PROGRAMA DE DOCTORADO EN ACTIVIDAD FÍSICA Y DEPORTE

Facultad de Educación y Deporte

Departamento de Educación Física y Deporte

Análisis del comportamiento táctico colectivo basado en el dato de posicionamiento en los deportes de equipo: revisión sistemática de las variables tácticas colectivas y valoración de la calidad de la medida

TESIS DOCTORAL

Presentada por

Markel Rico González

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TESIS DOCTORAL

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Vitoria-Gasteiz, 2020

A los que siempre están

A Marisol, mi madre

Por tanto amor. Gracias por cuidarme y preocuparte tanto. Eres el pilar principal que ha mantenido este proyecto en pie. Seguiré tu ejemplo.

A Luis, mi padre

Te aseguro saber descifrar tus maneras de demostrar. Eres la mejor persona que jamás he conocido. Seguiré tu ejemplo siempre.

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Por la ilusión de tenerme. Por el ladito en la cama cuando yo ya tenía la mía. Por no juzgarme nunca. Por dejarme ser vuestro hermano pequeño.

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Declaración

No era más de lo que soy. Un estudiante convencido de lo grande que es el mundo y de lo pequeño que se hace uno a medida que aprende. No soy más de lo que soy, una persona con una forma de ser forjada por la educación que me dieron mis padres y la sociedad que me rodea. Desde pequeño siempre tuve una cosa clara, yo quería hacer deporte. Así crecí, entre balones, raquetas y porterías, hasta que un día sentí que también quería enseñar. ¿No es así como comienza la conciencia humana? Lo que uno quiere saber. El conocimiento. Partiendo de un estímulo que deriva en inquietud, que, si no la enterramos pronto, nos persigue hasta convertirse en pregunta y más tarde en respuesta. Jorge Wagensberg (1998) diferencia de dos tipos de estímulos, los estímulos blandos, derivados de otras conciencias, y los estímulos duros, derivados de la propia. La inquietud por desarrollar mi conocimiento sobre el deporte y la enseñanza siempre fue fruto de la mía.

Este proyecto, siempre sobre las bases de mi vocación, nace de tres estímulos blandos encadenados. El primero, como estudiante en la universidad de Salamanca, donde percibí un patrón común que guiaba a los expertos que allí trabajaban. En el campo de la psicología se denomina *el efecto Pigmalión*. La idea fue la de asumir retos, y allí fue donde me planteé continuar mi formación con una tesis. El lector intuirá, no sin razón, que era un proyecto sin timón. En muchas ocasiones estás ideas precipitadas acaban en saco roto. Si uno no es capaz de ver el final con claridad, los proyectos pueden perderse. O no. En este caso, a pesar de no ser un estímulo concreto en un principio, acabó derivando en una inquietud que jamás fue enterrada.

El segundo de los estímulos llegó tiempo después, esta vez, como estudiante de la Universidad del País Vasco. Si es cierto que el proyecto seguía sin timón, pero intuía que, después de todo, ya no se hundiría. Y así fue. Durante el Máster de la Universidad conocí a Asier Los Arcos. No sé lo que tiene que sentir un profesor cuando un alumno le pide ayuda sobre nada en concreto, pero en principio comprendo que la situación sugiere mirar para otro lado. Este fue el momento clave. Asier me explico sus inquietudes, y más tarde, me encontraba delante de textos y textos que no podía dejar de leer. Después de mucho tiempo, sentí que tomaba las riendas. Lo que un día fue deporte, se concretó. Íbamos orientando el proyecto. Nada más por el momento.

El conocimiento avanza según devenga la inquietud inicial (Wagensberg, 1998). En mi caso, las inquietudes se solapaban y todavía el proyecto no estaba definido. Si algo estaba claro era la orientación investigadora de Pepe. El tercer estímulo vino de su mano. Su despacho es pequeño, pero siempre hay hueco para la poesía de Mario Benedetti: *la gente que me gusta*. Siempre esta definió la amistad entre los tres. Y entre conversación y conversación, también asumí una nueva y última inquietud.

Se trata de coincidir con gente que te haga ver cosas que tú no ves. Que te enseñen a mirar con otros ojos.

Mario Benedetti

Poco tiempo y muchos kilómetros después me senté en el escritorio de mi habitación, revisé las decenas de hojas llenas de garabatos, y sinteticé lo que creí haber comprendido. A la idea original se le añadían nuevos puntos de vista. Dos objetivos perfectamente compatibles, deportes de equipo y tecnología. Lo que cabe destacar es que los resultados de esta tesis nacen sin prejuicios de lo que se espera encontrar cuando uno sabe de lo que habla.

La guinda del pastel llegó después. En palabras de Jorge Wagensberg (1998): *todo hacer científico torna a la línea de salida, es redondo, las últimas frases de un ensayo científico suelen versar sobre las primeras. Cuando el punto de llegada coincide exactamente con el de partida el círculo es vicioso, condenado a la eterna rotación trivial. Triunfa aquel círculo que no se cierra, donde el punto de llegada coincide con el inicio de uno nuevo ligeramente desplazado. Se forma una espiral, hay precisión, hay virtud. Hay ciencia.* Estas palabras explican perfectamente el proyecto, una espiral que cuando pretendía ser cerrada asumió un nuevo punto de vista que abrió la puerta a un nuevo círculo. El tercer capítulo refleja el inicio de una metodología que sugiere ser tratada en adelante.

He aquí la síntesis de lo que me guió hasta presentar el proyecto que a partir de aquí se redacta, no sin antes, con la venia del tribunal, presentarme para clarificar mi posición durante el trabajo que se expone. En palabras de Victor Küppers (2012): *en la vida hay formadores y expertos. Expertos son los que saben. Hay personas que investigan, estudian, que desarrollan conceptos, que inventan, que crean. Y luego estamos los formadores. El trabajo del formador es copiar, pegar y transmitir las ideas que los expertos desarrollan.* Así que mi papel queda claro. He tratado de redactar, con cariño, las palabras que los líderes de este proyecto me explicaban, con el fin último de transmitir la aprehensión de un valor fundamental que separa al formador del experto: la inquietud por conocer y desarrollar estímulos derivados de la conciencia de uno mismo.

Listado de abreviaturas

Abreviation	Meaning
% FA	Percentage of free area
AMI	Average mutual information
AOA	Angle of arrival
ApEn	Approximate entropy
CA (t)	Convex hull area at each instant of time
CCP	Change of centroid position
Cross-SampEn	Cross-Sample entropy
DbP	Distance between players
EPS	Effective playing space
EPTS	Electronic performance and tracking systems
FIFA	Fédération Internationale de Football Association
GC	Geometrical centre
GIS	Geographical information system
GK	Goalkeeper
GNSS	Global navigation satellite system
GPS	Global position system
HDOP	High dilution of precision
Hz (frequency unit)	Hercios
ICC	Intraclass correlation coefficient
IPS	Indoor position system
LPM	Local position measurement
LPS	Local position systems
LpW ratio	Length per width ratio
M	Metres

Max%OA	Maximum percentage of overlapped area
MEMS	Micro electro mechanical systems
MMT	Minimum moving time patterns
P	*p* value
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-analyses
R	Pearson r
RFID	Radio frequency identification
RSS	Received signal strength
SampEn	Sample entropy
SEI	Spatial exploration index
SSG	Small-side games
TA	Total area
TDOA	Time difference of arrival
TL	Training load
TOA	Time of arrival
TS	Team separateness
UWB	Ultra-wide band
VID	Semi-automatic multiple-camera video technology

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Diseño de la tesis doctoral

La tesis doctoral, elaborada en formato clásico, está compuesta por introducción, método, resultados, discusión y conclusiones. La introducción ha sido ampliamente desarrollada con el objetivo de contextualizar al lector en la problemática que nos ocupa. La contextualización de la tesis doctoral fue organizada en siete secciones Los apartados (1) *deporte,* (2) *deportes de equipo* y (3) *comportamiento táctico colectivo* fueron desarrollados para contextualizar la tesis doctoral. Con el objetivo de profundizar en el comportamiento táctico colectivo de los deportes de equipo, el apartado (4) *evaluación del comportamiento táctico colectivo en deportes de equipo mediante el dato de posicionamiento* indagó en el origen y las modificaciones de las variables tácticas colectivas medidas a partir del dato de posicionamiento mediante una revisión sistemática.. Puesto que la calidad de la medida es un aspecto fundamental en el proceso de medición, el apartado (5), *tecnología para evaluar el comportamiento táctico colectivo*, presentó la tecnología utilizada para la medición de las variables tácticas colectivas. De manera complementaría, el apartado (6) *evaluación de la calidad de la medida con tecnología de radio-frecuencia para medir el comportamiento colectivo en deportes de equipo* propuso una novedosa herramienta de valoración (i.e., "*quality criteria standard*") sobre el proceso de obtención del dato mediante tecnología de radio-frequencia. El último apartado teórico de la introducción (7), *impacto de la cantidad de datos por segundo en la medida de las variables tácticas colectivas usando un sistema de información geográfica,* presentó al lector la problemática del sistema de información geográfica como medio para el análisis de las variables tácticas. En el apartado (7) se plantea la hipótesis y los objetivos de la tesis doctoral. Posteriormente, se presentarán la metodología, los resultados y la discusión de los dos estudios de campo llevados a cabo: (1) estudio *preliminar* (estudio 1) y estudio *partido de fútbol* (estudio 2). La tesis doctoral finalizará con las conclusiones, las limitaciones y las futuras líneas de investigación...

Resumen general de la tesis doctoral (normativa UPV-EHU)

Introducción

Desde un punto de vista jurídico, los deportes de equipo son deportes deóntico-jurídicos que se basan en el principio de sanción. Las reglas definen la "*lógica interna*", es decir, los rasgos pertinentes o *"constraints"* y las consecuencias práxicas (e.g., el comportamiento táctico colectivo) de cada deporte. Los deportes de equipo comparten dos rasgos de lógica interna (o "*constraints*") fundamentales: la presencia de compañeros y de adversarios. En consecuencia, los jugadores de deportes colectivos deben responder a la incertidumbre (i.e., falta de información) debida a sus propios compañeros, y en especial, a los adversarios. La incertidumbre social supone imprevisibilidad, interactividad, y procesos no lineales. Por tanto, los deportes de equipo pueden entenderse como sistemas complejos en los que se pueden valorar aspectos como la fase relativa y la variablidad en los tres tipos de variables del comportamiento táctico colectivo: el *punto geométrico* (GC), las *díadas* y el *área*.

Con el objetivo de profunizar en el análisis del comportamiento táctico colectivo en los deportes de equipo, el estado del arte fue abordado mediante una revisión sistemática que consideró el origen y las modificaciones de tres tipos de variables tácticas: el *punto geométrico* (GC), las *díadas* y el *área*. Para una declaración explícita, se seleccionaron las palabras clave siguiendo el diseño PICO y se realizó la búsqueda sistemática en cuatro bases de datos (i.e., SportDiscuss, PubMed, ProQuest y WoK). Los tres grupos de palabras clave fueron: a) deportes de equipo en los que el uso del móvil es simultáneo (*muestra*), b) términos sobre la herramienta de evaluación de las variables tácticas (*intervención*) y, por último, c) términos relacionados con lo que los autores esperaban encontrar (*resultados*). 3,973 documentos fueron resgistrados, de los cuales 1,779 eran duplicados y fueron eliminados. Después del análisis de los 2,178 artículos restantes, 36 fueron añadidos desde fuentes adicionales. Finalmente, de los 72 artículos que cumplieron los criterios de inclusión 1-3, 38 propusieron de manera original alguna variable táctica colectiva o técnica de análisis no lineal. En última instancia, los resultados fueron organizados en los tres grupos principales (el *punto geométrico* [GC], *díadas* y *área*).

Siete artículos propusieron variables tácticas originales relacionadas con el posicionamiento del *centro geométrico* (*GC*). Dos cálculos diferentes han sido sugeridos para medir el *GC* en los deportes de equipo, siendo la media [*x, y*] de varios o todos los jugadores del equipo el más utilizado. Aunque el *GC* original consideró el portero en el cálculo del *GC* en el fútbol, habitualmente, no suele ser considerado en la medición. Puesto que la ubicación de los jugadores respecto a la portería no es considerada para evaluar el *GC* en deportes de equipo, sería conveniente asociar variables tácticas complementarias como por ejemplo la distancia entre el portero o la portería y el *GC*. Los investigadores han aplicado dos técnicas (i.e., la transformación de Hilbert y el método *Cluster*) para analizar la sincronización (i.e. la fase relativa) y el *AMI* para evaluar la complejidad y la regularidad o la previsibilidad del *GC* en los deportes de equipo.

Veintiséis artículos propusieron variables tácticas originales relacionadas con las díadas durante las últimas dos décadas. En función de la naturaleza de los osciladores, las díadas se pueden clasificar en: (1) díadas de *jugador-jugador* (i.e., *jugador-oponente, jugador-compañero*), *jugador-espacio, jugador-móvil* y *GC-GC- jugador* / *espacio* / *portería*. La medición de la distancia o el ángulo entre jugadores permite evaluar la interacción entre dos jugadores, ya sean compañeros de equipo u oponentes. Estas díadas son de especial interés en los deportes en los que se usa el marcaje individual frecuentemente, como el baloncesto y el fútbol sala, y en los contextos cercanos a la diana (e.g., portería y canasta). Además, las díadas *jugador-jugador* se utilizan para valorar la longitud y la anchura del equipo y las díadas *jugador-GC* para evaluar la dispersión del equipo. Las díadas *espacio-jugador* han sido medidas para evaluar la distancia entre el jugador (o línea de equipo) y espacios relevantes como, por ejemplo, la diana. Aunque estas variables pueden ser interesantes de manera independiente, sería enriquecedor analizar la relación entre ellas.

La aplicación de la fase relativa y la entropía ha permitido el análisis de la sincronización y la complejidad y regularidad o previsibilidad de las díadas (i.e., *fase relativa*, método *Cluster*, entropía, *ApEn*, $ApEn_{ratioRandon}$, $ApEn_{ratioSuffle}$, *SampEn*, *cross-SampEn*, *AMI*). Por lo general, la fase relativa ha sido utilizada para medir la sincronización entre dos osciladores (i.e. transformación de Hilbert), pero varios autores han sugerido el método *Cluster* para evaluar la sincronización entre más de dos osciladores. Esta sugerencia aporta un análisis más complejo de los deportes de equipo. Con respecto a la *entropía*, diversos tipos de técnicas han sido sugeridas: *ApEn*, $ApEn_{ratioRandon}$, $ApEn_{ratioSuffle}$, *SampEn*, *cross-SampEn*. La falta de consenso dificulta la comparación entre los estudios.

Quince artículos sugirieron variables tácticas originales relacionadas con el *área*. Las variables tácticas de este grupo se pueden clasificar en 3 tipos: *espacio ocupado*, *espacio de exploración* y *espacio dominante o de influencia*. La mayoría de los estudios no consideraron el portero y el espacio de juego restante para evaluar el *espacio* *ocupado*, pero varios estudios han propuesto nuevas variables que consideran la totalidad del espacio de juego en la medición del uso del espacio: *espacio libre efectivo*, *área de superficie normalizada*. Solo ha sido sugerida una variable espacial de exploración colectiva: *el rango principal del centro geométrico* (GC). Esta sugerencia podría aplicarse para evaluar el *espacio de exploración* colectiva de varios jugadores (i.e. subsistema). La medición del *espacio dominante o de influencia* se ha basado en el cálculo de la *región de Voronoi* a partir de la distancia entre jugadores, aunque varios estudios basaron el cálculo en el tiempo *t* (i.e. el hipótetico tiempo que se necesitaría para alcanzar un punto en el espacio). También, varios estudios han propuesto diferentes *áreas dominantes ponderadas*: *dominant area weighted by the goal* y *dominant area weighted by the ball.* Con el objetivo de evaluar la previsibilidad del uso del espacio cuatro técnicas diferentes han sido utilizadas: *SampEn, cross-SampEn, ApEn,* $ApEn_{RatioRandom}$.

A pesar del uso frecuente de la tecnología de radiofrecuencia (RF) (GNSS / GPS) y sistemas de posición local (LPS) en la investigación deportiva, no existe un protocolo que establezaca cómo evaluar la calidad del proceso de recopilación de datos. Por lo tanto, en este capítulo fue sugerido un *estándar de criterios de calidad* basado en protocolos utilizados previamente para evaluar la calidad de los datos registrados mediante la tecnología RF en deportes de equipo. Se consideraron varios factores que podrían afectar la calidad de los datos: *fiabilidad y validez, frecuencia de muestreo, criterios de exclusión e inclusión de datos, el momento en que se extrajeron los datos, el bloqueo, sincronización de datos, la cantidad de puntos de referencia y satélites, condiciones ambientales y de infraestructura, instalación y posición de antenas, y método de medición*. Se propuso una herramienta de valoración de la calidad del proceso de recogida del dato compuesta por 14 ítems de criterios generales. Además, se incluyeron 4 itmes y 8 ítems adicionales para los sistemas GPS / GNSS y LPS, respectivamente (anexo 1).

La precisión en el registro del dato de posicionamiento de los jugadores es un aspecto crucial en la medición de las variables de comportamiento táctico. Uno de los factores que afectan a la precisión del registro es la frecuencia de muestreo empleada, cuyo aumento puede incrementar la resolución de la medida. El desarrollo de la tecnología aplicada a el deporte ha posibilitado que las empresas incorporen Sistemas de Información Geográfica (GIS) que permiten mostrar datos sobre la localización, ofreciendo amplias posibilidades para el análisis del posicionamiento táctico de los equipos mediante los datos vectoriales que reflejan el posicionamiento en forma de punto, línea y/o polígono. Sin embargo, el GIS es un complemento externo que las empresas añaden a los softwares. Debido a cuestiones técnicas derivadas del procesamiento de datos, estas aplicaciones asumen un límite de procesamiento de datos, que no permitirá importar y procesar todos los datos que se hayan registrado. Esta limitación podría suponer que la medida asuma cierta imprecisión, por lo que algunas empresas han propuesto diferentes soluciones. Concretamente, la empresa RealtrackSystems permite de manera adicional la inserción de mayor cantidad de datos por segundo que la que el GIS incorporado en el software tiene por defecto (1 Hz).

