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The use of technology and sampling frequency to measure variables of tactical positioning in team sports: a systematic review

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ABSTRACT

The aim of the study was to assess the use of different positioning systems and sampling frequencies to measure spatial-positioning variables in team sports. Articles were selected when the sampling frequency was detailed. 2,194 articles were identified and 59 works were selected for the systematic review. The sampling frequency used to measure tactical behaviour differed considerably among studies. For Global Navigation Satellite System, the sampling frequency ranged from 5- to 15 Hz for raw data, the most commonly used sampling frequency being 5 Hz. For Optic-based tracking systems, the sampling frequency ranged from 10- to 30 Hz. For Local Position System, the sampling frequency ranged from 45- to 100 Hz, the most commonly used sampling frequency being 42 Hz and 57.7 Hz. There is no common criterion in the sampling frequency used to measure each tactical variable. Further studies should investigate the impact of the sampling frequency on the measurement of the tactical variables.

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Technology; team behaviour; geometrical centre; dyad; area

Introduction

Initially, the positioning systems were used for military or scientific purposes, however, their development has given rise to wider applications, for example, making them available for use in team sports in order to quantify external training load (Beato, Jamil, & Devereux, 2018; Cummins, Orr, O'Connor, & West, 2013; Scott, Scott, & Kelly, 2015) and, for two decades, to assess tactical behaviour during training and matches in team sports (Araújo & Davids, 2016; Clemente, Figueiredo, Martins, Mendes, & Wong, 2016; Folgado, Gonçalves, & Sampaio, 2018; Memmert, Lemmink, & Sampaio, 2017). FIFA has classified these technologies as electronic performance and tracking systems (EPTS). EPTS technologies are differentiated into Global Navigation Satelite Systems (GNSS), which is an Outdoor Positioning System (OPS), Local positioning systems (LPS), and Optical-based systems (OPTs).

Through GNSS, the position of players can be calculated through trigonometry which requires at least four satellites to measure with sufficient accuracy and precision (Scott et al.,

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2015). The accuracy and precision of this information depends on the number of satellites connected with each device and the horizontal dilution of precision (HDOP) which provides a measure of precision of the GNSS horizontal positional signal determined by the geometrical distribution of the satellites. Regarding LPS, among different types of wireless Indoor Positioning Systems (IPSs), the ultra-wide band (UWB) is promising technology for indoor positioning and tracking (Alarifi et al., 2016) and also for outdoor venues where there is no possibility of the surrounding infrastructure interfering in the results. Its accuracy and precision in sports use have been demonstrated in previous studies (Bastida Castillo, Gómez Carmona, De la Cruz Sánchez, & Pino Ortega, 2018). The other option that researchers can choose among IPSs is OPTs. To calibrate the cameras, each one has information about points inside the court with known distances. Next, image based technologies or optical methods develop algorithms in image processing (Alarifi et al., 2016). Independently of the tool used, it is considered that for tactical analysis uses, the error of estimation of the position 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, Baca, & Ogris, 2011).

An important parameter to measure the spatial positioning of team sports players is the sampling frequency, which is measured in Hertz (Hz). Firstly, the frequency, that is, the amount of data recorded per second, depends on the capacity of the positioning systems used, and secondly, the decision of the researcher or sports technician, who can configure tools to extract more or less data from the training session or match. The first of them must avoid the Nyquist theorem, that is, the sampling frequency must be at least twice as high as the highest frequency given by the signal itself. In addition, researchers or sports technicians should consider that if the sampling frequency is too low, there will be errors in the recording (Winter, 2009), but if it is too high, noise could contaminate the desired signal. The other important point that should be considered is Software-derived data. Manufacturer's software often includes algorithms to identify poor quality data, and researchers can modify the frequency of data and the software automatically interpolates, smooths, or extracts software-derived data (Malone, Lovell, Varley, & Coutts, 2017). A greater amount of data per unit of time supposes higher sampling frequencies, which will not necessarily suppose better results. Higher-frequency noise continues to be a considerable problem (Winter, 2009), as the relevance of sampling frequency to measure tactical variables in team sports is a problem that has scarcely been studied. For tactical variables, higher sampling frequency may result in greater time-consuming step because of the consubstantiate amount of data to processed. One can argue whether it is paramount to gather tactical behaviour at each small time stamp. For instance, spread time series of football teams presented median frequencies lower than 1 Hz after frequency-domain analysis (Moura et al., 2013).

