent, showing increased differences with increasing speed.	The accuracy of LPS output was highly sensitive to relative positioning between field of play and walls/corners and anchor nodes. The LPS is not valid in calculating instantaneous speed from raw data.

Ant.: Antennae; CV: Coefficient of variation; GIS: Geographical Information System; Hz: Hertz; ICC: Intraclass correlation coefficient; LPM: Local Position Measurement; MAE: Mean absolute error; LPS: Local Positioning System; SSG: small-sided games; RMSE: root mean square error; TDOA: time difference of arrival; TEE: the typical error of estimate; TOA: time of arrival; UWB: ultra-wide band; WASP: Wireless Ad hoc System for Positioning.

References

1. Rico-González, M.; Pino-Ortega, J.; Nakamura, F.Y.; Moura, F.A.; Rojas-Valverde, D.; Arcos, A.L. Past, present, and future of the technological tracking methods to assess tactical variables in team sports: A systematic review. *Proc. Inst. Mech. Eng. Part P J. Sports Eng. Technol.* **2020**, 175433712093202. [CrossRef]
2. Fortino, G.; Giannantonio, R.; Gravina, R.; Kuryloski, P.; Jafari, R. Enabling Effective Programming and Flexible Management of Efficient Body Sensor Network Applications. *IEEE Trans. Hum.-Mach. Syst.* **2013**, *43*, 115–133. [CrossRef]
3. Jovanov, E.; Milenković, A.; Otto, C.A.; De Groen, P.C. A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation. *J. Neuroeng. Rehabil.* **2005**, *2*, 6. [CrossRef]
4. Salayma, M.; Al-Dubai, A.; Romdhani, I.; Nasser, Y. Wireless body area network (WBAN) a survey on reliability, fault tolerance, and technologies coexistence. *ACM Comput. Surv.* **2017**, *50*, 1–38. [CrossRef]
5. Cummins, C.; Orr, R.; O'Connor, H.; West, C. Global Positioning Systems (GPS) and Microtechnology Sensors in Team Sports: A Systematic Review. *Sports Med.* **2013**, *43*, 1025–1042. [CrossRef] [PubMed]
6. Rico-González, M.; Mendez-Villanueva, A. Los Arcos, A Training load periodization in soccer with one official match a week: A systematic review. In *An Essential Guide to Sports Performance*; NOVA Science publisher: New York, NY, USA, 2000; pp. 123–166, ISBN 978/1/5361/7608/7.
7. Hill-Haas, S.V.; Dawson, B.; Coutts, A.J.; Impellizzeri, F.M.; Coutts, A.J. Physiology of Small-Sided Games Training in Football: A Systematic Review. *Sports Med.* **2011**, *41*, 199–220. [CrossRef]
8. Low, B.; Coutinho, D.; Gonçalves, B.; Rein, R.; Memmert, D.; Sampaio, J.A. Systematic Review of Collective Tactical Behaviours in Football Using Positional Data. *Sports Med.* **2020**, *50*, 343–385. [CrossRef] [PubMed]
9. Rico-González, M.; Pino-Ortega, J.; Nakamura, F.Y.; Moura, F.A.; Arcos, A.L. Identification, Computational Examination, Critical Assessment and Future Considerations of Distance Variables to Assess Collective Tactical Behaviour in Team Invasion Sports by Positional Data: A Systematic Review. *Int. J. Environ. Res. Public Heal.* **2020**, *17*, 1952. [CrossRef]
10. Rico-González, M.; Pino-Ortega, J.; Nakamura, F.Y.; Arruda-Moura, F.; Arcos, A.L. Origin and modifications of the geometrical centre to assess team behaviour in team sports: A systematic review. [Origen y modificaciones del punto geométrico para evaluar el comportamiento táctico colectivo en deportes de equipo: Una revisión sistemática]. *RICYDE. Rev. Int. de Cienc. del Deport.* **2020**, *16*, 318–329. [CrossRef]