Por lo tanto, los objetivos de la tesis doctoral fueron: a) evaluar y valorar el impacto de la cantidad de datos insertados por segundo en la medida del GC y el área total (TA) cubierta durante varias tareas de entrenamiento controladas y b) evaluar y valorar el impacto de la cantidad de datos insertados por segundo en la medida del GC, la distancia media entre jugadores (mean-DbP) y el área total cubierta durante un partido de fútbol.

Método

El software S PRO, RealTrack Sytems, Almeria, Spain permite insertar datos por segundo para el uso del GIS. El impacto de la inserción de datos fue evaluado y valorado para las variables tácticas GC, mean-DbP y TA tanto durante varias tareas controladas, en el que se comparó el valor obtenido con la medida real, como durante un partido 7+GK vs 7+GK. En concreto, cuatro cantidades diferentes de dato fueron insertadas: 10 datos por segundo (GIS 10 Hz), 4 datos por segundo (GIS 4 Hz), 2 datos por segundo (GIS 2 Hz) y 1 dato por segundo (GIS 1 Hz).

Resultados

Los valores de cGCp fueron significativamente ($p<0.01$) y sustancialmente (ES = *large*) diferentes en comparación a la medida real entre todas las cantidades de datos insertados por segundo durante todas las tareas controladas: 10 datos por segundo (GIS 10 Hz), 4 datos por segundo (GIS 4 Hz), 2 datos por segundo (GIS 2 Hz) y 1 dato por segundo (GIS 1 Hz). Sin embargo, los valores de TA fueron similares ($p > 0.05$; ES = *trivial*) a la medida real para todas las cantidades de datos insertados por segundo.

Los valores de cGCp fueron significativamente ($p<0.001$) y sustancialmente (ES = *moderate-large*) diferentes en función de la cantidad de datos insertados por segundo (10 datos por segundo (GIS 10 Hz), 4 datos por segundo (GIS 4 Hz), 2 datos por segundo (GIS 2 Hz) y 1 dato por segundo (GIS 1 Hz)) en el partido de fútbol. Los valores de *mean-DbP* fueron significativamente ($p<0.01$) y sustancialmente (ES =

moderate-large) diferentes al comparar los valores obtenidos tras la inserción de 1 dato y 10 datos por segundo (1 vs 10 datos, ($p < 0.01$). Los valores de TA fueron significativa y sustancialmente similares ($p > 0.05$; ES = *trivial*) en a todas las cantidades de datos insertados por segundo en el partido de fútbol.

Discusión y conclusiones

Hasta la fecha, no hay consenso sobre la cantidad de datos que se debe emplear para medir las variables tácticas colectivas en los deportes de equipo. Además, ningún estudio ha hecho referencia al tratamiento de los datos en el GIS, lo que sugiere una falta de información sobre las limitaciones de su uso. Esta tesis doctoral, sugiere el uso de, al menos, 10 datos insertados por segundo para medir el cGCp (GC) y la mean-DbP. Sin embargo, la inserción de más de un dato por segundo no supone ningún beneficio en la medición del TA durante el entrenamiento de fútbol. Por tanto, los técnicos deportivos e investigadores no deberían emplear el mismo número de datos para medir las variables tácticas colectivas en los deportes de equipo.

Introduction

Sports

The concept of "sport" is commonly used and its meaning seems clear (Parlebas, 2001); however, it is a polysemic term (Parlebas, 2001). As mentioned by Meier (1981), there are few words that have as many divergent meanings as “sport”, and its meaning varies considerably according to the prism through which we approach the term (Belski, Forsyth, & Mantzioris, 2019; Cohen, Baluch, & Duffy, 2018; Malcolm, 2008; Meier, 1981; Osterhoudt, 1996; Parlebas, 2001). Among other definitions, sport has been defined as: (1) all physical activities that are not necessary for the survival of the individual or the race and that are dominated by an obligatory element (McIntosh, 1970); (2) habitual worship of intensive muscular exercise based on the desire for progress and capable of reaching the point of risk (Cobertin as cited in Groves (1972); (3) a kind of play that can be described as voluntary satisfaction of the non-material needs of an individual in physical and aesthetic activity in the form of a creative and socially significant activity (Novikov and Grishin as cited in Ponomarev (1974); (4) an artistic form of kinetic play, most frequently developed within a context of broader social forms of play or sociability (Carlton, 1975).

From the prism of the science of motor action, sport is a set of *coded* motor situations in the form of *institutionalized competition* (Parlebas, 2001). Each sport is defined by its own system of rules that differentiates it from the rest (Parlebas, 2001), is involved in a confrontational situation (i.e. competition) (Martínez-Santos, 2018) and, unlike traditional and street games, is led by officially institutionalized instances (Parlebas, 2001). This doctoral thesis will consider motor situations that meet the aforementioned criteria (i.e., *coded* situations in the form of *competition* that are *institutionalized*).

Sports from a juridic point of view.

Games are born when the rules representing the game are declared (Martínez-Santos, 2018). Although several authors understand the rules as *constraints* of the task (Araújo & Davids, 2016; Newell, 1986), they are not part of the game but prior to it (Martínez-Santos, 2018). Like instructions, the rules create situations in which it is not reasonable to behave anyhow (Martínez-Santos, 2018), and in the case of sports, the rules are established and modified by the competent institution (e.g., federation or committee).

According to Robles (1984), we can differentiate between *direct rules*, those that regulate the participation of players, and *indirect rules*, whose omission mean the disappearance of the game. Based on this classification, Martínez-Santos (2018) proposed a classification of three kinds of rules in order to analyze sports from a juridic point of view:

(1) *ontic rules* are indirect rules, which create the elements of the system related to the human (space, time, subjects and competences) but which do not guide action;

(2) *technical rules* have a direct nature and are based on the principle of annulment. These types of rules establish how it is necessary to operate in order for the generic action to be ontic-practical (i.e. they guide the action);

(3) *deontic rules*, with a direct nature, are based on the sanction principle. These rules are directed to the participant demanding a duty, a behavior or a conduct (i.e. they guide the action).

It can be understood from the combination of these three types of rules, that the different modalities of sport confrontation correspond to different types of ordering of motor behaviors that make up two main categories of games (Martínez de Santos, 2007):

(1) *technical-juridic*, in the case of competitions and careers;

(2) *deontic-juridic*, in the case of duels. The present doctoral thesis will consider *deontic-juridic* sports (i.e. duels), specifically, collective duels.

Team sports

The obligation to comply with the rules imposes an *internal logic* that, to a certain extent, guides the motor behaviors of the participants beforehand (Parlebas, 1996). In other words, the rules determine the internal logic of each sport modality and, therefore, define the sport game (Parlebas, 2001). *Internal logic* is defined as a system of relevant structural traits [or "constraints" (Newell, 1986)], and the consequences (e.g. players´ behavior) that it involves for the performance of the corresponding motor action. In other words, the internal logic is a system of obligations, a kind of framework that limits the action of the players during the game (Parlebas, 2001).

In this way, the *internal logic* makes it possible to understand the sport game from the particular way in which the players can relate to the space, to time, to the other participants and to the mobile (Lagardera, 2003). All of them should be conceived as a set of indissoluble elements, where any change in the structural traits of a component directly affects the whole set (Fotia, 2015). So, a sport game (i.e. sport) is a set of instructions to situate people with respect to the four main axes of the *internal logic*: relationship with the others, space, time and projectile (Martínez-Santos, 2018).

As mentioned before, the nature of the relevant structural traits of each sport regulates the behavior of the players and, consequently, of the team (Parlebas, 1996). Similarly, Newell (1986) suggested that pattern formation in systems (e.g. sports) arises from the confluence of different "*constraints*" (i. e. restrictions). Specifically, the author differentiated three types of "*constraints*" (Newell, 1986):

(1) *internal "constraints"*: the organism

Internal "*constraints*" refer to the participating subject: on the one hand, their structural characteristics (e. g. age, height, weight, muscle mass, and muscle fiber composition) and, on the other hand, their physical or emotional response.

The internal "*constraints*" comprise one of the independent variables of the motor situations, the characteristics (age, sex, abilities ...) of the players (Parlebas, 1998) and the practical consequences (e.g. physiological demand).

(2) external "*constraints*"

According to Newell (1986) the external "*constraints*" are foreign to the subject´s characteristics, which could make us think that they refer to the *internal logic* of motor situations (Parlebas, 2001):

a. the *environment*

Environmental factors would refer to the *internal logic* structural traits of the tasks. Both the climatic/environmental factors, that is, the uncertainty of the physical environment (Parlebas, 2001), and the rest of the *internal logic* structural traits (i.e. relationship with others, space, time and mobile) of the tasks (Parlebas, 2001).

b. the task

In Newell's (1986) opinion the "*constraints*" regarding the task are related to the objective (i.e. to score a goal or basket) and the task rules. From the perspective of motor action, the "objective" would refer to the type of *mark interaction* (Parlebas, 2001), that is, to another structural trait of the *internal logic*, and the rules would not be "*constraints*" but rather the instructions prior to the game.

Similarly, the ecological approach (Gibson, 1979) suggests that environmental "*constraints*" (i.e. interactive *constraints*) regulate action (Warren, 2006), in the case of team sports, motor action. The presence of teammates and opponents and their corresponding uncertainty forces the player, in particular, and the team, in general, to plan, organize and make constant decisions (Davids, Araújo, Vilar, Renshaw, & Pinder, 2013). Gibson (1979) suggested that decision-making is conditioned by the "*environmental information*" of the task (i.e. *internal logic*), which assumes a different amount of uncertainty (i.e. lack of certainty). In the opinion of Araújo, Davids, and Hristovski (2006), from a practical point of view, the dynamics of perception, action and cognition can be described from two levels of analysis:

(1) the interactions between the player and the "environmental *constraints*", with players´ actions that detect information. This interaction forces the player to identify and manage the "environmental" information and conditions the players´ behavior. The response of the player or players in a structured environment (i.e. *internal logic*) over time, causes the emergence of functional behavioral patterns (i.e., regularities).

(2) the temporal evolution of behavior (i.e., behavioral dynamics), that is, the variability of functional patterns.

Based on three structural constraints of *internal logic* (Parlebas, 2001) or "*constraints*" (Gibson, 1979; Newell, 1986), the presence or absence of uncertainty (i.e. lack of information) due to social relationships (i.e. teammate [C] / opponent [A]) and the physical environment [I], internal logic defines 8 groups that classify every sport game (i.e. categories of motor situations) (Parlebas, 2001). Specifically, 2 psycho-motor domains: psycho-motor [0] and psycho-motor with uncertainty of the physical environment [I], and 6 sociomotor action domains: collaboration [C], collaboration with uncertainty of the physical environment [CI], opposition [A], opposition with uncertainty of the physical environment [AI], collaboration-opposition [CA] and collaboration-opposition with uncertainty of the physical environment [CAI]. The last two motor action domains refer to team sports (i.e. collective duels), that is, those sports in which the interaction with the teammate and the opponent is a constituent part of the task resolution (e.g. soccer, basketball, handball, rugby, hockey, volleyball, tennis [doubles]). As Parlebas (2017) suggests, and we will take as a criterion, the smallest micro-society of a team sport will be the 2 vs. 2.

In addition, team sports can be classified according to the degree of uncertainty due to the physical environment. In this case, we can differentiate the team sports that are played indoors (e.g. basketball and handball), with very low uncertainty, and those that are played outdoors (e.g. soccer and rugby), with moderate uncertainty (i.e. semi-wild (Castellano & Hernández Mendo, 2000)).

Although of special practical interest, the classification based on uncertainty due to social relationships and the physical environment (i.e., *motor action domains*), can be considered too general depending on the type of study that is intended. For example, the analysis of collective behavior (Schöllhorn, 2003) in team sports. The inclusion of different *internal logic* structural traits (i.e. criteria) in the classification of team sports allows them to be re-categorized into more similar sport families. One of these structural traits is the type of *inter-motricity* (i.e. field and nature of motor situations whose realization is based on the execution of cooperation and / or opposition motor interactions between several participants (Parlebas, 2001)[1]) based on the time parameter. Martínez de Santos (2007) differentiated three kinds of *inter-motricity*: *alternate*, with *alternate use of the mobile*, and *simultaneous*. In the present doctoral thesis, team sport *simultaneous inter-motricity* (e.g. soccer, basketball or hockey) will be considered.

Although the *internal logic* guides the motor behaviors of the participants in advance (Parlebas, 1996), it assumes a certain regularity in the players' behaviors, the uncertainty (i.e. lack of information) due to the teammate (i.e. positive interaction) and the opponent (i.e. negative interaction) assume unpredictability and nonlinearity of behavior (Casamichana, San Román, Calleja, & Castellano, 2016). Therefore, as social systems, team sports have been treated as complex and dynamic systems (Araújo & Davids, 2016; Parlebas, 2002).

Kugler, Kelso and Turvey (1980) suggested the analysis of coordination in humans based on the concept of dynamical system. Its objective was to propose a model construct in terms of which the control and coordination of movement might be understood; specifically, the coordination among different muscles. This construction model was proposed to identify a system whose internal degrees of freedom regulate

[1] This brief definition should be reconsidered when talking about the network of changes in the sociomotor roles of team sports since at certain times not all players have the *right to play* with the ball (Martínez de Santos, 2007)

themselves with minimum recourse to an "intelligent regulator" (Kugler et al., 1980). In the opinion of Kugler et al., (1980) "open systems" are characterized by the presence of stochastic elements and non-linear components, that is, by the unpredictability due to social and/or physical environment uncertainty.

Collective tactical behavior

Team sports lend themselves to an investigation that distinguishes independent variables (i.e. characteristics of the players [i.e. age, sex, ...] and factors of *internal logic* [i.e. relationship with space, time, mobile and with others] and dependent variables (i.e. players´ behavior and physical-physiological demand) (Parlebas, 1998). Among these dependent variables, collective tactical behavior becomes highly relevant with the aim of evaluating the socio-motor team sport dynamics (Frencken, 2009; McGarry, Anderson, Wallace, Hughes, & Franks, 2002; Parlebas, 2017).

Motor behavior refers to the set of observable manifestations of an acting individual and is defined according to what is perceived from the outside (Parlebas, 2001). Although the assessment of individual behavior is of interest (Clemente, Couceiro, Martins, Dias, & Mendes, 2013; Gonçalves et al., 2017; Yue, Broich, Seifriz, and Mester, 2008), the observable manifestations at the collective level gain greater relevance in team sports (Frencken, 2009; Frencken, Lemmink, Delleman, & Visscher, 2011; Moura, Santana, Marche, Aguiar, & Cunha, 2011; Yue et al., 2008). For this reason, this doctoral thesis will not consider the variables of individual tactical behavior (i.e. isolated analysis of the behavior of a single player) and will prioritize the collective ones, that is, the relationships between teammates and/or opponents in time and space (Clemente, Sequeiros, Correia, Silva, & Martins, 2018). The measurement of these variables allow us to infer the meaning of collective tactical behavior from the interpretation of the sports technician and to use this information in the design of training tasks (Ometto et al., 2018) and the preparation for the competition (Memmert, Raabe, Schwab, & Rein, 2019; Palucci Vieira et al., 2018).

Assessment of collective tactical behavior in team sports by positional data: collective tactical variables

Since Schöllhorn (2003) suggested, among other measures, the geometrical centre (GC) to analyse team sports matches, this approach has been one of the most commonly used to assess the behaviour of the whole team. The GC represents, in a single point computed considering *x* and *y* coordinates of the players, the relative positioning of each team in forward-backward and side-to-side movements (Araújo & Davids, 2016). Different terms (*centroid* (Frencken et al., 2011), *centre of gravity* (Lames, Ertmer & Walter, 2010), *spatial centre* (Bourbousson et al., 2010a), *centre of the team* (Frencken, 2009) have been used to refer to the 'same' concept in team behaviour assessment studies. However, to our knowledge, no study has analysed whether these terms are computed in the same way and are conceptually equal. Thus, it is relevant to analyse the origin, modifications, and computation of the GC over the last few decades since its interpretation and the assessment of derivative team behaviour variables (e.g. GC-GC distance, relative phase and entropy) (Bourbousson et al., 2010a; Duarte et al., 2013; Silva, Duarte, et al., 2014; Travassos et al., 2012) could differ considerably.

Although all players constantly interact with one another during team sports matches and tasks, the nature of these interactions differs considerably (Grehaigne et al., 1997) according to the location of the ball (Travassos et al., 2011, 2012), the location of players with respect to the goal (Silva, Travassos, et al., 2014; Vilar et al., 2014), and the team in possession of the ball (Frencken, 2009; Yue, Broich, Seifriz, & Mester, 2008). For this reason, the decomposition of the team into micro-structures (or sub-systems (Grehaigne et al., 1997)) has been suggested in order to assess team behaviour. This decomposition means a reductionist approach (Grehaigne et al., 1997) of the social system (i.e., a collective duel) (Araújo & Davids, 2016; Parlebas, 2001), but allows analysis of relevant and special interactions among several players. Based on studies (Palut & Zanone, 2005) on racket games, the assessment of the interaction of two players (i.e., dyad), teammates or opponents, has been suggested through the measurement of the distance between both players and several proceeding techniques (i.e., *player-player*, *player-opponent*, *relative phase* of two players' movements, *entropy* of a two player data set) (Bourbousson et al., 2010a, 2010a; Gonçalves et al., 2017; Olthof et al., 2018; Passos et al., 2009; Silva, Duarte, et al., 2014; Silva, Travassos, et al., 2014; Vilar et al., 2014). In addition, several studies have considered the distance of the players in a particular zone of the pitch, that is, they have measured several *player-space* dyads (Esteves et al., 2016; Passos, Araújo, Davids, Gouveia, & Serpa, 2006; Vilar et al., 2014). Other articles have proposed angles instead of distances as the relationship method between two oscillators or one oscillator and space (Vilar, Araujo, Davids, & Travassos, 2012; Vilar et al., 2014). After more than twenty years, many types of dyads have been used to assess team behaviour in team sports (Bartlett et al., 2012; Bourbousson et al., 2010a; Esteves et al., 2016; Gonçalves et al., 2017; Olthof et al., 2018; Passos et al., 2008; Sampaio & Maçãs, 2012; Shafizadeh et al., 2016; Silva, Travassos, et al., 2014; Silva, Duarte, et al., 2014; Vilar et al., 2014; Yue et al., 2008). However, it would be interesting to classify and analyse these dyads and their derivative variables in order to assess their practical application in team sports training and matches.