Therefore, the aim of this systematic review was to assess the use of different positioning systems and the sampling frequency applied by each tool to measure collective spatial-positioning variables in team sports.

Method

Search strategy

The systematic review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) guidelines (Moher, Liberati, Tetzlaff, &

Altman, 2009). The protocol was not registered prior to initiation of the project and did not require Institutional Review Board approval. A systematic search of four databases was performed by the authors (MR, ALA, JPO) to identify articles published before 13 November 2018. The PICO (Moher et al., 2009) design was used to provide an explicit statement of the question. The search was carried out using two filters where the database allowed this: journal article; and title/abstract, except in Web of Science, which was searched throughout the text. In addition, in the final database the sports sciences branch was selected. The search was made using combinations of the following terms linked with the Boolean operators "AND" (inter-group Boolean operator) and "OR" (intra-group Boolean operator). Three main groups were created: 1) "Soccer", "football", "team sport*", "basketball", "rugby", "handball", "hockey"; 2) "GPS", "global position system*", "GNSS", "Global navigation satellite system*", "UWB", "ultra wide band", "local position", "LPP", "LPS", "LPS", "EPTS", "electronic performance and tracking systems*", "video", "video tracking", "tracking system*", "electronic*", "satellite system*", "GIS", "geographical information system*"; and, 3) "formation*", "tactic*", "behaviour*", "performance*", "position*", "spatiotemporal", "spatio-temporal", "synchronization*", "coordination*", "pattern*", "synerg*", "Voronoi", "Delaunay", "decision-making", "decision making".

Screening strategy and study selection

When the referred authors had completed the search, they compared their results to ensure that the same number of articles had been found. Then, one of the authors (MR) downloaded the main data from the articles to an Excel spreadsheet (Microsoft Excel, Microsoft, Redmond, USA) and removed the duplicate records. Subsequently, the two authors (MR, ALA) screened the remaining records to verify the inclusion-exclusion criteria using a hierarchical approach in two phases: Phase-1, titles and abstracts were screened and excluded by two authors (MR, ALA), where possible; Phase-2, full texts of the remaining papers were then accessed and screened by the same two authors (MR, ALA). Inclusion criteria included studies that were: (1) Team sports in which the use of the mobile (e.g. ball, puck) is simultaneous (e.g. soccer, hockey); (2) The main objective of the study is to assess tactical performance or dimension in team players; (3) Studies that include a tactical variable regarding the position of the players using EPTS; (4) Studies that aim to measure a tactical variable; (5) Studies that aim to analyse the position of more than one player, whether they are rivals or not; (6) Studies that include the sampling frequency used in the data collections for at least the raw data or for the data after the filter.

Results

A total of 3,973 documents were initially retrieved from the mentioned databases, of which 1,779 were duplicated. Thus, a total of 2,194 articles were screened. Next, the titles and abstracts were verified against criterion 1 and studies excluded where possible. The abstracts and full texts of the remaining articles were screened and the inclusion/exclusion criteria 1–6 were applied, leading to the exclusion of 2,145 articles. A further 16 records were removed as they were not articles and another 2 were not found. Therefore, 34 articles were initially included in this review. In addition, by reviewing the references of the selected articles, the authors found and added 25 articles that met inclusion criteria 1–6. In the majority of these studies, the search tool (group 2) was not detailed in the title or the abstract. Finally, 59 articles were included (Figure 1).

Considering each study independently, except in two articles that used a different sampling frequency for the positional and kinematic variables (Moura et al., 2013) and different sampling frequency to compare the results measuring distance between players (Duarte et al., 2010), all studies used the same sampling frequency to measure all the chosen tactical variables.

Taking together all studies, the sampling frequencies (i.e. Hz) used to avoid noise were GNSSs between 5 Hz and 15 Hz, LPSs between 45 Hz and 100 Hz, and OPTs between 10 Hz and 30 Hz. On the other hand, to resample the data in software, GNSSs measured between 1 Hz and 2 Hz, LPSs between 42 Hz and 100 Hz, and OPTs at 7.5 Hz (Tables 1–3). Butterworth cut-off frequencies were between 0.4 Hz and 6 Hz for OPTs and for GNSS was 7.5 Hz.