11. Rico-González, M.; Pino-Ortega, J.; Clemente, F.; Rojas-Valverde, D.; Arcos, A.L. A systematic review of collective tactical behavior in futsal using positional data. *Boil. Sport* **2020**, *37*. [CrossRef]
12. Castellano, J.; Alvarez-Pastor, D.; Bradley, P.S.; Castellano, J. Evaluation of Research Using Computerised Tracking Systems (Amisco®and Prozone®) to Analyse Physical Performance in Elite Soccer: A Systematic Review. *Sports Med.* **2014**, *44*, 701–712. [CrossRef] [PubMed]
13. Pons, E.; García-Calvo, T.; Resta, R.; Blanco, H.; Del Campo, R.L.; García, J.D.; Pulido, J.J. A comparison of a GPS device and a multi-camera video technology during official soccer matches: Agreement between systems. *PLOS ONE* **2019**, *14*, e0220729. [CrossRef] [PubMed]
14. Rago, V.; Brito, J.; Figueiredo, P.; Costa, J.; Barreira, D.; Krustrup, P.; Rebelo, A. Methods to collect and interpret external training load using microtechnology incorporating GPS in professional football: a systematic review. *Res. Sports Med.* **2019**, 1–22. [CrossRef]
15. Malone, J.J.; Lovell, R.; Varley, M.C.; Coutts, A.J. Unpacking the Black Box: Applications and Considerations for Using GPS Devices in Sport. *Int. J. Sports Physiol. Perform.* **2017**, *12*, S218–S226. [CrossRef]
16. Rico-González, M.; Arcos, A.L.; Nakamura, F.Y.; Moura, F.A.; Pino-Ortega, J. The use of technology and sampling frequency to measure variables of tactical positioning in team sports: A systematic review. *Res. Sports Med.* **2020**, *28*, 279–292. [CrossRef] [PubMed]
17. Bastida-Castillo, A.; Gómez-Carmona, C.D.; De La Cruz-Sánchez, E.; Reche, X.; Ibáñez, S.J.; Pino-Ortega, J. Accuracy and Inter-Unit Reliability of Ultra-Wide-Band Tracking System in Indoor Exercise. *Appl. Sci.* **2019**, *9*, 939. [CrossRef]
18. Linke, D.; Link, D.; Lames, M. Validation of electronic performance and tracking systems EPTS under field conditions. *PLoS ONE* **2018**, *13*, e0199519. [CrossRef]
19. Alarifi, A.; Alsalman, A.; Alsaleh, M.; Alnafessah, A.; Al-Hadhrami, S.; Al-Ammar, M.A.; Al-Khalifa, H. Ultra Wideband Indoor Positioning Technologies: Analysis and Recent Advances. *Sensors* **2016**, *16*, 707. [CrossRef]

20. Leser, R.; Baca, A.; Ogris, G. Local Positioning Systems in (Game) Sports. *Sensors* **2011**, *11*, 9778–9797. [CrossRef]
21. Rico-González, M.; Arcos, A.L.; Rojas-Valverde, D.; Clemente, F.M.; Pino-Ortega, J. A Survey to Assess the Quality of the Data Obtained by Radio-Frequency Technologies and Microelectromechanical Systems to Measure External Workload and Collective Behavior Variables in Team Sports. *Sensors* **2020**, *20*, 2271. [CrossRef]
22. Ogris, G.; Leser, R.; Horsak, B.; Kornfeind, P.; Heller, M.; Baca, A. Accuracy of the LPM tracking system considering dynamic position changes. *J. Sports Sci.* **2012**, *30*, 1503–1511. [CrossRef] [PubMed]
23. Bastida-Castillo, A.; Gómez-Carmona, C.D.; Sánchez, E.D.L.C.; Pino-Ortega, J. Accuracy, intra- and inter-unit reliability, and comparison between GPS and UWB-based position-tracking systems used for time–motion analyses in soccer. *Eur. J. Sport Sci.* **2018**, *18*, 450–457. [CrossRef] [PubMed]
24. Bastida-Castillo, A.; Gómez-Carmona, C.D.; Sánchez, E.D.L.C.; Pino-Ortega, J. Comparing accuracy between global positioning systems and ultra-wideband-based position tracking systems used for tactical analyses in soccer. *Eur. J. Sport Sci.* **2019**, *19*, 1157–1165. [CrossRef] [PubMed]