Gréhaigne proposed the assessment of the use of the space in team sports more than 20 years ago (Gréhaigne, 1992). Specifically, the author suggested measurement of the effective *play-space* in soccer (Gréhaigne, 1992). Later, several authors proposed and measured different variables to assess the use of space in team sports (Low et al., 2019; Rico-González, Los Arcos, Nakamura, Moura, & Pino-Ortega, 2019). In addition to tactical position and distance variables, a recent systematic review provided a comprehensive summary of tactical variables that are used to analyse the use of the space in soccer, with a particular focus on organising the methods (Low et al., 2019). However, to our knowledge, no study has identified the original spatial tactical variables and has assessed their conceptual and computational modifications during the last few years in team sports (e.g., soccer, futsal, basketball, rugby, and hockey). This type of study would allow assessment and understanding of the proposal of new tactical variables and their conceptual and computational modifications at a practical level to analyse the use of space in team sports. Since team sports are complex systems, in addition to traditional methods of linear analysis (Low et al., 2019), it would be interesting to identify the nonlinear tools used to analyse the predictability of the use of space in team sports.

As we have indicated, the analysis of the aforementioned variables are sometimes complemented with non-linear processing techniques (i.e., *relative phase* and *entropy*) (Schmidt, O´ Brien, & Sysko, 1999; Silva, Duarte, Esteves, Travassos, & Vilar, 2016). From the sport context, the relative phase was suggested as a collective variable data processing technique to capture the modes of movement that two oscillators demonstrate during games, showing two patterns of relative motion: in-phase (0º) (i.e., the oscillators move in the same direction) and anti-phase (i. e., ±180º) (the oscillators move in opposite directions) (Palut & Zanone, 2005). These signals could be used to assess the synchronisation between different types of oscillators. Despite the fact that coordination is a very critical factor in team sports, the uncertainty is also another important characteristic. So, *entropy* (Pincus, 1991) was transferred to team sports due to its appropriateness for analysing the results of nonlinear dynamical systems such as sports teams (Passos et al., 2009). This data processing technique has been used to assess the complexity and regularity or predictability of the team´s *GC*, distances or area variable time series (Barnabé, Volossovitch, Duarte, Ferreira, & Davids, 2016; Duarte et al., 2013; Gonçalves et al., 2017; Passos et al., 2009; Silva, Duarte, et al., 2014).

A systematic review was carried out in order to identify the origin and modifications of the GC, dyads, area and non-linear analysis techniques in the assessment of team behaviors in team sports. It was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) guidelines (Moher et al., 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 (i.e., SportDiscuss, PubMed, ProQuest y WoK) was performed by the authors (MR, ALA, JPO) to identify articles published before 13 November of 2018. The authors were not blinded to journal names or manuscript authors. The PICO (Moher et al., 2009) design was used to provide an explicit statement of question. The search was carried out using two filters where the database allowed this: journal article; and title (TI)/abstract, except in WoS, which was searched throughout the text. In addition, in the last-mentioned database the sports sciences branch was selected. Three main groups were created to separate team sports; the first group included the team sports (i.e. at least two players per team) in which the use of the mobile object is simultaneous (*population*), the second group considered words about assessment tools (*intervention*), and the third group included words about the results that the authors hoped to find (*outcomes*). The keywords were connected with AND to combine the three groups and OR to link the words in each group (Table 1).

Table 1. Database search strategy

Search Term	Keywords
1. Team sports in which the use of the mobile object (e.g., ball or disc) is simultaneous.	"Team sport*" OR soccer OR football OR basketball OR rugby OR handball OR hockey
2. Assessment tools	GPS OR "global position system*" OR GNSS OR "Global navigation satellite system*" OR UWB OR "ultra wide band" OR "local position" OR LPP OR LPS OR LPS OR EPTS OR "electronic performance and tracking systems*" OR video OR “video tracking” OR "tracking system*" OR electronic* OR "satellite system*" OR GIS OR "geographical information system*"
3. Outcomes	formation* OR tactic* OR behaviour* OR performance* OR position* OR spatiotemporal OR spatio-temporal OR synchronisation* OR coordination* OR pattern* OR synergy* OR Voronoi OR Delaunay OR “decision-making” OR “decision making”

When the 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 (title, authors, date, and database) to an Excel spreadsheet (Microsoft Excel, Microsoft, Redmond, USA) and removed the duplicate records. Subsequently, the same authors screened the remaining records to verify the inclusion-exclusion criteria, using a hierarchical approach (Table 2) 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).

Table 2. Inclusion/exclusion criteria

Criteria	Inclusion	Exclusion	Primary Screen type
1	Team sports in which the use of the mobile object (e.g., ball, disc) is simultaneous (e.g. soccer, basketball, rugby, hockey).	Team sports in which the use of the mobile object is alternate (e.g. volleyball, squash, tennis, badminton).	Title/Abstract/Full text
2	The main objective of the study is to assess tactical performance or dimension in team players by positional data	Studies that do not assess the tactical performance or dimension in team sports (e.g., studies that only quantify external training load). Studies that consider referees. Studies that do not assess tactical performance or dimension using EPTS.	Abstract / Full text/
	Studies that include a tactical variant regarding the position of the players	Studies that do not assess tactical performance or dimension using EPTS.	Abstract / Full text/
3	Studies that aim to analyse the position of more than one player, whether they are rivals or not	Studies that analyse the position of the players individually.	Abstract / Full text/
4	Studies that provided new variables (i.e. *GC*, dyad or area) or non-linear analysis techniques, or any modification of the variables or computation criteria.	Studies that did not provide new variables or non-linear analysis techniques, or any modification of the variables or computation criteria.	Full text

Any disagreements on the final inclusion-exclusion status were resolved through discussion in both the screening and excluding phases. Moreover, relevant articles not previously identified were also screened in an identical manner and the studies that complied with the inclusion-exclusion criteria were included and labelled as ‘not identified from search strategy’.

A total of 3,973 documents were initially retrieved from the above-mentioned databases, of which 1,779 were duplicates. A further fourteen records were removed as they were not articles and another two were not found. Thus, a total of 2,178 articles were screened. Next, the titles and abstracts were verified against criteria 1-3 and studies were excluded where possible. The full texts and abstracts of the remaining articles were screened and the inclusion/exclusion criteria were applied, leading to the exclusion of 2,142 articles. Therefore, thirty-six articles were initially included in this review. In addition, reviewing the references of the included articles, the authors found and added thirty-six articles that met inclusion criteria 1-3 (Figure 1). Finally, from the seventy-two articles that were analysed, only thirty-eight proposed origin and modification of the collective tactical variables (Table 3).

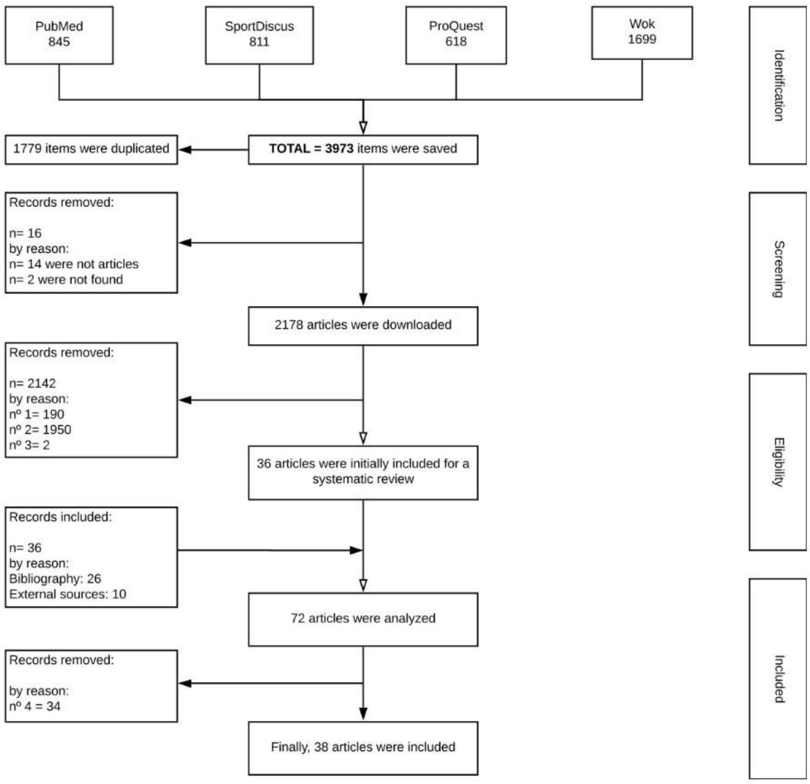


Figure 1. Flow diagram

Table 3. Classification of the collective tactical variables

Variable	Group and sub-groups of variables	Variables included in each group
GC	*GC*	*Geometrical centre of the team*
Dyads	Distance between two points (i.e., *GC* of several players, players, space, ball)	
	Player-player	
	Player-opponent	*Player-opponent. Team separateness*
	Player-teammate	*Player-teammate. Length; Width*
	Player-space	*Player-line. Player-goal.*
	Player-ball	*Player-ball*
	GC – GC	*GC-GC*
	GC – Player	*Own/opponent GC-player*
	GC – Space	*GC-defensive line /goal*
Area	*Occupied space*	*Surface area. Covered area*
		Effective playing space
	Influence space	*Major ranges of GC*
	Dominant space	*Dominant region area/Voronoi cells*
		Weighted dominant region area
		Superimposed Voronoi diagrams
		Maximum percentage of overlapped area
		Percentaje of free area

GC: Geometrical Centre

Origin and modifications of the *geometrical centre* to assess team behavior in team sports.

As was mentioned in the flow diagram (Figure 1), from the thirty-eight articles that were included, thirty-one did not fulfil inclusion criterion 4 for the *geometrical centre*. So, only seven articles were included. Among them, three were originals or showed modification of *GC* (Table 4) and four were originals or proposed modifications of non-linear techniques (Table 5).

Habitually, the *GC* is computed as the mean [*x*,*y*] of several or all players of the sports team. Despite the relevance of the location of the players respect to goal, habitually, the goalkeeper/target has not been considered in the measurement of the *GC*. Two techniques (i.e. Hilbert transformation and cluster analyses) have been applied to analyse the synchronisation (i.e. *relative phase*) and the *AMI* to assess the complexity and regularity or predictability of the *GC* in team sports.

Collective tactical variables

More than 15 years ago, Schöllhorn (2003) proposed, among other measures, the *geometrical centre* (*GC*) (i.e., the common centre of gravity of several or all team members) in order to quantify tactical behaviour in team sports. However, this tactical variable was not measured in team sports until 2008. Yue et al (2008) calculated the *GC* (they also used this term) of two teams as functions of time to assess its amplitude in longitudinal and lateral directions and its movements regarding the ball during a professional soccer match (Yue et al., 2008). The authors defined the *GC* of each team, including goalkeepers (Figure 2), in both directions (Yue et al., 2008). One year later, Frencken & Lemmink (2009) used the term *centre of team* instead of *GC* but the same mathematical concept proposed by Yue et al. (2008), *the mean [X,Y] of all players of the team* (Frencken & Lemmink, 2009), to measure this tactical variable during soccer small-sided games (Figure 3). In comparison to Yue et al. (2008), they did not consider the goalkeeper in the computation (Frencken & Lemmink, 2009). Later, Moura et al. (2011), based on the suggestion of Graham (1972), proposed a different mathematical computation, *the centroid of the geometric form of the team's convex hull*, to measure the *GC* during a futsal match (Figure 4) (Moura et al., 2011).

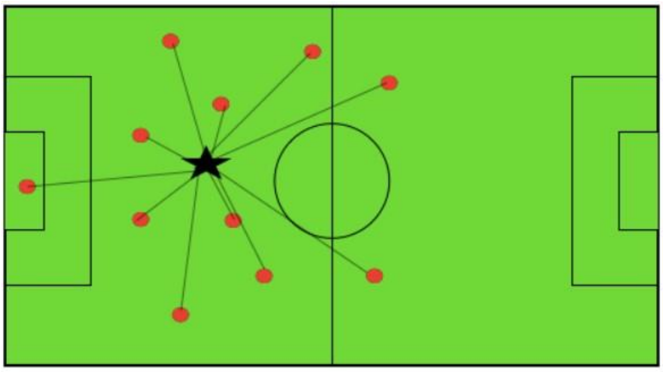


Figure 2. Graphic representation of *GC* from mean position of all outfield players and goalkeeper

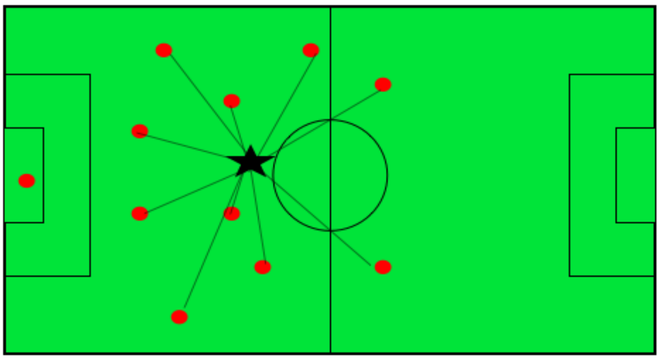


Figure 3. Graphic representation of *GC* from mean position of all outfield players

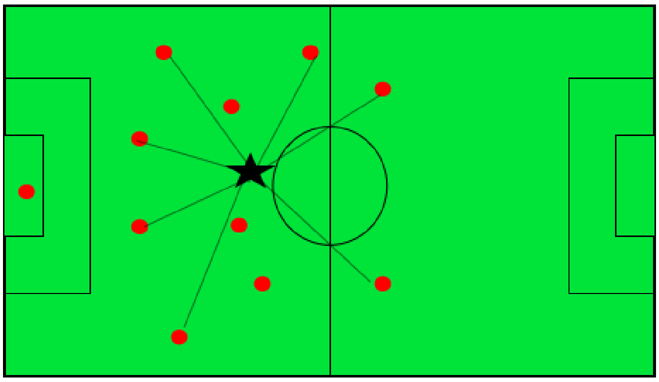


Figure 4. Graphic representation of *GC* with convex hull (without goalkeeper)

Currently, the majority of studies (Bourbousson et al., 2010a; Frencken et al., 2011; Lames, Ertmer, & Walter, 2010) apply the mathematical concept suggested by Yue et al. (2008) and Frencken and Lemmick (2009) and, if applicable, exclude the goalkeeper to measure the *GC* (also named *centre of gravity* (Lames, Ertmer, & Walter, 2010) and *spatial centre* (Bourbousson et al., 2010a)). Thus, all or some (i.e., subgroups (Duarte et al., 2012; Gonçalves et al., 2014; Silva, Travassos, et al., 2014)) outfield players, according to the team sport, are often considered to represent, in a single variable, the relative positioning of each team in forward-backward and side-to-side movements (Araújo & Davids, 2016). This means that, in several sports, the constant interaction between the goalkeeper and the rest of the players, that is, the influence of one of the most relevant structural traits of some sports (i.e., the orientation in the space) on the players´ decision-making is not considered to measure the *GC*. Further studies should assess how the goalkeeper's position affects the *GC* in different types of team sports tasks and according to the location of the ball on the field during the matches because several tactical variables are measured based on the *GC*. For example, the distances between the *GC* and players or space locations (Bartlett et al., 2012; Duarte et al., 2012; Frencken, 2009; Sampaio et al., 2014; Sampaio & Maças, 2012;

Silva, Travassos, et al., 2014; Yue et al., 2008), the inter-team coordination (i.e., *coupling stretch* and *relative phase*) (Bartlett et al., 2012; Lames, Ertmer, & Walter, 2010; Sampaio & Maçãs, 2012; Silva, Vilar, Davids, Araújo, & Garganta, 2016), and the "pressure" index between teams (Frencken & Lemmink, 2009). Since the *GC* does not consider the goalkeepers and team dispersion, this measure should be interpreted with caution, but together with other tactical variables can provide interesting information for team sports technical staff.

Table 4. Origin and modifications of the *geometrical centre* (*GC*)

Author	Used Term	Sport	Competition Level	Task	EPTS	Computation
Yue et al. (2008)	Geometrical centre	Soccer	Professional	Soccer match	VID	Algorithm was included in the article
Frencken & Lemmink (2009)	Centre of team	Soccer	Youth elite	Small-sided games (9 attacks)	LPS	The mean (x, y) of all players of one team (goalkeepers excluded).
Moura et al. (2011)	Centroid	Futsal	Professional	Futsal Challenge match (58 specific situations of shots to goal and 120 tackles)	VID	The centroid of the geometric form of the team convex hull

LPS: local position measurement system; VID: semi-automatic multiple-camera video technology

Non-linear analysis techniques

Although the first studies on the assessment of team behaviour represented and compared the movements of the *GC*s (Frencken & Lemmink, 2009; Yue et al., 2008) and the values of the surface areas (Frencken & Lemmink, 2009) and radius (Yue et al., 2008) of the two teams during soccer SSGs and matches, the relative phase was not computed. This technique was applied for the first time in team sports by Bourbousson et al. (2010a, 2010b) and Lames, Ertmer, and Walter (2010) in basketball and soccer, respectively. Bourbousson et al. (2010a, 2010b) computed the relative phase for the spatial centres and stretch indexes of both teams and for intra- and inter-team dyads and Lames, Ertmer, and Walter (2010) measured the relative phase of the *GC*s and *ranges* of both teams. In addition, Travassos et al. (2012) measured the *relative phase* of the *GC*s by the Hilbert transform when the goalkeeper of the attacking team was substituted for an extra outfield player in futsal.