The most commonly used sampling frequencies for GNSS was 5 Hz for raw data, while for OPTs it was 25 Hz for raw data, and 42 Hz and 57.7 Hz for raw data using LPSs. Among all EPTS, LPS was the tool which measured at the highest frequencies (from 45 Hz to 100 Hz) (Tables 1–3).

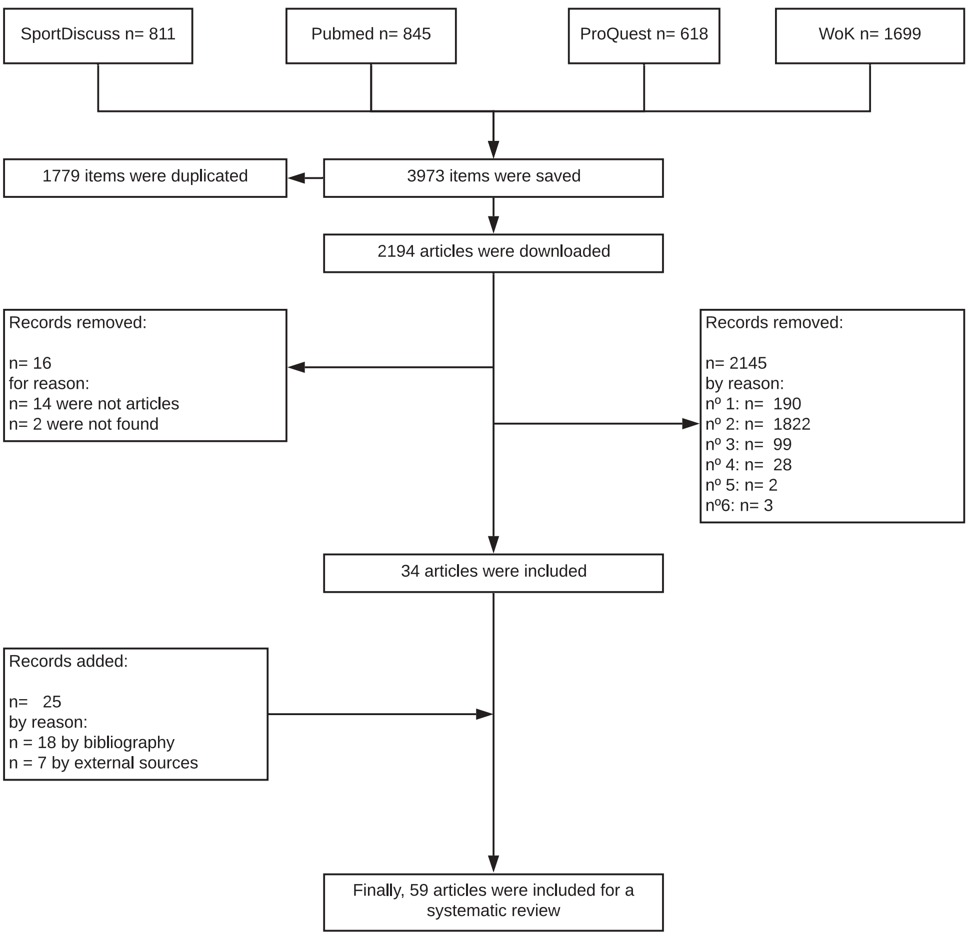

Figure 1. Flow diagram of the study.

Figure 2. The use of EPTS to measure tactical variables of spatial positioning in the 21st century.

Regarding data reduction, 32 articles mentioned the sampling frequency only once. From the remaining 31 articles, 9 articles used GNSS, only 1 LPS, and 21 used OPTs (Tables 1–3).

Discussion

The aim of the systematic review was to assess the use of different positioning systems and the sampling frequency applied by each tool in order to measure collective spatial-positioning variables in team sports. The main findings were: a) the sampling frequency used to measure tactical behaviour differed considerably among studies, although all of them used the selected sampling frequency to measure all considered tactical variables, b) for GNSS, the sampling frequency ranged from 5- to 15 Hz for raw data, the most commonly used sampling frequency being 5 Hz, c) For OPTs, the sampling frequency ranged from 10- to 30 Hz, and d) For LPS, the sampling frequency ranged from 45- to 100 Hz, the most commonly used sampling frequency being 42 Hz and 57.7 Hz.