25. Frencken, W.G.; Lemmink, K.; Delleman, N.; Visscher, C. Oscillations of centroid position and surface area of soccer teams in small-sided games. *Eur. J. Sport Sci.* **2011**, *11*, 215–223. [CrossRef]
26. Hopking, W. Measures of reliability in sports medicine and science. *Sports Med.* **2000**, *30*, 1–15. [CrossRef]
27. Scott, M.T.; Scott, T.J.; Kelly, V.G. The Validity and Reliability of Global Positioning Systems in Team Sport. *J. Strength Cond. Res.* **2016**, *30*, 1470–1490. [CrossRef]
28. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Int. J. Surg.* **2010**, *8*, 336–341. [CrossRef]
29. Buchheit, M.; Allen, A.; Poon, T.K.; Modonutti, M.; Gregson, W.; Di Salvo, V. Integrating different tracking systems in football: Multiple camera semi-automatic system, local position measurement and GPS technologies. *J. Sports Sci.* **2014**, *32*, 1844–1857. [CrossRef]
30. Colino, E.; Garcia-Unanue, J.; Sanchez-Sanchez, J.; Calvo-Monera, J.; Leon, M.; Carvalho, M.J.; Gallardo, L.; Felipe, J.L.; Navandar, A. Validity and Reliability of a Commercially Available Indoor Tracking System to Assess Distance and Time in Court-Based Sports. *Front. Psychol.* **2019**, *10*, 2076. [CrossRef]
31. Hoppe, M.W.; Baumgart, C.; Polglaze, T.; Freiwald, J. Validity and reliability of GPS and LPS for measuring distances covered and sprint mechanical properties in team sports. *PLoS ONE* **2018**, *13*, e0192708. [CrossRef]
32. Sathyan, T.; Shuttleworth, R.; Hedley, M.; Davids, K. Validity and reliability of a radio positioning system for tracking athletes in indoor and outdoor team sports. *Behav. Res. Methods* **2013**, *44*, 1108–1114. [CrossRef] [PubMed]
33. Frencken, W.G.; Lemmink, K.A.; Delleman, N.J. Soccer-specific accuracy and validity of the local position measurement (LPM) system. *J. Sci. Med. Sport* **2010**, *13*, 641–645. [CrossRef] [PubMed]
34. Siegle, M.; Stevens, T.; Lames, M. Design of an accuracy study for position detection in football. *J. Sports Sci.* **2012**, *31*, 166–172. [CrossRef]
35. Stevens, T.G.; De Ruiter, C.; Van Niel, C.; Van De Rhee, R.; Beek, P.J.; Savelsbergh, G.J.; T, G.A.S.; G, J.P.S. Measuring Acceleration and Deceleration in Soccer-Specific Movements Using a Local Position Measurement (LPM) System. *Int. J. Sports Physiol. Perform.* **2014**, *9*, 446–456. [CrossRef] [PubMed]
36. Leser, R.; Schleindlhuber, A.; Lyons, K.; Baca, A. Accuracy of an UWB-based position tracking system used for time-motion analyses in game sports. *Eur. J. Sport Sci.* **2014**, *14*, 635–642. [CrossRef] [PubMed]
37. Link, D.; Weber, M.; Lames, M.; Linke, D. Can Positioning Systems Replace Timing Gates for Measuring Sprint Time in Ice Hockey? *Front. Physiol.* **2019**, *9*, 1822. [CrossRef]
38. Luteberget, L.S.; Spencer, M.; Gilgien, M. Validity of the Catapult ClearSky T6 Local Positioning System for Team Sports Specific Drills, in Indoor Conditions. *Front. Physiol.* **2018**, *9*, 115. [CrossRef]
39. Serpiello, F.R.; Hopkins, W.G.; Barnes, S.; Tavrou, J.; Duthie, G.; Aughey, R.J.; Ball, K.A. Validity of an ultra-wideband local positioning system to measure locomotion in indoor sports. *J. Sports Sci.* **2018**, *36*, 1727–1733. [CrossRef]
40. Stelzer, A.; Pourvoyeur, K.; Fischer, A. Concept and Application of LPM—A Novel 3-D Local Position Measurement System. *IEEE Trans. Microw. Theory Tech.* **2004**, *52*, 2664–2669. [CrossRef]