In order to evaluate the synchronisation between more than 2 oscillators, based on the proposal of Kuramoto (1984) and the adaptation of Frank and Richardson (2010), Duarte et al. (2013) applied the *cluster method* in team behaviour analysis. Specifically, Duarte et al. (2013) used the *cluster method* to measure whole team and *player–team* (i.e. *GC-GC-player*) synchrony. Silva et al. (2014) introduced the *average mutual information* (*AMI*) as a measure of information that one random variable (e.g. team´s *GC*) contains about another random variable (e.g. opposing team´s *GC*) in both longitudinal and lateral directions. This method allows quantification of the information on one variable, through checking the other variable. So, it is the reduction in the uncertainty of one random variable due to the knowledge of the other (Cover & Thomas, 2005).

Table 5. Origin and modifications of the application of the non-linear analysis techniques in the *geometrical centre* (*GC*)

Data processing technique	Author	Variable	Sport	Competition Level	Task	EPTS	Computation
Relative phase	Bourbousson et al. (2010b)	*Spatial centres* of the two teams	Basketball	Professional	Match	VID	Hilbert transform
	Travassos et al. (2012)	*Defending team-attacking team*	Futsal	National Futsal University	5 vs.(4+GK)	VID	Hilbert transform
	Duarte et al. (2013)	*Team-team*	Football	Professional	Match	VID	*Cluster phase* analysis
AMI	Silva et al. (2014)	*GC-GC-Player*	Soccer	Young (regional and national level)	(4 + GK) vs. (4 + GK)	VID	Yes (Silva, et al., 2014)

AMI: average mutual information; GK: goalkeeper; GPS: global position system; VID: semi-automatic multiple-camera video technology

Origin and modifications of the *dyads* to assess team behavior in team sports.

As was mentioned in the flow diagram (Figure 1), from the thirty-eight articles that were included, twelve did not fulfil inclusion criterion 4 for the dyads. So, twenty-six articles were included. Among them, eighteen were originals or showed modification of dyads (Table 6) and twelve articles were originals or proposed modifications of non-linear techniques (Table 7).

According to the nature of the oscillators, the dyads can be classified into *player-player* (i.e. *player-opponent*, *player-teammate*), *player-space*, *player-ball*, and *geometrical centre* (i.e. *GC-GC/player/space/goal* dyads). Player-opponent dyads are of special interest in those team sports in which man-marking is commonly used and in the micro-structure close to scoring situations in all team sports. In addition, *player-player* dyads are used to measure the length and the width of the team and *player-GC* dyads to assess the dispersion of the team. The *player-space* dyads have been measured to assess the distance of the *player/team* to relevant areas of the playing space. Several techniques have been applied to analyse the synchronisation (*relative phase* by the Hilbert transformation and the *cluster analyses*) and the complexity and regularity or predictability (various *approximate entropies*, *sample entropy*, *cross-Sample entropy* and *average mutual information*) of the dyads in team sports, revealing the lack of consensus among researchers.

Collective tactical variables

The interaction between two players, assessed in distance (i.e., dyad (Schmidt, O´ Brien, & Sysko, 1999)), is the most commonly analysed micro-structure in team sports (Bourbousson et al., 2010a; Esteves et al., 2016; Gonçalves et al., 2017; Olthof et al., 2018; Passos et al., 2008; Shafizadeh et al., 2016; Travassos et al., 2012; Vilar et al., 2014; Yue et al., 2008), although the same concept has been also used to assess the distance between different types of oscillators (i.e., points of union): *GC-GC*, *GC-player*, *GC-space*, *GC-ball*, *player-space*, *player-ball* (Duarte, Araújo, Freire, et al., 2012; Folgado, Gonçalves, & Sampaio, 2018; Sampaio & Maçãs, 2012; Silva, Duarte, et al., 2014; Yue et al., 2008). In fact, the first proposed dyad considered the distance between the player and the basket (Schmidt, O´ Brien, & Sysko, 1999).

The measurement of dyads in team sports was suggested by Araújo, Davids, Bennett, Button, and Chapman, (2004). Specifically, the author proposed the positional balance between attacker and defender in basketball (Araújo et al, 2004). Although Passos et al. (2006) considered the attacker and defender as oscillators, they calculated the distance of each player from the try and lateral lines. Thus, Passos et al. (2008) measured the distance between a defender and their opponent (i.e., player-opponent dyad) for the first time (Figure 5). The authors compared the impact of both interpersonal distance and relative velocity on *attacker–defender* dyads during an experimental task that was representative of a typical sub-phase of rugby union (i.e. 1 vs. 1 near the try line) (Passos et al., 2008). Next, Bourbousson et al. (2010a) measured the distance between the attacker and the defender in fixed *player-opponent* dyads (i.e., the players of the dyad do not change during the analysis) in a basketball match and Silva, Duarte, et al., (2014) calculated the distances separating each player from their nearest opponent, that is, no fixed *player-opponent* distance, in order to assess their uncertainty during soccer SSGs and conditioning games. Thus, *player-opponent* dyads (i.e., individual duels) have been assessed during play considering the same two opponents (i.e., fixed dyad) continuously, and varying the opponents of the dyad during play. Fixed *player-opponent* dyads are of special interest in those sports in which man-marking is commonly used, such as basketball (Bourbousson et al., 2010a) and futsal (Travassos et al., 2011) although it is also interesting to measure this micro-structure close to scoring situations in other team sports such as soccer and rugby (Duarte, Araújo, Davids, et al., 2012; Passos et al., 2008; Vilar et al., 2014). Non-fixed *player-opponent* dyads could be more relevant in sports in which zonal marking is applied by the trainers.

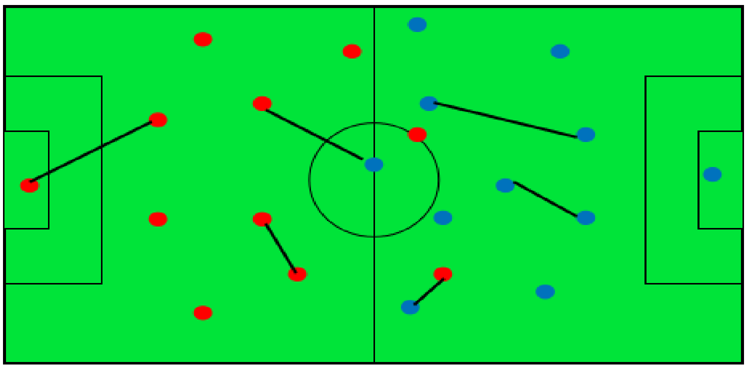


Figure 5. Graphic representation of *player-teammate* and *player-opponent* dyad

Based on the defender-attacker dyad, Silva, Duarte, et al., (2014) proposed *team separateness* (TS) (Figure 6), the sum of distances between each team player and the closest opponent (i.e., a collective computation) during small-sided and conditioned games (SSCG), because this could be a more interesting variable than the *GC* to analyse the pressure exerted by one team on another. The authors defined *TS* as a measure of the degree of free movement that each team has available (Silva, Duarte, et al., 2014). Silva et al. (2016) proposed a modification of the *TS*. They understood the *TS* as the average distance between all players and their closest opponent and this was interpreted as the average radius of action free of opponents (Silva, Vilar, et al., 2016). Based on the distance between the opponents, Silva, Travassos, et al. (2014) proposed the measurement of the distances separating the teams' horizontal and vertical opposing line-forces in order to examine inter-team coordination. As the authors explained, they assessed these variables instead of the *GC* because the former did not capture the existence of eventual differences in the players' interactive behaviours at specific team locations (e.g., wings and sectors) (Silva, Travassos, et al., 2014). The idea in this study was to calculate two horizontal lines and two vertical lines per team in several SSGs (Silva, Travassos, et al., 2014). Each team's horizontal lines were calculated by averaging the longitudinal coordinate values of the two players furthest from, and nearest to, their own goal line, which corresponded to the forward and back lines, respectively. Similarly, the vertical line-forces of each team were computed by averaging the mean lateral coordinates of the players furthest to the left and to the right of the pitch, corresponding to the left and right lines, respectively (Silva, Travassos, et al., 2014). Finally, Shafizadeh et al. (2016) assessed the distances between the shooter and the goalkeeper, regarding this measure as a candidate action-relevant variable informing goalkeepers about co-adapted positioning needed for goal saving.

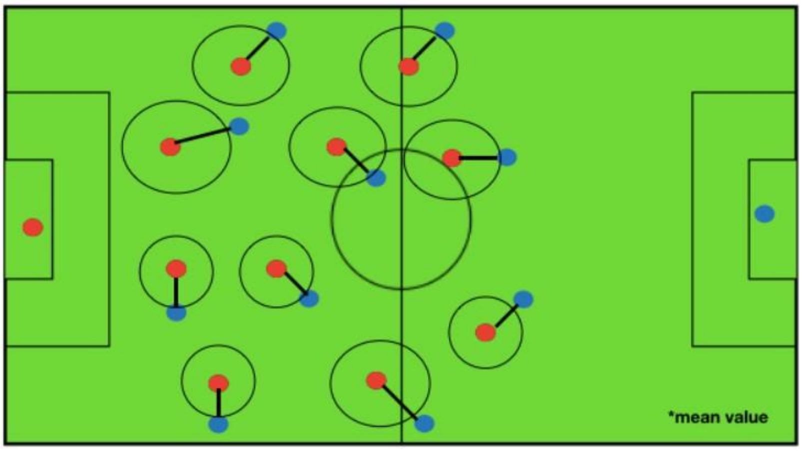


Figure 6. Graphic representation of *team separateness*

Another *player-player* dyad, the distance between two teammates (Figure 5), has been widely assessed in team sports (Bourbousson et al., 2010a; Gonçalves et al., 2017; Lames, Ertmer, & Walter, 2010; Olthof et al., 2018). The first time that the distance between two teammates was assessed, Lames, Ertmer, and Walter (2010) measured the distance between the maximum and minimum position of the players (i.e., non-fixed dyad) of the same team (i.e., the range per team) in order to assess the occupation of the space in the direction of goal to goal. Soon after, several studies (Folgado, Lemmink, et al., 2014; Frencken et al., 2011) proposed the measurement of the range in longitudinal (i.e. *length*) and lateral (i.e. *width*) directions (Figure 7). Later, Bourbousson et al. (2010a) assessed the *player-teammate* dyad, but considering the distance between fixed dyads (i.e., two playing positions), that is, the distance between the same teammates during a basketball match. A further study (Folgado, Duarte, et al., 2014) took into consideration all possible *player-teammate* dyads formed by the outfield players in order to asses intra-team relations (the absolute values (m) and variability in the distance between players). Moreover, Olthof et al. (2018) proposed a different non-fixed *player-teammate* dyad that considered the goalkeeper. Specifically, they measured the distance that remained behind the defensive line, which was a measure of the distance between the goalkeeper and the last defender. Thus, *player-opponent* and -*teammate* dyads were analysed independently in order to observe the positional balance between both players (Passos et al., 2006), and then as a collective index considering all or several dyads (Bourbousson et al., 2010a; Coutinho et al., 2018; Folgado, Duarte, et al., 2014; Folgado, Lemmink, et al., 2014; Gonçalves et al., 2017; Lames, Ertmer, & Walter, 2010; Olthof et al., 2018) in order to assess intra-team and inter-team distances.

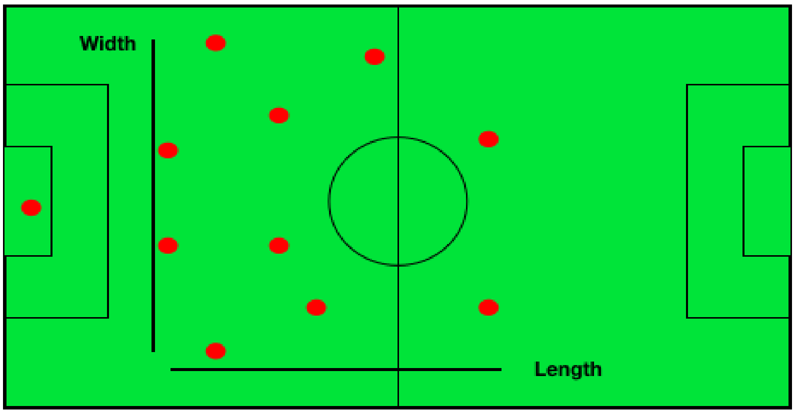


Figure 7. Graphic representation of team´s *length* and *width*

As mentioned above, Passos et al. (2006) measured a dyad in team sports for the first time. Specifically, a *player-space* dyad: the distance of the attacker and the defender from the try line (i.e., absolute distance of each player from the try line over time, calculating the distance along a straight line between the closest point of the try-line and each player) and distance of attacker and defender from both lateral lines (i.e., absolute distance of each player from the lateral lines) during a rugby training task. Besides presenting a 3-D analysis of interpersonal dynamics of *attacker-defender* dyads, the authors also aimed to identify parameters to measure dynamical system properties in these dyads (Passos et al., 2006). Similarly, Vilar et al. (2014) suggested measurement of the difference between the attacker's and defender's distances to the centre of the goal (i.e., relative distance to the goal) in order to analyse how players coordinate their actions to create/prevent opportunities to score goals in futsal matches. Moreover, they proposed the assessment of the defender´s angle to the goal and the attacker (i.e., inner product of the defender´s vector to the centre of the goal, and the defender´s vector to the attacker) (Vilar et al., 2014). Further studies should consider and add the influence (i.e. distance) of the goalkeeper in this type of analysis. In the same line of thought, Esteves et al. (2016) linked the distance between the ball carrier and their immediate defender (i.e., player coordinates) and the distance of the ball carrier to the basket (i.e., player and space coordinates) in order to assess the distance between these two points when a shot is attempted or when possession is lost during competition basketball games. Thus, *player-space* dyads have been measured taking into account the *player-opponent* relative position and distance to the goal, basket, or end zone (Esteves et al., 2016; Passos et al., 2006; Vilar et al., 2014). Regarding the *player-ball* distance, Yue et al. (2008) measured this type of dyad for the first time, with several studies considering the position of the ball in the analysis of the team behaviour variables (Travassos et al., 2011).

Taking into account the relative positioning of each team, expressed in single x and y coordinates, Frencken and Lemmink (2009) measured the distance between the GCs of the teams (Figure 8) in order to assess the "pressure" between the teams. Later, several studies proposed other tactical variables (Silva, Duarte, et al., 2014) as the GC-GC could be an excessive reduction in the relation between both teams. Since the same GC location can be due to very different player positions, it is necessary to assess the location of the players with respect to the *GC* of the team (i.e., the *dispersion*). Together with the computation of the *GC*, Yue et al. (2008) proposed the measurement of the instantaneous radius (also named *stretch index* or *spread* (Yue et al., 2008)) of each team, calculating the average distance between all players and the *GC* of the team at that moment. In a later study, Barttlet et al. (2012) picked up Yue's idea (Yue et al., 2008) but applied a new calculation formula. It summarised the distances of all players from the team GC (x_c), and because the team *GC* is computed from the position (x_i) of all players, then the *stretch index* incorporates all inter-player distances.

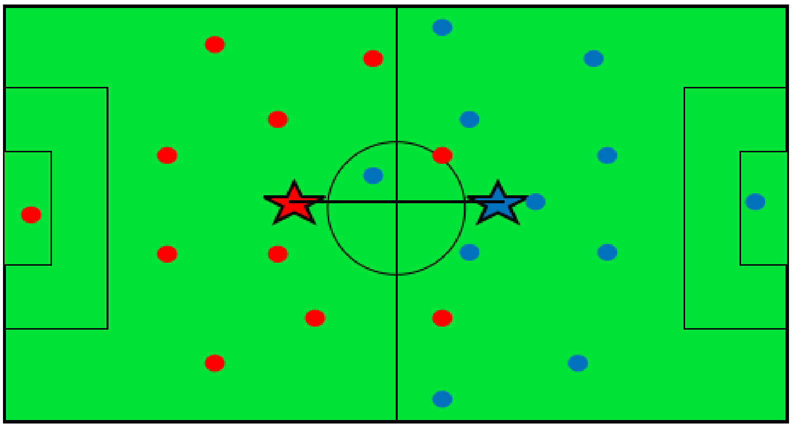
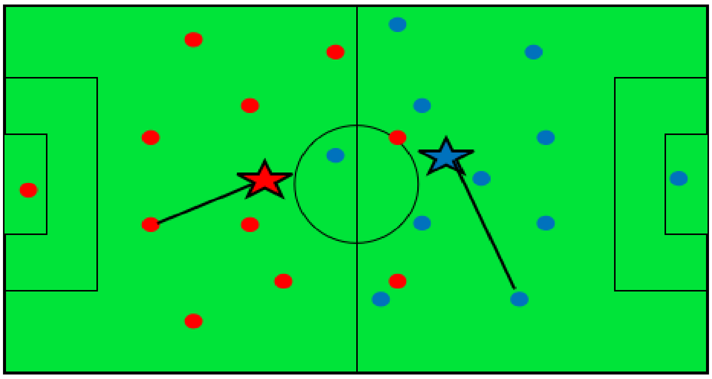


Figure 8. Graphic representation of *GC-GC*

The radius was used to analyse the counterphase relation in which it was observed how the team with possession expanded against the contraction of the defending team (Yue et al., 2008). In 2012, Sampaio and Maças (2012) proposed the measurement of the absolute distance between the *GC* and each player (Figure 9A) to assess the coordination of each player and *GC* using the *relative phase* (this data processing technique will be discussed in the next section). In addition, these authors proposed the measurement of the maximal and minimal distance of the farthest and closest player with respect to the *GC* (Sampaio & Maças, 2012). Together with the distance from their own *GC*, Sampaio et al. (2014) suggested the distance between each player and the opponent´s *GC* in order to assess how player movement patterns are coordinated with all their teammates' and opponents' positioning expressed as a single value (i.e., *GC*).