Although the sampling frequency used to measure tactical variables differed considerably among studies, all of them used the selected sampling frequency to measure all considered tactical variables independently of their characteristics (i.e. node, line or area) (Tables 1–3). It could mean reviewing a large amount of unnecessary data, or, failing that, making large reductions that eliminate significant data from the variation in the position of players during the data analysis. Researchers must consider the period of time for which they want to record the raw data (e.g. N + 500). This period, expressed in milliseconds, will be a function of the sampling frequency. The higher the frequency chosen or the shorter the period of time in milliseconds will prescribe the representative data, signifying that the greater the amount of information, the greater the data repetition. On the other hand, if the researchers increase the period of time, the data

Table 1. EPTS and Hertz used to measure geometrical centre of several players.

Article	EPTS	Raw Data (Hz)	Variable description: Resampling (Hz)	Butterworth cut-off frequency (Hz)	Other smoothing techniques
Yue et al. (2008)	OPTs	10			
Frencken (2009)	LPS	50			
Lames, Ertmer, and Walter (2010)	OPTs	25	1		
Bourbousson, Sève, and McGarry (2010b)	OPTs	25		1	
Frencken, Lemmink, Delleman, and Visscher (2011)	LPS	45			
Travassos, Araújo, Duarte, and McGarry (2012)	OPTs	25		6	
Sampaio and Maçãs (2012)	GNSS	5			
Duarte, Araújo, & Freire, (2012)	OPTs	25		6	
Bartlett, Button, Robins, Dutt-Mazumder, and Kennedy (2012)	OPTs	10			
Duarte et al. (2013)	OPTs	10			
Clemente, Couceiro, Martins, & Mende (2013)	OPTs	30			
Frencken, Van Der Plaats, Visscher, and Lemmink (2013)	LPS	100			
Clemente et al. (2013)	OPTs	30			
Gonçalves, Figueira, Maçãs, and Sampaio (2014)	GNSS	5			
Folgado, Lemmink, Frencken, & Sampaio (2014)	OPTs	25			The original time series was smoothed twice using a 10 frame window
Sampaio, Lago, Gonçalves, Maças, and Leite (2014)	GNSS	5			
Sampaio, Gonçalves, Rentero, Abrantes, and Leite (2014)	GNSS	5			
Travassos, Gonçalves, Marcelino, Monteiro, and Sampaio (2014)	GNSS	15			
Clemente, Santos Couceiro, Lourenço Martins, Sousa Mendes, and Figueiredo (2014)	OPTs	30			
Aguiar et al. (2015)	GNSS	5			
Ric et al. (2016)	GNSS	5	1		
Olthof, Frencken, and Lemmink (2018)	LPS	100	42-100		
Clemente et al. (2018)	GNSS	10			
Bueno et al. (2018)	OPTs	30		0.4	
Movements of the point which represents the average position					
Yue et al. (2008)	OPTs	10			
Moura et al. (2013)	OPTs	30	7.5	0.4	
Moura et al. (2012)	OPTs	30	7.5	0.4	
Ric et al. (2016)	GNSS	5	1		
Moura et al. (2016)	OPTs	30		0.4	
Bueno et al. (2018)	OPTs	30		0.4	
Palucci Vieira et al. (2018)	OPTs	30		0.4	

GNSS: Global Navigation Satellite System; Hz: Hertz; LPS: Local Position System; %: percentage; OPTs: Optical-based tracking systems

will be less representative of reality, given that there will be data that will go unnoticed, in exchange for better performance and simplification of the data to work with. This process, in general, before being analysed, goes through recording and subsequent processing: raw data and software-derived data.

Frequency has been much discussed in the field of acceleration (Cardinale & Varley, 2017); however, in the field of tactical positioning this issue should begin to be dealt with, in two

Table 2. EPTS and Hertz used to measure distance relation.

Article	EPTS	Raw Data (Hz)	Resampling (Hz)	Butterworth cut-off frequency (Hz)	Other smoothing techniques
			Variable description		
Player-Player					
Passos, Araújo, Davids, Gouveia, and Serpa (2006)	OPTs	25			
Passos et al. (2008)	OPTs	25			
Bourbousson, Sève, and McGarry (2010a)	OPTs	25		1	
Duarte et al. (2010)	OPTs	25		3 and 6	
Duarte et al. (2012)	OPTs	25		3	
Esteves et al. (2012)	OPTs	25		6	
Duarte et al. (2013)	OPTs	10			
Vilar et al. (2014)	OPTs	25		6	
Folgado, Duarte, Fernandes, and Sampaiol (2014)	GNSS	5		3	
Silva et al. (2014)	GNSS	15			A moving average filter with a time scale of 0.2 s
Esteves et al. (2015)	OPTs	25		6	
Leser et al. (2015)	LPS	50,7			
Shafizadeh, Davids, Correia, Wheat, and Hizan (2016)	OPTs	25			
Esteves et al. (2016)	OPTs	25		6	
Gonçalves et al. (2017)	GNSS	5			Two-points moving average.
Ric et al. (2017)	GNSS	5			
Coutinho et al. (2017)	GNSS	15		3	
Olthof et al. (2018)	LPS	100	42-100		
Folgado et al. (2018)	GNSS	5			
Coutinho et al. (2018)	GNSS	5		3	
Team separateness					
Silva et al. (2014)	GNSS	15			A moving average filter with a time scale of 0.2 s
Castellano, Silva, Usabiaga, and Barreira (2016)	GNSS	10	2		
Silva, Vilar, Davids, Araújo, and Garganta (2016)	GNSS	15	2		
Length/Width					
Frencken et al. (2011)	LPS	45			
Bartlett et al. (2012)	OPTs	10			
Duarte et al. (2013)	OPTs	10			
Ric et al. (2016)	GNSS	5	1		
Barnabé, Volossovitch, Duarte, Ferreira, and Davids (2016)	GNSS	15			
Castellano et al. (2016)	GNSS	10	2		
Coutinho et al. (2017)	GNSS	15		3	
Olthof et al. (2018)	LPS	100	42-100		
Player-Element/Space					
Santos et al. (2018)	GNSS	5			
Ric et al. (2017)	GNSS	5			
Travassos et al. (2012)	OPTs	25		6	
GC-GC					
Frencken (2009)	LPS	50			
Duarte et al. (2012)	OPTs	25		6	
Bartlett et al. (2012)	OPTs	10			
Frencken et al. (2013)	LPS	100			
Folgado et al. (2014)	OPTs	25			The original time series was smoothed twice using a 10 frame window

(*Continued*)

Table 2. (Continued).

			Variable description		
Article	EPTS	Raw Data (Hz)	Resampling (Hz)	Butterworth cut-off frequency (Hz)	Other smoothing techniques
Silva et al. (2014)	GNSS	15			A moving average filter with a time scale of 0.2 s
Silva et al. (2014)	GNSS	15			
Silva et al. (2016)	GNSS	15	2		
Aguiar et al. (2015)	GNSS	5			
Olthof et al. (2018)	LPS	100	42-100		
GC-Player					
Yue et al. (2008)	OPTs	10			
Sampaio and Maçãs (2012)	GNSS	5			
Sampaio et al. (2014)	GNSS	5			
Sampaio et al. (2014)	GNSS	5			
Aguiar et al. (2015)	GNSS	5			
GC-Space					
Duarte et al. (2012)	OPTs	25		6	
Silva et al. (2014)	GNSS	15			
Average point between several distances					
Yue et al. (2008)	OPTs	10			
Bourbousson et al. (2010b)	OPTs	25		1	
Frencken et al. (2011)	LPS	45			
Bartlett et al. (2012)	OPTs	10			
Duarte et al. (2013)	OPTs	10			
Clemente et al. (2013)	OPTs	30			
Sampaio et al. (2014)	GNSS	5			
Silva et al. (2014)	GNSS	15			
Travassos et al. (2014)	GNSS	15			
Barnabé et al. (2016)	GNSS	15			
Ric et al. (2016)	GNSS	5	1		
Silva et al. (2016)	GNSS	15	2		
Olthof et al. (2018)	LPS	100	42-100		
Clemente et al. (2018)	GNSS	10			
Coutinho et al. (2018)	GNSS	5		3	