A)



B)

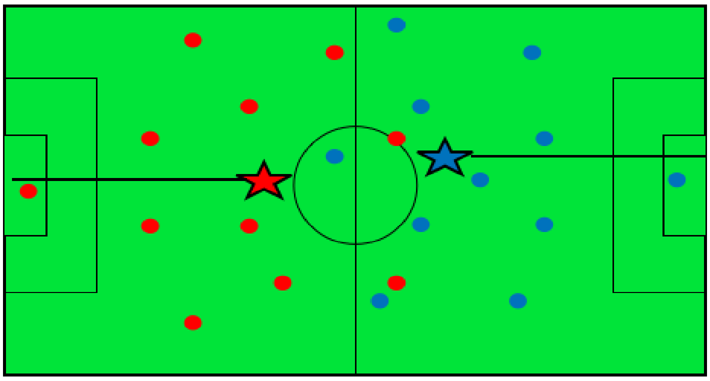


Figure 9. Graphic representation of *GC-player* and *GC-goal* dyads

Similarly to the player-space dyad (Esteves et al., 2016; Passos et al., 2006; Vilar et al., 2014), the *GC-space* dyad was suggested in order to assess the collective behaviour of particular sub-groups of players involved in the creation/prevention of goal scoring (Duarte, Araújo, Freire, et al., 2012). Specifically, Duarte, Araújo, Freire, et al., (2012) implemented a 3 vs. 3 SSG task in which a line was drawn to simulate the task *constraints* of the 7-a-side off side rule for this age level (i.e., *defensive line*) and the distance measured between the GC and the defensive line in soccer. In the same line of research, Silva, Travassos, et al. (2014) calculated the *centroid*'s distance to the goal centre (Figure 9B) defended by a goalkeeper and to the end line where the mini-goals were placed during several soccer SSGs. Thus, the *GC-space* dyad has been suggested for assessing the relative position of the team, expressed as a single value, with respect to different types of goals.

Table 6. Origin and modifications of the dyads

Author	Type of dyad	Definition	Sport	Competition Level	Task	EPTS
Passos et al. (2008)	*Player – opponent*	*Attacker–defender* dyadic: interpersonal distance and relative velocity	Rugby	Young	1vs 1 task	VID
Bourbousson et al. (2010a)		*Player-opponent* dyad matched for playing position	Basketball	Professional	Match	VID
Silva, Duarte, et al. (2014)		The *TS* for a team was defined as the sum of distances between each team player and the closest opponent.	Soccer	National-level and RLP-regional-level players	4 vs (4+GK)	GPS
Silva, Vilar, et al. (2016)		The average distance between all players and their closest opponent (*TS*)	Soccer	U-15	3 vs 3 4 vs 4 5 vs 5	GPS
Silva, Travassos, et al. (2014)		Teams' horizontal and vertical opposing line-forces (i.e. the distances separating the teams' vertical opposing line-forces and the distances separating the teams' horizontal opposing line-forces	Football	National-level and RLP-regional-level players	5 vs 5 5 vs 4 5 vs 3	GPS
Shafizadeh et al. (2016)		Closing distance gap between shooter and goalkeeper	Football	Professional	Match (1 vs 1 direct shoot situations)	VID
Lames, Ertmer, and Walter (2010)	*Player – teammate*	*Range* per team. Difference between max and min position of players except goalkeeper	Soccer	Professional	Match	VID
Bourbousson et al. (2010a)		The inter-team dyads made between two players of each position	Basketball	Professional	Match	VID
Goncalves et al. (2017)		Variability in the distance between players	Soccer	Professional	3 experimental conditions	GPS
Olthof, Frencken, and Lemmink (2018)		Represents the space between *goalkeeper* and nearest defender (defending line).	Soccer	Young	4 vs (4+GK)	LPS
Passos et al. (2006)	*Player – space*	*Player (attacker and defender)-try line* distance	Rugby	Young	1 vs 1	VID
		Player (attacker and defender)-both lateral lines distance	Rugby	Young	1 vs 1	VID
Vilar et al. (2014)		Relative distance to the goal.	Futsal	Professional	Match (1 vs 1 sequences)	VID
Esteves et al. (2016)		The distance of the ball carrier to the basket at the time of either shooting or losing ball possession.	Basketball	Young	Match	VID
Yue et al. (2008)	*Player – ball*	*Player-ball* distance in the x- and y-direction	Soccer	Professional	Match	VID

Frencken and Lemmink (2009)	*GC-GC*	Distance between two *GC*s of the teams	Soccer	Elite Youth	4 vs (4+GK)	LPS
	GC- Player	Distance between *GC*s and players	Soccer	Elite Youth	4 vs (4+GK)	LPS
Yue et al. (2008)	*Own team GC-player*	Average distance between all players and the *GC* of the team [*Radius*]	Soccer		Match	VID
Bartlett et al. (2012)		Radial, along pitch and across pitch Frobenius norm	Soccer	Professional	Match	VID
Sampaio and Maçãs (2012)		*Absolute* distance of each player from the *GC* of the team**	Soccer	University Student	5 vs 5	GPS
		Maximal distance of the farthest player from the *GC* of the team	Soccer	University Student	5 vs 5	GPS
		Minimal distance of the nearest player from the *GC* of the team	Soccer	University Student	5 vs 5	GPS
Sampaio et al. (2014)	*Opponent team´s GC-player*	Distance between each player and the *opponents' centroid*	Basketball	Junior	5 vs 5	GPS
	GC-Space	Distance between *GC*s and a point in the space	Basketball	Junior	5 vs 5	GPS
Duarte, Araújo, Freire, et al., (2012)	*GC-defensive line*	the smallest distance of the centroid to the defensive line using x-component motion values	Soccer	Young	3 vs 3	VID
Silva, Travassos, et al., (2014)	*GC-goal*	The *centroid*'s distance to the goal centre	Football	National-level and RLP-regional-level players	5 vs 5 5 vs 4 5 vs 3	GPS

GC: geometrical centre; GK: goalkeeper; GPS: global positioning system; LPS: local position system; TS: teams' separateness; VID: semi-automatic multiple-camera video technology

Non-linear analysis techniques

Relative phase

Regarding relative phase for intra-team dyads, Bourbousson et al. (2010a) suggested the analysis of the relationship between several playing positions (i.e., centre vs. guard; shooting guard vs. smart-forward; small forward vs. power forward). Further studies calculated the *relative phase* for all pairs of players Folgado, Duarte, et al., (2014) and suggested the assessment of the relative phase for every player with respect to the team and individual's relative phase with the group measure (Duarte et al., 2013). On the other hand, regarding relative phase for inter-team dyads, Bourbousson et al. (2010a) assessed the five inter-team dyads made between two players from each position, and due to the importance of the score, several studies suggested this analysis of the 1 vs. 1 dyad close to the target (e.g. goal or basket) in order to assess the performance in these special play situations in team sports (Duarte, Araújo, Davids, et al., 2012; Esteves et al., 2015).

Later, Travassos et al. (2011) assessed the *relative phase* of five new types of dyads: *Player-ball* and *player-teammate* dyads differentiating attacking and defending teams and the player-opponent dyad. In addition, Travassos et al. (2012) measured the relative phase for several new dyads by the Hilbert transform: *Defending team-*, *attacking team-*, *teams-ball* dyads (i.e., *GC-ball* dyad), and *defending-attacking* dyads (i.e., *GC-GC* dyad). These studies suggested that ball dynamics determine the relations between players (Travassos et al., 2012, 2011). In-phase attractions between players were reported to be stronger between defenders than attackers (Travassos et al., 2011): (a) stronger phase relations with the ball for the defending team than the attacking team

(Travassos et al., 2012) and (b) phase relations between each team and ball, and, to a lesser extent, between teams themselves, produced greater stability in the lateral (side-to-side) direction than the longitudinal (forward-backward) direction. The phase attraction between players and ball showed how the mobile object and its dynamic is an important constraint on behaviour in a futsal game (Travassos et al., 2011). In addition, unlike other sports such as basketball (Bourbousson et al., 2010a), a greater in-phase relationship was found between defenders than attackers in the lateral directions (Travassos et al., 2011). In the same way, the second study found a higher in-phase relation between the defending team and the ball in both axes, and a higher in-phase relation between teams in the lateral direction (Travassos et al., 2012).

The above-mentioned studies used the relative phase to measure synchronisation between two oscillators. In order to evaluate the synchronisation between more than 2 oscillators, Duarte et al. (2013) applied the *cluster method*. Specifically, Duarte et al. (2013) used the cluster method to measure *player-team* synchronisation (i.e. degree to which the behaviour of any one player in the team is synchronised to the movements of a team as a whole). In addition, after assessing the *relative phase* of all pairs of outfield players in several pre-season soccer matches, Folgado, Duarte, et al., (2014) applied the k-means *cluster analysis* to capture intra-team dyads with similar levels of synchronisation. This analysis was applied to the percentage of time of dyadic synchronisation and they classified each dyad into one of three groups according to its synchronisation level: the higher, intermediate and lower synchronisation groups.

Entropy

To our knowledge, Passos et al. (2009) used the *ApEn* in team sports for the first time. Specifically, the authors measured *ApEn* in the micro-structure 1 vs. 1, that is, in a *player-opponent* dyad (Passos et al., 2009). Based on the proposal of Stergiou, Buzzi, Kurz, & Heidel, (2004), the authors considered the number of observation windows to be compared (*m*) and the tolerance factor for which similarity between observation windows is accepted (*r*). Higher values of *ApEn*, close to 2, signified more complexity and less regularity and predictability. After analysing the relative position between defender and attacker during the micro-structure 1 vs. 1 near to the try line in rugby, they found that system complexity increased with changes in relations between players (Passos et al., 2009). Moreover, the authors suggested the use of *ApEn* for other micro-structures involving more agents (Passos et al., 2009), and several studies have followed this proposal (Sampaio, Lago, Gonçalves, Maças, & Leite, 2014; Silva, Duarte, et al., 2014; Vilar, Araújo, Davids, & Bar-Yam, 2013). A further study suggested two normalised measures based on the original *ApEn* (i.e. normalised with respect to a maximum value of *ApEn* of a series of length N or of that particular set of points), which are less dependent on time series length, in order to measure the complexity and the regularity and predictability of a rugby union *attacker–defender* micro-structure (Fonseca, Milho, Passos, et al., 2012).

Silva, Duarte, et al., (2014) analysed the uncertainty of interpersonal distance values during soccer small-sided and conditioned games by means of *sample entropy* measures (*SampEn*), specifically the *SampEn* of distance to nearest opponent, that is, the entropy of *player-opponent* dyad. The use of *SampEn* instead of *ApEn* was suggested by Richman and Moorman (2000) for two main reasons: a) *ApEn* was heavily dependent on the record length and is uniformly lower than expected for short records and b) it lacks relative consistency.

Also using *SampEn*, Barnabé et al. (2016) measured the predictability of the team´s *length* (i.e. between the most forward and the most backward players) and *width* (i.e. between the farthest players on both sides) and *stretch index*. In addition, the same authors (Barnabé et al., 2016) used the *cross-SampEn* to assess the asynchrony of the same variables. *Cross-SampEn* was developed by Richman and Moorman (2000) because *Cross-ApEn*, presents the necessity for each template to generate a defined nonzero probability, and *cross-SampEn* remains relatively consistent for conditions where *cross-ApEn* does not. A new step was suggested by Gonsalves et al. (2017), who, unlike Barnabé et al. (2016), measured the predictability in the distance between all players' dyads formed by outfield player using *ApEn*.

Table 7. Origin and modifications of the application of the non-linear analysis techniques in the dyads

Author	Variable	Sport	Competition Level	Task	EPTS
Relative phase					
Passos et al. (2009)	*Player-Opponent*	Rugby	Young, national level	1 vs 1	VID
Bourbousson et al. (2010a)	*Player-teammate*	Basketball	Professional	Match	VID
	Player-opponent	Basketball	Professional	Match	VID
Bourbousson et al. (2010b)	*Stretch indexes*	Basketball	Professional	Match	VID
Travassos et al. (2011)	*Player-ball* for attacking and defending teams*	Futsal	National Futsal University	5 vs (4+GK)	VID
	Player-teammate for attacking and defending teams*	Futsal	National Futsal University	5 vs (4+GK)	VID
	Player-opponent dyads*	Futsal	National Futsal University	5 vs (4+GK)	VID
Travassos et al. (2012)	*Defending team-ball*	Futsal	National Futsal University	5 vs (4+GK)	VID
	Attacking team- ball	Futsal	National Futsal University	5 vs (4+GK)	VID
	Teams- ball	Futsal	National Futsal University	5 vs (4+GK)	VID
Duarte et al. (2013)	*Every player-team*	Football	Professional	Match	VID
	*Player-team**	Football	Professional	Match	VID
Folgado, Duarte, Fernandes, and Sampaio, (2014)	*Player-teammate**	Football	Professional	Match	GPS
Entropy					
Passos et al. (2009)	*Player-Opponent*	Rugby	Young, national level	1 vs. 1	
Sampaio and Maçãs (2012)	Absolute distance of each player from the *GC* of the team	Soccer	University Student	5 vs 5	GPS
	Maximal distance of the farthest player from the *GC* of the team	Soccer	University Student	5 vs 5	GPS
	Minimal distance of the nearest player from the *GC* of the team	Soccer	University Student	5 vs 5	GPS
Fonseca, Milho, Passos, Araújo, and Davids, (2012)	*Player-Opponent*	Rugby	-	1 vs 1	
Silva, Duarte, et al. (2014)	*Player-Opponent*	Soccer	Young (regional and national level)	(4 + GK) vs. (4 + GK)	GPS
Barnabé et al. (2016)	*Player-teammate (team´s length)*	Soccer	Young	(5 + GK) vs. (5 + GK)	GPS

	Player-teammate (team´s width)	Soccer	Young	(5 + GK) vs. (5 + GK)	GPS
	Player-GC (stretch index)	Soccer	Young	(5 + GK) vs. (5 + GK)	GPS
Goncalves et al. (2017)	Players´ dyads formed by the outfield teammates	Soccer	Professional	10 vs 9 LSG	GPS

ApEn: approximate entropy; GPS: global positioning system; LSG: large-sided game; SampEn: sample entropy; VID: semi-automatic multiple-camera video technology; *: *cluster analysis* was applied

Origin and modifications of the area variables to assess team behavior in team sports.

As was mentioned in the flow diagram (Figure 1), from the thirty-eight articles that were included, twenty-three did not fulfil inclusion criterion 4 for the area. So, fifteen articles were included. Among them, twelve were originals or showed modification of the area (Table 8) and four articles were originals or proposed modifications of non-linear techniques (Table 9).

The main findings were: a) spatial team sports tactical variables can be classified into 3 principal types: *occupied space*, *exploration space* and *dominant/influence space*; b) most of the *occupied space* tactical variables did not consider the GKs and the rest playing space to assess the *occupied space*, but several studies have proposed new variables that consider the total playing space (i.e. effective free-space, normalized surface area); c) only a collective *exploration space* variable has been suggested: the major range of the GC; d) the *dominant/influence space* has been based on the Voronoi region while several studies based their computation on the distance *d* and others suggested the use of the time *t*; e) four different techniques (i.e. SampEn, cross-SampEn, ApEn, $ApEn_{RatioRandom}$) have been used to assess the predictability of the use of the space; and f) the lack of consensus on computation methods and techniques to assess the use of the space and its predictability makes it difficult to compare studies.

Collective tactical variables

Occupied space

Gréhaigne (1992) suggested the *effective playing-area* (EPS), the polygonal area (i.e. occupied play-space) obtained by a line that links all players of both teams, except the goalkeepers, positioned at the periphery of the play (Gréhaigne & Caty, 2005) in order to assess the use of space in soccer. Since then, several new variables and modifications have been applied to analyse the space occupied by the players in team sports. Despite those previous studies, it seems that using a simple tool that technical staffs and researchers understand in a similar way, there have been several differences that have been found regarding to its conceptualization and computation.

Okiharaet et al., (2004) measured the *team area*, the quadrilateral formed by the four outfielders of each team, during a futsal match. In addition, they measured *team area* by multiplying the length (i.e., between the front and the tale) by the width (i.e. between the left-edge player and the right-edge player) during a soccer match. Four years later, Frencken and Lemmink (2009) suggested that the *surface area* represents the overall team 'position' and as a complement of geometrical centre to measure the "pressure" (Figure 10). Specifically, they measured the total field coverage of one team, excluding the goalkeepers, to describe goal-scoring opportunities in soccer. The mathematical methods to compute the quadrilateral formed by the four outfielders and the *surface area* were not provided by Okihara et al. (2004) and Frencken & Lemmink (2009), respectively. Later, Frencken et al. (2011) defined the *surface area* as the total space covered by the outfield players, referred to as the area within the convex hull, in a new study carried out in soccer during a SSG. They computed the convex hull for both teams using a modified Graham algorithm (Graham, 1972) and the convex hull area (CA) by summing the triangles formed from geometrical centre to each of the consecutive points of the convex hull. Following studies applied different concepts and methods to compute the occupied space in team sports (Bueno et al., 2018; Clemente et al., 2013; Duarte, Araújo, Freire, et al., 2012; Frencken et al., 2011; Moura et al., 2012). Duarte, Araújo, Freire, et al., (2012) calculated the *surface area* of each team as the area of a triangle with a formula for Cartesian coordinates (Table 8) in a 3+GK vs 3+Gk soccer SSG. Moura et al. (2012) used the Quickhull technique (Barber et al., 1996) to compute the convex hull during a soccer match and, unlike Frencken et al. (2011), showed the division of the convex hull into triangles formed between the closest players to propose the computation of the CA at each instant of time (CA(t)) by summing the areas of all of these triangles (Moura et al., 2012).

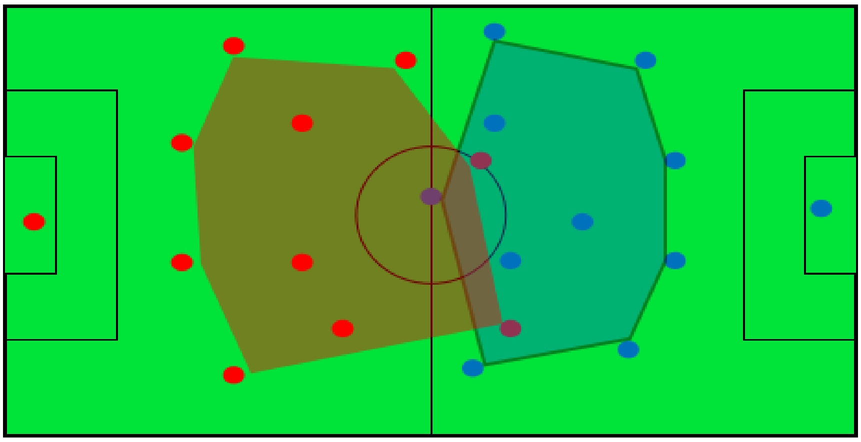


Figure 10. Graphic representation of teams´ *surface area*

All studies mentioned above did not consider the GKs to measure the occupied space (i.e. *EPS*). This match space reference has been habitually used to design training strategies in team sports. However, actual *effective playing-area* is all of the playing space which is used according to the rules of each team sport (e.g., offside rule). At a practical level, caution is necessary when the *EPS* area is used as a reference to limit the playing space in training tasks. In addition to considering the GK to measure the *EPS* at the initial time, Clemente et al. (2013) suggested several practical applications to assess the use of the space based on the *EPS* and their corresponding computation methods. They focused in the effective free-space (i.e. the *real area* that a team covers without intercepting the effective area of the opposing team) instead of the original *EPS per se*. Specifically, they calculated (1) all of the *non-overlapping area* (i.e. triangles) formed by the players of the same team and (2) the area (i.e. triangles) of each team without interception. In the same line, Bueno et al. (2018) suggested and measured the *surface area* that a team can present on the court in futsal normalized by the maximum possible value. These variables can be useful when designing training strategies in team sports because the occupied space is assessed regarding to the total playing space. On the other hand, aforementioned studies used different mathematical methods to calculate *EPS*, making it difficult to compare studies. In the future, it would be interesting to compare the impact of the different concepts and computational methods in the measurement of the *EPS*.

In a complementary manner, Gonçalves et al. (2018) suggested the measurement of the *EPS* for sub-groups of 3-10 players to assess the use of the space for sub-systems in a soccer match. They used the smallest inter-player distance to identify the sub-groups. The *EPS* presented an increase with a higher number of players, especially considering the transition from 3 to 4 players. At a practical level, the match *EPS* values according to the number of the players can be used as a reference to design training tasks.

Exploration space

Major ranges (*MR*) were proposed in order to assess the mean position of each player during the game (Yue et al., 2008). The *MR* was defined by an ellipse centred at the 2D mean location of the player, with semi-axes being the standard deviations in *x* – and *y*-directions. Similarly, Gonçalves et al. (2017) suggested a novel variable to explain the covering space by each player: the *Spatial Exploration Index* (*SEI*). It was obtained for each player by calculating his mean pitch position, computing the distance from each positioning time-series to the mean position and, finally, computing the mean value from all the obtained distances (Gonçalves et al., 2017). Based on the fifth exclusion/inclusion criteria, these variables cannot be considered as a collective tactical variable. However, the *major range* concept was applied to assess the *exploration space* of the team by the measurement of the *major range* of the *GC* (i.e., the relative positioning of the team) (Yue et al., 2008) (Figure 11). This suggestion could be applied to assess collective *exploration space* variables at a sub-system level (i.e. pairs of players, intra-line, inter-line). At a practical level, this variable should be measured to distinguish possession and no-possession playing in each team phase to assess the explored space links of the playing style of the team.

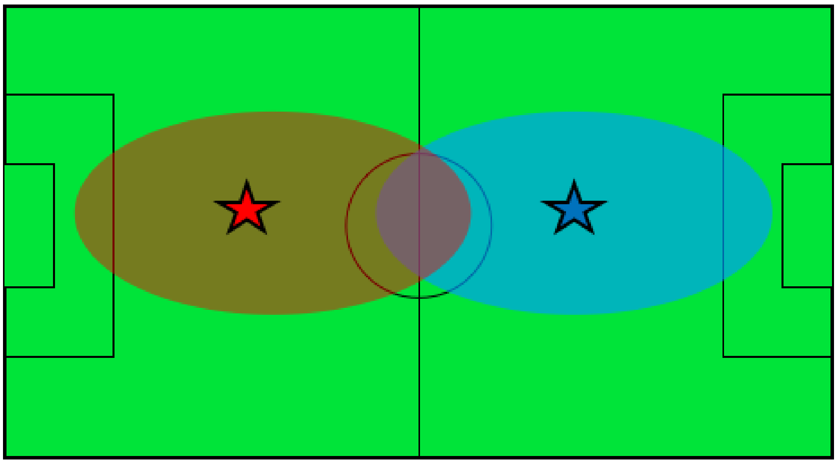


Figure 11. Graphic representation of *GC´s dominant regions*

Dominant space

In addition to the *occupied* and *exploration* spaces, *dominant* space variables have been applied to evaluate the use of the space in team sports. These variables have been based on the *Voronoi region* (Okabe, Boots, & Sugihara, 1992). This allows expression of the spatial territory of each point (e.g., player) in relation with the rest of points (e.g. players) in a space (Okabe et al., 1992). Thus, it has been considered as a collective tactical behaviour. It is calculated by applying the concept of nearest-neighbour rule, which is associated to all parts of the pitch that are nearer to that particular player compared to any other (Clemente, Sequeiros, Correia, Silva, & Martins, 2018; Okabe et al., 1992).

Taki, Hasegawa and Fukumura (1996) suggested, for the first time, the *dominant region* to assess *space management* and *cooperative movement* in team sports. They defined the *dominant region* as a region where the player can arrive earlier than all of the others (Taki, Hasegawa, & Fukumura, 1996). In comparison to *Voronoi region* (Figure 12), they replaced the distance *d* by time t_s (i.e. minimum moving time pattern [MMT])" to assess dominant space in `dynamic environments´ like team sports (Taki &

Hasegawa, 2000). In order to calculate the shortest time of an individual to each point *x*, they suggested considering: a) the position, b) the speed, and c) the accelerating ability of the player at the moment that is needed (Taki, Hasegawa, & Fukumura, 1996). The first two were estimated from images and the accelerating ability was modelled as a set of acceleration patterns based on the physical ability of an average player (Taki, Hasegawa, & Fukumura, 1996). This suggestion was applied for the first time in a team sport (i.e. soccer) by Taki and Hasegawa (2000).

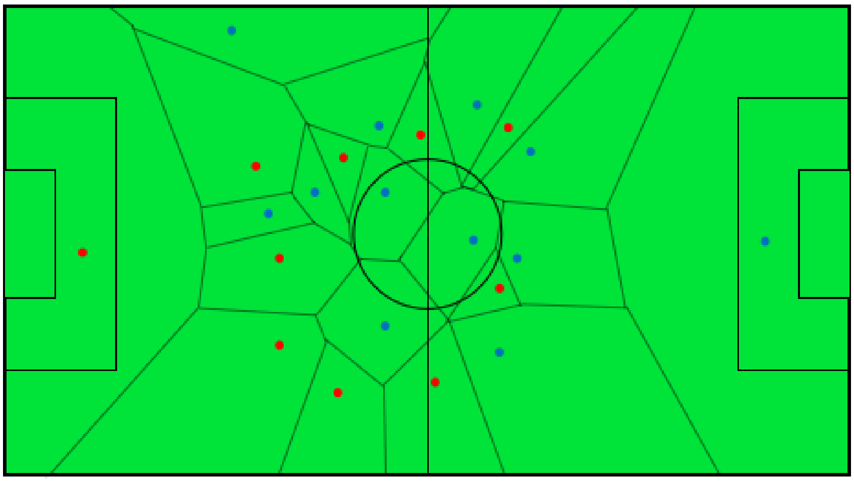


Figure 12. Graphic representation of *Voronoi diagrams*

Based on the *dominant region* (Taki, Hasegawa, & Fukumura, 1996), Taki and Hasegawa (2000) measured the *dominant region* to assess the sphere of influence in soccer and handball. Similarly, they considered the shortest time of an individual to each point *x* (Taki & Hasegawa, 2000) instead of the distance *d*. They also assessed the sphere of influence based on each individual's movement and physical ability (Taki & Hasegawa, 2000). Later, Fujimura and Sugihara (2005) measured the *dominant region* in field hockey using a different motion model to measure players´ acceleration. In comparison to Taki and Hasegawa (2000), they did not assume that each player's acceleration is constant and considered a resistive force that decreases the velocity. In comparison to the original *Voronoi region*, the three aforementioned studies and the *k-region* (Filetti et al., 2017) measured the *dominant region* in a different way. They considered time *t* instead of distance *d* to measure this tactical variable. This suggestion is interesting because it considered the parameter *time*, due to the fact that time is "managed" in team sports (i.e., `arrive a time´ does not depend solely on the physical fitness). However, *dominant region* values measured based on the time *t* should be assessed with caution.

In order to go into detail in the assessment of players' contributions to teamwork, (Fujimura & Sugihara, 2005) there has been a proposal of *weighted dominant areas*. Authors have suggested that the measurement of the *dominant area* according to the location of each player with respect to the goal and the ball: the *dominant area weighted by the goal* and the *dominant area weighted by the ball* (Fujimura & Sugihara, 2005). The player's *weighted dominant area* was measured, giving higher scores to points nearer to the goal, and giving higher scores to points nearer the ball (Fujimura & Sugihara, 2005). As this and other studies (Fonseca, Milho, Travassos, et al., 2012) found, the structural traits (Newell, 1986; Parlebas, 2002) of each team sport determine the use of the space. In this case, the location of the player with respect to the target (i.e. the orientation of the space) determines the dominant region of the player.

Based on the original *Voronoi region* (Figure 12) (i.e., the distance between players to measure dominant region), Fonseca, Milho, Travassos, et al., (2012) measured the *dominant region* during the 5 vs 4 phase in futsal. They defined the *Voronoi cells* by dividing the plane by mean values of the assignment of the points of the field of each player which is closer to other players versus any other. The key findings in this study were that the *dominant regions* could be dependent on the role that each team is performing at a given time. As Fonseca, Milho, Travassos, et al., (2012) noted, the distance values are used to compute *dominant regions* (i.e. Voronoi cells) in team sport (Baptista et al., 2018; Clemente, Couceiro, Martins, Mendes, & Figueiredo, 2015; Fonseca et al., 2013; Lopes, Fonseca, Leser, & Baca, 2015). At a practical level, *Voronoi cells* have been used to assess passing effectiveness (Filetti et al., 2017; Rein et al., 2017).

As Taki, Hasegawa and Fukumura, (1996) suggested, “team dominant region” can be measured considering the *dominant regions* of all players of the same team. This single region represents the dominant area of the team. In this line, based on the original *Voronoi region* (i.e. the distance), Fonseca et al. (2013) suggested the *Superimposed Voronoi Diagram* (*SVD*) for describing inter-team spatial interaction patterns of behaviour in futsal. They superimposed the *Voronoi diagrams* of the two competing teams and measured the *maximum percentage of overlapping area* (*Max%OA*) and the *percentage of free area* (*%FA*) (Fonseca et al., 2013) to describe the spatial interaction behaviour at an individual and collective level. The *Max%OA* was the maximum percentage of that player’s *Voronoi region* covered by the *Voronoi region* of an opponent, while *%FA* was the remaining space (Fonseca et al., 2013). The authors postulated that these spatial variables allow description of the interaction between two teams by comparing the spatial pattern formed by their respective players. This is largely dependent on the interaction established among pairs of opponents (i.e. man-to-man vs zonal).

Table 8. Collective area variables in team sports

Study	Variable / Computation	Sport	Competition Level	Task	EPTS
Collective occupied space variables					
Okihara et al. (2004)	*Team area**^ The quadrilateral formed by the four outfielders	Futsal	Professional	Match	VID
	Team area^ The dimension of a square = length (between the front and the tale)* width (between the left-edge player and the right-edge player)	Soccer	Professional	Match	
Frencken and Lemmink (2009)	*Surface area* is the total field coverage of one team Area (m^2) *^	Soccer	Young	4+GK vs 4+GK	LPS
Frencken and Lemmick (2011)	*Surface area*^: the area within the convex hull. CH: modified Graham algorithm (Graham, 1972). [CA(t)]: the area was calculated by adding the triangles of consecutive points of the CH and the centroid	Soccer	Young	4+GK vs 4+GK	LPS
Duarte, Araújo, Freire, et al., (2012)	*Surface area*^: the area of a triangle Area: Area (A, B, C): abs((xB*yA-xA*yB) + (xC*yB-xB*yC) + xA*yC-xC*yA))/2	Soccer	Young	3+GK vs 3+GK	VID
Moura, Martins, Anido, De Barros, and Cunha, (2012)	*Coverage area*^: the area that a team covers CH: Quickhull technique (Barber et al., 1996) [CA(t)]: they divided the team convex hull into triangles. Then, they summed the areas of all triangle within the convex hull	Soccer	Professional	Match	VID
Clemente, Couceiro, Martins, and Mendes, (2013)	*Effective free-space*: the real area that a team covers without intercepting the effective area of the opposing team. The GK was considered. Triangles as the combinations of the total number of players within a team	Soccer	Young	7+GK vs 7+GK	VID
Bueno et al. (2018)	*Surface area^ normalized* by the maximum possible value that a team can present on the court The surface area was represented by the CA(t), calculated from the position of the players of the same team. CH: their vertices were calculated using quickhull technique (Barber et al., 1996) [CA(t)]: their vertices were calculated using quickhull technique (Barber et al., 1996)	Futsal	Young and professional	Match	VID
Collective influence space variables					
Yue et al. (2008)	Major range of GC	Soccer	Professional	Match	VID

Collective dominant space variables					
Taki and Hasegawa (2000)	*Dominant region*: the region where the individual can arrive earlier than any other individual when starting at *t*.	Soccer	Professional	Match	VID
Fujimura and Sugihara (2005)	*Weighted dominant region area**: player's weighted dominant area was obtained by summing the weighted pixel values in his dominant region *Dominant area weighted by the goal*: higher scores are given to points nearer to the goal *Dominant area weighted by the ball*: higher scores are given to points nearer the ball.	Field Hockey	-	Match	VID
Fonseca, Milho, Travassos, et al., (2012)	*Voronoi cells:* division of the plane by means of the assignment of the points of the field to each player which are closer to that player than any other.	Futsal	Senior	5-v-4+Gk	VID
Fonseca et al., (2013)	*Superimposed Voronoi Diagram (SVD)*: Superimposition of the Voronoi diagrams of the two teams. *Maximum percentage of overlapped area (Max%OA)*: maximum percentage of that player's Voronoi region covered by the Voronoi region of an opponent; and *Percentage of free area (%FA)*: the remaining space	Futsal	Senior	5-v-4+Gk	VID

GK: Goalkeeper; * As Taki and Hasegawa (2000) they also considered the time instead of the distance. But they did not assume that each player's acceleration is constant and considered a resistive force that decreases the velocity.

[CA(t)] Convex hull area at each instant of time *t*.; GC: geometrical centre; GK: Goalkeeper; GPS: global positioning system; LPS: local position system; VID: semi-automatic multiple-camera video technology; *: The mathematical method to determine the metric was not provided; ^: excluding goalkeeper

Non-linear analysis techniques

Nonlinear analysis techniques have been suggested to assess uncertainty due to the social interaction between teammates and opponents (Araújo & Davids, 2016; Newell, 1986; Parlebas, 2002). In comparison to linear techniques, they allow the assessment of the team sports as a complex systems (Stergiou et al., 2004). One of these is *entropy*, which assesses the regularity of time series, and obviates the predictability of a system. *Entropy* was suggested by Pincus (1991) as a preliminary mathematical development of this family of formulas and statistics. The author emphasised the application of the *Approximity Entropy* (*ApEn*) in a variety of contexts (Pincus, 1991). One of these contexts was team sports, where the entropy technique has been applied to assess the predictability of the *occupied space* and *dominant area* but not the *exploration space* (Table 9).

The measurement of the complexity and conditional irregularity of the *surface area* was suggested in team sports by Barnabé et al. (2016). They used two different techniques: the *Sample Entropy* (*SampEn*) and *the cross-SampEn* (Barnabé et al., 2016). In addition, the measurement of the regularity pattern of Voronoi cells was measured using the ApEn and $ApEn_{RatioRandom}$ (Baptista et al., 2018; Fonseca, 2012). Thus, there is a lack of consensus of the technique that is used to assess the predictability of the use of space in team sports. Initially, *Shannon´s entropy* and *ApEn* were applied to assess the predictability in complex systems such as team sports (Silva, Duarte, et al., 2016). However, Richman and Moorman (2000) suggested the use of the *SampEn* instead of *ApEn* for two main reasons: (1) *ApEn* was heavily dependent on the record length and is uniformly lower than expected for short records, and (2) it lacks relative consistency. In addition, Richman and Moorman (2000) developed *cross-SampEn* because while *Cross-*

ApEn presented the necessity for each template to generate a defined nonzero probability, *cross-SampEn* remained relatively consistent for conditions where cross-*ApEn* did not. It would be necessary to compare the impact of each entropy technique on the measurement of the spatial tactical variables to assess the comparison between studies.

Barnabé et al. (2016) assessed two teams with different maturity and experience level and compared the irregularity and predictability among them with respect to *surface area* values. They found a greater synchronization between offensive and defensive surface areas in older age groups. Fonseca et al. (2012) assessed the regularity of time series data from area *dominant region* (i.e. Voronoi cells) during 5 vs 4+Gk phase in futsal using the $ApEn_{RatioRandom}$. They suggested that a greater unpredictability (i.e., variability) of the use of space is played to generate uncertainty in the opposing team, while the defending team tends to be more stable in the use of the space to counter the opposing team. In addition, Baptista et al. (2018) found that predictability was dependent on the team´s formation (Baptista et al., 2018).

Finally, Low et al. (2018) suggested the assessment of the synchronisation patterns between teams' *EPS* signals and *length per width* (LPW) ratio (Folgado, Lemmink, et al., 2014) using the the *relative phase* (Low et al., 2018). The computation was performed using Hilbert Transformation (Palut & Zanone, 2005). They compared the *EPS-LPW* synchronization between deep-defending vs high-press defending strategies. For the first time, they suggested the analysis of synchronisation on the use of space. In addition, they combined a spatial tactical variable and a distance variable. The combination of *GC* or distance variables with *space* variables to assess the synchronisation in team sports could provide a more complete picture of the use of space in team sports.