GNSS: Global Navigation Satellite System; Hz: Hertz; LPS: Local Position System; %: percentage; GC: Geometrical centre; OPTs: Optical-based tracking systems

continuous processes but with different objectives. The researcher must know the limit of Hz above which noise will affect the results at higher frequencies. When the data are recorded, the deletion of poor data must ensure that no significant position data are eliminated. For this reason, researchers record at higher frequencies that they end up reducing. The key is to choose a balanced period of time that allows good performance, but that in the software-derived data, ensures not all significant position data of the players' variations of position can be deleted. To avoid recording at unnecessarily high frequencies the researchers could respect the sampling frequency theorem. However, in order not to violate the theorem, it is necessary to know the frequency of movement which is going to be measured. Some articles have measured the velocity of the node (Bueno et al., 2018; Moura, Martins, Anido, De Barros, & Cunha, 2012; Moura et al., 2013, 2016; Palucci Vieira et al., 2018; Ric, Torrents, Gonçalves, Sampaio, & Hristovski, 2016; Yue, Broich, Seifriz, & Mester, 2008). Maybe using this data it is possible to establish the frequency to record raw data respecting the sampling frequency theorem for centroids, but, to our knowledge, no articles have mentioned the number of Hz that should be used for software-derived data for each variable. One study measured using different cut-off frequencies, differentiating spatial positioning tactical variables and kinematic

Table 3. EPTS and Hertz used to measure area relation.

Article	EPTS	F. Raw Data (Hz)	Variable description: Resampling (Hz)	Butterworth cut-off frequency (Hz)	Other smoothing techniques
Occupied Space					
Surface area					
Frencken (2009)	LPS	50			
Frencken et al. (2011)	LPS	45			
Moura et al. (2012)	OPTs	30	7.5	0.4	
Duarte et al. (2012)	OPTs	25		6	
Bartlett et al. (2012)	OPTs	10			
Clemente et al. (2013)	OPTs	30			
Duarte et al. (2013)	OPTs	10			
Vilar, Araújo, Davids, and Bar-Yam (2013)	OPTs	10			
Moura et al. (2013)	OPTs	30	7.5	0.4	
Clemente et al. (2013)	OPTs	30			
Barnabé et al. (2016)	GNSS	15			
Castellano et al. (2016)	GNSS	10	2		
Timmerman, Farrow, and Savelsbergh (2017)	GNSS/OPTs	10/25			
Olthof et al. (2018)	LPS	100	42-100		
Palucci Vieira et al. (2018)	OPTs	30		0.4	
Bueno et al. (2018)	OPTs	30		0.4	
Metulini, Manisera, and Zuccolotto (2018)	OPTs	10			
Effective Playing Space					
Clemente et al. (2013)	OPTs	30			
Silva et al. (2014)	GNSS	15			A moving average filter with a time scale of 0.2 s
Gonçalves et al. (2018)	GNSS	5			
Area of influence					
Dominant region area					
Ueda, Masaaki, and Hiroyuki (2014)	OPTs	30			
Density					
Timmerman et al. (2017)	GNSS/ OPTs	10/25			
Spatial exploration index					
Gonçalves et al. (2017)	GNSS	5			A two-points moving average
Coutinho et al. (2017)	GNSS	15		3	
Voronoi diagram					
Clemente, Couceiro, Martins, Mendes, and Figueiredo (2015)	OPTs	30	1		

EPS: Effective playing space; GNSS: Global Navigation Satellite System; Hz: Hertz; LPS: Local Position System; %: percentage; s: second; OPTs: Optical-based tracking system

measures (Moura et al., 2013). If different frequencies are necessary to measure different questions, perhaps each group of variables needs a different frequency due to, among other things, the magnitude of the measurement unit or the different relations of the oscillators in each group of variables. Moreover, this may not be enough and a measure for each variable might be necessary because each of them involves different velocities.

Currently, only one study has reported different results between frequencies. Duarte et al. (2010) found less variation using a 6 Hz than 3 Hz cut-off frequency when they measured distance between players. It might be practical to analyse the most commonly used frequencies. GNSSs used 5 Hz for raw data (i.e. 56%) while among the articles which reported that the frequency was reduced, two made it to 80% and 40% and one used smoothing techniques. If frequencies are set for recording lower data, the possibility of a noise affect is less. The highest frequencies were recorded using LPSs, but this could be unnecessary because they could provide a lot of information with little significance regarding the variation in position.

Conclusions

The sampling frequency used to measure tactical behaviour differed considerably among studies, although all of them used the selected sampling frequency to measure all considered tactical variables. Due to the lack of investigations about the optimal sampling frequency to measure positioning tactical variables, the researchers only can consider the most commonly used frequencies. Thus, further studies should study the impact of the sampling frequency on the measurement of the tactical variables.

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