Table 9. Assessment of the non-linear analysis techniques (i.e. *relative phase* and *entropy*) to assess the use of the space in team sports

Study	Variable / Computation	Sport	Competition Level	Task	EPTS
Occupied space					
Barnabé et al. (2016)	*SampEn* was used to measure the complexity of the *surface area* during the defensive and offensive game phases.	Soccer	Junior	5+GK vs 5+GK	GPS
	Cross-SampEn was used to measure the asynchrony (conditional irregularity) of the tactical variations of an attacking team and an opposing defending team for the *surface area*	Soccer	Soccer	5+GK vs 5+GK	
Dominant space					
Fonseca, Milho, Travassos, et al., (2012)	The regularity of time series data from area *dominant region* (i.e. Voronoi cells) was measured using the $ApEn_{RatioRandom}$	Futsal	Senior	5-v-4+Gk	VID
Baptista et al. (2018)	*ApEn* was measured to identify the regularity pattern of *Voronoi cells*	Soccer	Semi-professional	7+GK vs 7+GK	GPS
Relative phase					
Low et al. (2018)	Relative-phase analysis was performed to assess synchronisation patterns between teams' EPS signals and length per width (LPW) ratio	Soccer	Professional	11+GK vs 10+GK	GPS

ApEn: approximate entropy; Cross-SampEn: cross-sample entropy; Gk: goalkeeper; GPS: global positioning system; SampEn: sample entropy; VID: semi-automatic multiple-camera video technology

Technology to assess collective tactical behavior: Electronic Performance and Tracking Systems

Telecommunication is a technique that consists of transmitting a voice, data, or image message at a distance. Among the different uses of telecommunications, positioning systems (i.e., outdoor and indoor systems) are used in the process of determining the spatial position of people, equipment, and other objects (Alarifi et al., 2016). Global Positioning Systems (GPS*)* have been developed and used for many years to detect the spatial positioning of team sports players in outdoor locations (Rico-González, Los Arcos, Nakamura, Moura, & Pino-Ortega, 2019). On the other hand, indoor position systems (IPS) are systems which use wireless technologies (i.e. LPSs) or optical-based indoor positioning systems (Alarifi et al., 2016). Nowadays, indoor position systems are used in outdoor places too using local positioning tracking systems.

The main objective of Electronic Performance and Tracking Systems (EPTS) is to track player (and ball) positioning on the field during training and competition. However, different forms of EPTS have different principles of use. Global position navigation systems (GNSS)/global position systems (GPS) and local position systems (LPS) are based on radio-frequency (RF) technology (Linke et al., 2018; Pettersen et al., 2018). Meanwhile, when semi-automatic multiple-camera video technology (VID) are used, the objects are tracked by image segmentation using different techniques of image recognition (Linke et al., 2018). RF technologies can also be used in combination with microelectromechanical system (MEMS) devices, such as accelerometers, gyroscopes, and heart rate monitors, to measure load or physiological parameters. A chip (i.e., a reception antenna with wireless technology: Bluetooth or ANT+) is incorporated into the device, and a strap on the chest detects the heart´s electric signal and sends it to the device. GNSS/GPS and LPS have been used to analyse four kinds of variables in team sports: physiological analysis (internal load), time-motion analysis (external workload), neuromuscular analysis (external workload), and tactical analysis (Leser, Baca, & Ogris, 2011; Low et al., 2019).

GNSS/GPS calculate the position of players, using a known positioning system (i.e. satellites) as a reference and an object with an unknown position (Figure 13) through RF. There are four constellations of satellites (European Galileo [nº of satellites in operation = 22]; Russian GLONASS [nº satellites in operation = 24]; US-American GPS [nº satellites in operation = 31]; and Chinese Beidou [nº satellites in operation = 33]) (Shen et al., 2019). A minimum of 24 satellites is needed to obtain useful and valid data during outdoor tracking. In order to calculate the positioning of players, the satellites and receptors have to carry a high precision synchronized atomic clock. First, a satellite sends a signal at the speed of light to indicate the moment of signal departure, thus allowing the receiver to determine how long the signal has taken to arrive and to multiply the corresponding value by the speed (distance = time × speed). In this way, and by knowing the radius (distance), a sphere is established. The position of the player can be at any of the points of the circle/sphere reflected on the earth’s surface (Treviño, 2014). When a second circle is computed, its position can be at one of the two points where the two spheres intersect on the earth. Thus, a third satellite is needed for accurate data to be obtained. Thus, the receiver placed on the player’s back (T2-T4 interscapular) using a specially designed vest, locate the player’s position through this technique, which is called trigonometry (Cummins et al., 2013; Jackson et al., 2018; Malone et al., 2017; Treviño, 2014). Due to the high economic cost of high-precision clocks, the use of a fourth satellite was suggested (Treviño, 2014). The time parameter enters as an unknown variable and is calculated together with the spatial coordinates (Treviño, 2014). For this reason, we find discrepancies regarding the minimum number of satellites needed to calculate the position of the players (Larsson, 2003; Scott et al., 2015). As this signal is sent through waves that can be dispersed due to contact with ceilings, walls, or other objects, in recent years *indoor positioning systems* (IPSs) have been developed (Alarifi et al., 2016).

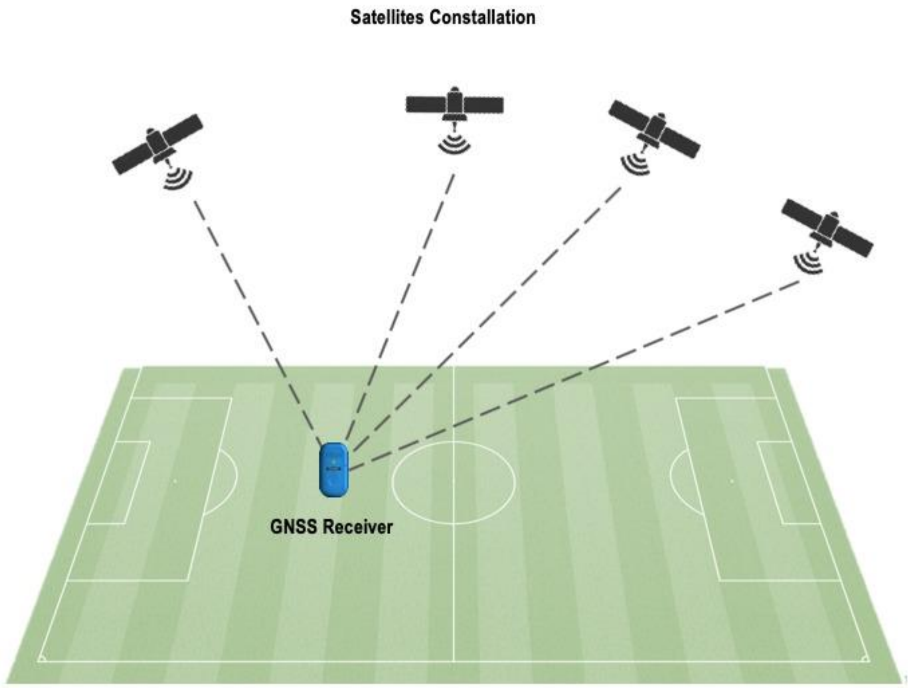


Figure 13. Player positioning detection using GPS

Although LPS are based on unique technology, the principles of its use are quite similar to those of GNSS/GPS (Alarifi et al., 2016; Leser et al., 2011; Malone et al., 2017). LPSs, replacing satellite navigation networks, use nodes in a close and previously known position (Figure 14). Wireless systems establish communication in the absence of a physical medium, using electromagnetic waves which carry data. These technologies contain receiver and transmitter devices, which are interconnected to permit communication without interference from other devices (Alarifi et al., 2016). One of these two components is in a moving object and the other in a static known place, so the position of the receiver and, therefore, of its carrier, is established with respect to the known position of the transmitters. The values of these waves are measured over time, and represented by curves, called sinusoids. These curves appear in a certain shape according to their values. Mathematically, these sinusoids are the result of the number of beats or cycles per second (frequency), the power of each frequency component (amplitudes), and the delay or advantage of a signal (phase), which describe the angular displacement of two sinusoidal functions. The key to transmitting the information is through the use of waves with more complex shapes, as a result of a combination of different sinusoids (Winter, 2009). Depending on the frequency of these waves, indoor positioning wireless technologies are classified into infrared, radio-frequency (Radio frequency identification (RFID), Wi-Fi, Bluetooth and Ultra-wide band [UWB]), and ultrasound systems (Alarifi et al., 2016). Among different types of wireless IPSs, UWB is a 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 (Rico-González et al., 2019). UWB accuracy and precision in sports use have been demonstrated in previous studies (Bastida Castillo et al., 2018; Leser et al., 2014; Ridolfi et al., 2018). In sports, the transmitters are placed around the field and the players wear the devices (receptors). The distances are calculated by UWB positioning algorithms, which are classified into five main categories based on some estimating measurements: time of arrival (TOA); angle of arrival (AOA); received signal strength (RSS); time difference of arrival (TDOA); and a hybrid algorithm (Alarifi et al., 2016). The information is presented through a Cartesian (X, Y, and Z coordinates) system (Bueno et al., 2018; Olthof et al., 2018), although in studies that measure spatial positioning variables of players, data are in X and Y coordinates.

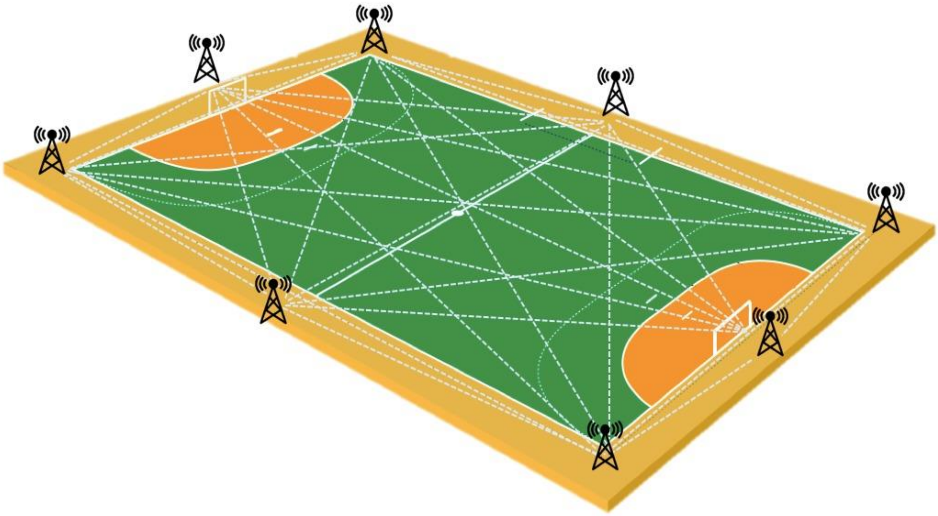


Figure 14. Player positioning detection using LPS

The other option that researchers can choose among IPSs is semi-automatic multiple-camera video technology (VID). In comparison to indoor positioning wireless, optical indoor positioning systems include camera and computer vision-based technologies. These are divided into ego-motion (the motion of the camera is used in a rigid scene to stimulate the position) and static sensor (that locate moving objects in the images) systems (Alarifi et al., 2016). The cameras are fixed throughout the match. Each camera covers half of the court, in a way that together they cover the complete play area (Figure 15). The cameras are calibrated and 2-D image reconstructions constructed. To calibrate the cameras, each one has information about points inside the court with known distances (Moura et al., 2011). Next, image based technologies or optical methods develop algorithms in image processing (Alarifi et al., 2016).

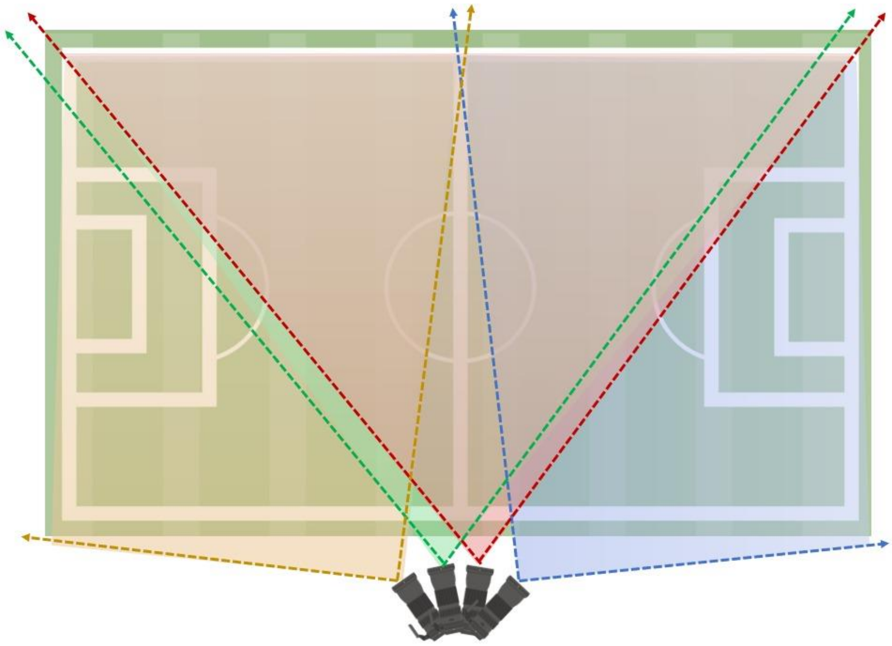


Figure 15. Player positioning detection using VID

Team sports coaches and scientists use technology with the expectation that it will translate into a competitive advantage (Coutts, 2014). This information is then used to prescribe training sessions, adjust and individualize training programs, and prepare the competition to optimize the performance of the players and the team (Pettersen et al., 2018). The frequency of use of GPS/GNSS and VID is very similar, while LPSs are used very infrequently (Rico-González et al., 2019). However, this cannot be interpreted as equality over time. The use of VID overtook notational analysis to analyse the matches and could improve the insufficiency of publications on the position of the players (Grehaigne et al., 1997). VID is a methodology for analysing players´ and teams´ performance based on multiple high-definition cameras that track players placed around the field. This system allows researchers to access the trajectory data to assess players’ performance and the interaction among them (Bartlett et al., 2012; Pons et al., 2019). Until 2014, the use of this system was greater (Figure 2) and several articles analysed the competition through the VID (Bourbousson et al., 2010a, 2010b; Castellano, Alvarez-Pastor, & Bradley, 2014; Fujimura & Sugihara, 2005; Lames, Ertmer, & Walter, 2010; Okihara et al., 2004; Palucci Vieira et al., 2018; Passos et al., 2006; Taki & Hasegawa, 2000; Yue et al., 2008). However, due to installation difficulties (i.e., many stadiums made the installation of multiple high-definition cameras around the field impossible due to their infrastructure) (Bastida-Castillo, Gómez-Carmona, De la Cruz-Sánchez, et al., 2019), VID were installed in official match stadiums, making the assessment of the competition possible but rarely the monitoring of the training process (Linke et al., 2018). It seems that the limitation to analyse collective tactical behaviour during the training process by VID was resolved using GPS/GNSS (Table 3). The results of this systematic review reported that the use of GPS/GNSS to assess collective tactical behaviour has grown exponentially since 2014. Although several studies have found slight differences between the external load measured by VID and GPS/GNSS (Pons et al., 2019), to our knowledge, no study has assessed the agreement between these systems (i.e. VID and GPS/GNSS) to measure collective tactical behaviours. Thus, the collective tactical behaviour information measured by both technologies (i.e. VID and GPS/GNSS) should not be interchanged until the agreement between both systems has been analysed during competition and training. Fortunately, for example in soccer, the clubs requested to be allowed to use radio frequency technologies during official matches and FIFA amended its rule number four to permit the use of GPS/GNSS and LPS in competitive matches (Hennessy & Jeffreys, 2018). Moreover, FIFA took the initiative to create the department of EPTS. Thus, team sports technical staffs will be able to assess collective tactical behaviours using the same technology (i.e. GPS or LPS) during competition and training. Since several studies have showed the higher accuracy of LPS technologies than the rest tools (Bastida Castillo et al., 2018; Bastida-Castillo, Gómez-Carmona, De La Cruz Sánchez, et al., 2019; Linke et al., 2018; Ogris et al., 2012), it is suggested that the use of these systems will grow in the future.

Assessing the quality of the measurement by radio-frequency technologies to measure collective behavior variables in team sports: a quality criteria standard

In research, detailed reporting standards are considered necessary in the field of measurement to ensure that outputs conform to standards for reporting trials (CONSORT) or observational studies (STROBE). Many recent studies have used EPTS to assess variables, such as internal and external loads, in different individual and team sports scenarios (Clemente, 2018; Nedergaard et al., 2017; Pino-Ortega et al., 2019; Rojas-Valverde et al., 2019; Svilar, Castellano, & Jukic, 2018). However, although several studies has highlighted considerations that should be taken when utilizing GPS to collect data in a sports setting (Castellano, 2014; Hennessy & Jeffreys, 2018; Malone et al., 2017), at present, to the best of our knowledge, no study has developed a quality criteria standard for the use of RF technology in practical sports applications. For this reason, this study aimed to develop the first quality criteria standard for collecting, processing, and reporting GNSS/GPS and LPS data. To this end, the criteria were divided into two groups: (1) general criteria, which are valid both for GNSS/GPS and LPS technologies, and (2) a group of specific criteria for each of them. A quality check sheet was proposed considering 14 general criteria items. Four additional items for GNSS/GPS and eight additional items for LPS were suggested. To ensure that high-quality data are collected, processed, analysed, and reported, researchers should address this *quality criteria standard* and report it in their methods (Appendix 1).

General criteria

The general criteria, which are valid both for GNSS/GPS and LPS technologies, are reliability, validity, sampling frequency, data exclusion and inclusion criteria, the time at which the data was extracted, technology lock and data synchronization

Reliability and validity

In order to rely on a system´s output for player monitoring, the data should be both valid and reliable (Adesida et al., 2019). A high level of consistency among the measurements recorded by a system indicates that the system is able to reliably detect meaningful changes in an athlete´s performance (Roell et al., 2018). All technologies are prone to some percentage of error. Due to inevitable errors, there is a need to explore the accuracy of these technologies under various sport environments. These errors are the responsibility of the manufacturer. Hence, the sports scientist should ensure that the technology used is reliable and valid. In fact, the technology is continually improving through developments related to microprocessors, data processing, and software. In fact, new models/brands sometimes differ in terms of sampling rates, chip sets, filtering methods, and data processing algorithms. For these reasons, sports scientists are continuously investigating whether the reliability and accuracy of each device are acceptable (Malone et al., 2017). However, in practice, due to time it takes for the research to be published, the use of this technology is sometimes recurrent when this fundamental information is unknown (Malone et al., 2017).

Tests for accuracy will help to warrant the optimal use of these technologies by coaches, athletes, and other staff. Planimetry, calibration (Niu et al., 2013), external factors during the signal travel time, or multipath are examples of these problems (Alarifi et al., 2016). Planimetry positioning refers to the combination of x and y coordinates over a plane and is understood as the distance between the recorded position and the real position. In the same way, the aging and manufacture of the sensors lead to calibration error (i.e., misalignment and a lack of orthogonality of the axes). Scale calibration can affect both the gyroscope and the accelerometer. It behaves like a bias error when integrating the signal, and the error accumulates due to the temperature during the time when the device is on (Nagahara et al., 2019). On the other hand, although the measurement method assumes that the signal´s velocity is constant, when the signal goes through the biosphere and troposphere, the signal suffers delays and the distance data assume errors. Finally, the multipath condition has become a problem and has no solution yet. However, due to the large data rate, bandwidth, and extremely short pulses, waveforms allow UWB to reduce the effect of multipath interference (Alarifi et al., 2016).

The sport or variable in which the data will be recorded should be considered because the validity and accuracy processes are expected to be different for different sports. In fact, when scientists try to assess variables considering multiple players (i.e., collective positioning), the inter-unit reliability should be assessed. Meanwhile, if a scientist wants to record individual variables, inter-unit reliability is not necessary (Malone et al., 2017). Moreover, Linke, Link, and Lames (2018) showed that validity and reliability studies can be divided into three categories: (1) studies that analyse position accuracy, (2) studies that analyse speed and acceleration data, and (3) studies that propose continuous situations such as real conditions. The accumulative error associated with the first and second categories can lead to errors in the last one (Linke et al., 2018). So, even though there is no standard system that provides perfect accuracy, authors should cite articles in which their brand/model has been assessed in continuous situations. Finally, it is important to note that for GPS/GNSS and LPS alike, the magnitude of the error is increased for the peak acceleration and deceleration of the tracking objects (Linke et al., 2018; Stevens et al., 2014). However, MEMSs have allowed the quantification of high speed running with high accuracy without RF signals (Roell et al., 2018).

Sampling frequency

An important parameter used to assess variables is the amount of data recorded per second, namely hertz (Hz) (Adesida et al., 2019). In fact, the sampling frequency is related to the accuracy of technology both in terms of acceleration or velocity (Stevens et al., 2014) and positioning variables (Rico-González et al., 2019). As such, technology is not useful if the Hz is not considered before each intervention. Firstly, the frequency depends on the capacity of the positioning systems used in the intervention. Secondly, it depends on the decision of the researcher or sports technician who can configure tools to extract more or less data from the session (Rico-González et al., 2019). It is crucial that the Nyquist theorem is avoided. That is, the sampling frequency must be at least twice as high as the highest frequency given by the signal itself. In addition, sports technicians should consider that if the sampling frequency is too low, there will be errors in the recording (Winter, 2009) and that if it is too high, noise could contaminate the desired signal. On the other hand, software-derived data should be considered carefully (Malone et al., 2017). Manufacturers' software often includes algorithms that can be used to identify poor-quality data. Researchers can modify the frequency of the data, and the software will automatically interpolate, smooth, or extract software-derived data (Malone et al., 2017). A greater Hz value is correlated with higher sampling frequencies, which will not necessarily yield better results (Rico-González et al., 2019). So, although data per unit of time could be dependent on each variable, further studies should study the influences of the raw data and software-derived data on the measurement of cinematic, physiologic, or tactical variables.

To normalize the data and avoid the type of noise mentioned above, the accelerometer chip manufacturer usually applies a first filtration process. The filtration details are not commonly specified by the device fabricant, and the user cannot change the chip's configuration. In order to better understand this process, the manufacturers could give more information about the filtration stages in the chip, software, and user options. This information could give the user valuable knowledge about how the data is collected and processed before the "raw data" is available for the user. This would allow the sports scientist to make inter-device comparisons and, in turn, to understand the main differences between them.

Exclusion/inclusion criteria

Due to factors outside of the practitioner´s control, there can be moments in which data should be eliminated from analyses. Raw traces of velocity and acceleration should be checked to detect spikes or outliers in the data generated from the technology by itself. These irregularities could be justified by a sudden loss in the satellite signal connection, thus leading the detection of data to be delayed. In fact, the number of satellites and high dilution of precision (HDOP) values could be used by a criterion to delete data (Malone et al., 2017). Therefore, researchers are encouraged to detail the specific procedure and filtration processes that were considered when extracting the data. Performing this task will clarify which exclusion criteria were used to avoid signal bias.

Real-time vs post-game data

Currently, international sport regulations allow technology in the technical area to be tracked in real time. In some sports, such Australian football, the use of EPTS is allowed during matches (Aughey & Falloon, 2010). However, there is a debate about the difference in accuracy between data downloaded during a match or training session and data downloaded after a match or training session. Among the advantages of using GNSS/GPS or LPS for real-time data are (1) the possibility to record multiple players at the same time, (2) the time effectiveness of the analysis, and (3) the possibility to give feedback in real time and make fast and opportune decisions (Dogramaci et al., 2011). However, when real-time data are to be used, any factors should be considered, such as (1) where and how the calculation is going to be made (i.e., within devices or on an external PC); (2) system delay, coverage technology, or technology used; (3) the use of a necessary infrastructure that does not affect the signal; (4) the number of devices that can be displayed at the same time; (5) the number of variables and whether choosing them is possible; and (6) the possibility of setting alarms to provide feedback quickly. On the other hand, when data are extracted after the session, other considerations must be made, including (1) whether the system allows raw data extraction, (2) the download time, and (3) whether the software allows the user to manage and analyse data freely. Aughey and Falloon (2010) investigated whether data can change depending on whether they are downloaded in real time or post-session. Although the correlations between real-time data and post-game data were strong for all parameters, the difference in the mean and total error was large with a wide range of scores. Although more studies are required, the results showed that caution is needed when the data have been downloaded in real time, especially when the intensity of effort is high. Usually, the data is downloaded after training or the match when the aim of the data collection is to publish an article. This is consistent with other research is which the data monitored in real time were significantly inaccurate relative to the post-session data for the external load parameters of maximum velocity, overall distance covered, high speed distance, high intensity activity, and sprint distance (Dallaway, 2013). Thus, research articles should mention the moment at which the researchers download the data.

Technology lock

Whether GNSS/GPS or LPS should be used depends on the reference system connected to the devices. In order to avoid GPS lock, researchers must ensure that the receptors have satellite or antennae connections before the training session or match starts. This can be achieved by placing the devices in a clear outdoor space (for GNSS/GPS devices) or in the middle of the antennae system, which is usually indicated on the manufacturer´s device by flashing light signals (Malone et al., 2017). Duffield et al. (Duffield et al., 2010) reported that GPS/GNSS should be activated 15 min prior to data collection to allow for the acquisition of satellite signals.

Data synchronization

Even though previous studies have recorded raw data and then reduced it with different techniques (i.e., smooth, Butterworth filter, cut-off frequencies) to extract software-derived data, the accuracy of the positional information that is used to determine the distance between multiple units is different from the precision of individual variables (Malone et al., 2017). To record collective variables when GNSS/GPS technology is used to record data, the satellite´s atomic clock sends a signal, and the receptor records the data and the time at which the signal was sent. Therefore, as there is no common clock that is shared by the devices, the data can be recorded at different times. For this reason, the researchers should explain which solution method they have used to avoid it. On the contrary, LPS systems avoid the synchronisation problem using different techniques provided by the manufacturers. So, these techniques should be described in the method section of the studies.

Specific criteria for Global Positioning Systems/Global Navigation Satellite Systems

Number of satellite connections and HDOP

The signals received by devices from satellites influence the accuracy of the data recorded, and the signal quality may change depending on the place where the intervention is done (Malone et al., 2017). An assessment of whether the signal is acceptable can be based on two parameters: (1) the number of satellites connected to the device and (2) the orientation of the satellites in the atmosphere. Although these parameters vary during the session and it is difficult to report exact conditions, the mean conditions should be reported in studies (Jackson et al., 2018; Townshend et al., 2008). Although only three satellites are required for trigonometry, a fourth satellite is necessary to eliminate the need for expensive clocks. Thus, a minimum of four satellites is needed for the level of connection of a system to be deemed adequate. However, the use of additional satellites is recommended to ensure the coverage of large areas. Malone et al. (2017) anecdotally report that if the GPS/GNSS receiver is connected to fewer than six satellites, the connection tends to be weak, and the data tend to be of poor quality. However, Linke et al. (2018) reported that the numbers of satellites connected in validation studies were 8 ± 1, 9.5 ± 2, and 12.3 ± 0.3. Although further studies are needed to confirm this, manufacturers should consider that the number of constellations used whose satellites are connected with devices could influence the area covered and the number of satellites connected with devices (Jackson et al., 2018).

On the other hand, the horizontal dilution of precision (HDOP) refers to the geometrical organization of the satellites in the atmosphere and could influence the accuracy of the data obtained. The HDOP value is higher the closer the satellites are to each other, and high HDOP values are associated with poor-quality data. So, the greater the dispersion of the satellites, the better the quality of the reported data, with an HDOP value of less than 1 considered optimal (Malone et al., 2017). As has been mentioned, GNSS can yield lower HDOP values than GPS, which use only one constellation (i.e., American).

Environmental and infrastructure conditions

GNSS/GPS were initially proposed for military use in outdoor environments. However, indoor position systems have recently been developed to replace GNSS/GPS in indoor environments. GNSS/GPS signal quality can be influenced by infrastructure (e.g. houses, walls) or the weather, which means that the data used to report a study's results cannot be done in adequate fields or days. In fact, GNSS/GPS are suitable and efficient for outdoor environments or places without tall buildings, as opposed to indoor environments or stadiums because the satellite radio signal cannot penetrate solid walls, curved roofs, or obstacles (Alarifi et al., 2016) and, thus, can provide unreliable data because fewer satellites are available to triangulate signals from devices (Cummins et al., 2013). Therefore, authors must explain these conditions in their methods.

Specific criteria for Local Positioning Systems

Environmental and infrastructure conditions

As has been mentioned, when an LPS are used, a reference system is installed around the court. Low temperatures, humidity gradients, and slow air circulation can allow for easier positioning within this small area (Alarifi et al., 2016). Although many technologies (e.g., ultrasound) are not useful because of their sampling frequency capacity or interference with several multipaths (Leser et al., 2011), different kinds of technology have been used to measure different variables (Frencken, Lemmink, Delleman, & Visscher, 2011; Leser, Schleindlhuber, Lyons, & Baca, 2014). One of these types of technology is UWB, which is still subject to interference caused by metallic materials.

Installation

Unlike GNSS/GPS, when an LPS is used, the antennae installation shape and height must be considered because these factors can influence the final data. The scientist must consider that each antenna has an error margin around it, like a circumference (Figure 16). The antennae are installed around the court. The antennae in the corners are the closest to the court lines, while the antennae collocated in the middle of the court and (when eight antennae are installed) behind the goals are farther away from the court lines (Bastida-Castillo, Gómez-Carmona, De la Cruz-Sánchez, et al., 2019). This means that the error margins are not as prominent inside the court where the players tend to run the most. So, although it is difficult in some places, the optimal shape of the antennae installation is a circumference (Ridolfi et al., 2018), and if this circumference is deformed along the lateral or longitudinal axes, the accuracy of the x or y data, respectively, will be decreased. Moreover, although it is common to install the antennae around the court, if teams want to install fixed antennae, they must consider that the higher the antennae are, the greater error they are prone to make (Luteberget et al., 2018). Thus, it is suggested that future studies provide details about the shape and height of installed antennae.

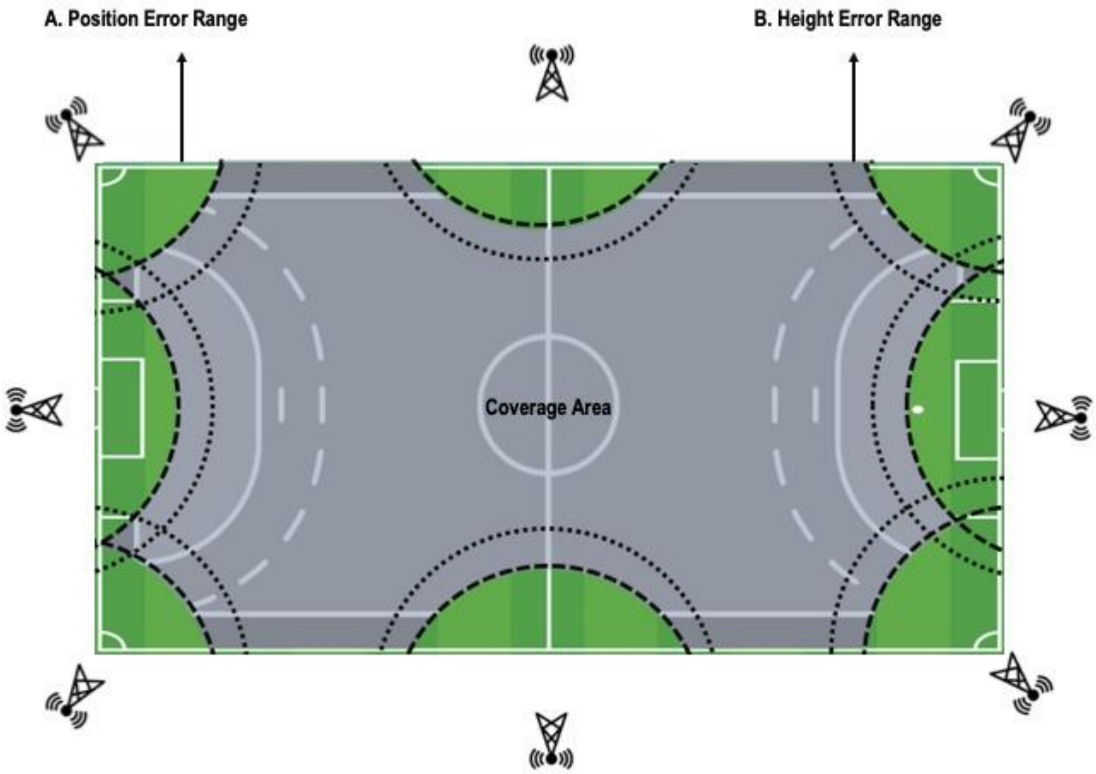


Figure 16. Positioning calculation error due to (1) antennae disposition (2) installation height

Measurement method

UWB is a very promising technology. 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): (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. An understanding of the accuracy, environment, estimation technique, space, and purpose of use of these algorithms is critical because of their differences and the appropriateness of their use in different situations.

AOA is less practical than the other four types of algorithms because of the difficulty and cost of maintaining the required large dimensions of antenna arrays and sensors. Moreover, this algorithm requires high cooperation among the sensors and is subject to error accumulation (Kułakowski, Vales-Alonso, Egea-López, Ludwin, & García-Haro, 2010). Although this method has acceptable precision, AOA and RSS are more suitable than other algorithms for systems that use narrowband signals with a high UWB bandwidth (Alarifi et al., 2016). Because of its suitability for the narrowband method, RSS is less attractive than other measurement methods that allow high accuracy. However, TOA performs better in wideband systems, like UWB (Alarifi et al., 2016). In terms of accuracy, small errors in AOA will negatively impact precision when the target object is far away from the base station. However, TOA and TDOA have higher accuracy relative to other algorithms because of the high time resolution of the UWB signals. Clock synchronization and clock jitter are important factors that affect the accuracy of TOA because, as mentioned earlier in this study, clock synchronization is needed between the receivers to estimate the TOA's precision. However, TDOA is a more effective option if there is no synchronization between the receivers and antennae when the reference nodes are synchronized among themselves (Gezici et al., 2005). Hybrid algorithms have been found to be the most effective solutions for UWB positioning systems because they combine the advantages of all the algorithms (Alarifi et al., 2016).

Impact of the amount of data per second on the measurement of collective tactical variables using Geographic Information Systems

EPTS have been used to analyse four kinds of variables in team sports: physiological (internal load), time-motion (external workload), neuromuscular (external load), and tactical (Leser et al., 2011; Low et al., 2020), which are processed by the manufacturer´s software. Each of these variables is checked in a different part of the software. During recent years, the rapid development of this software is offering more opportunities such as geographic information system (GIS) methods (Jia et al., 2017) and their applications in team sport research. In fact, the GIS developed in the early 1960s, have been gaining more attention and are increasingly being used in sport research (Bastida-Castillo, Gómez-Carmona, De la Cruz-Sánchez, et al., 2019). This application is composed of computer systems that help to capture, store, check and display data with location information, which offering many opportunities for team sport performance analyses thanks to their ability to handle complex spatial information and increasing spatial data (Jia et al., 2017). Overall, there are two classes of GIS data:

vector data (i.e. representing real-world features in the form of points, lines or polygons with geographic coordinates) and raster data (i.e. map of grids or cells with a value assigned to each grid/cell, such as color infrared high-resolution Digital Orthophoto Quarter Quadrangle images) (Jia et al., 2017). Therefore, manufacturers have the possibility of adding some complements to their software such as geographic information systems (GIS), which provide customers with ample possibilities to show tactical behaviour data (Bastida-Castillo, Gómez-Carmona, De la Cruz-Sánchez, et al., 2019).

Using EPTS, one of the parameters that researchers can modify according to their needs is the sampling rate of data collected per second, called “raw data” and expressed in hertz (Hz) (Winter, 2009). Deciding before the investigation which sampling frequency is to be used when recording the data (i.e. raw data) is fundamental to avoid violating the Nyquist sampling theorem. The theorem shows that the sampling frequency must be at least twice as high as the highest frequency given by the signal itself (i.e. if the amount of Hz is too low, errors or bias will occur in the recording) (Winter, 2009). However, when the sampling frequency is too high, the signal may be distorted by noise, which increases linearly with frequency (Winter, 2009). In this sense, lowpass digital filtering of noisy signals has been an important procedure because the objective of any filtering technique is to attenuate noise and leave the true signal unaffected and stable (Winter, 2009). Once recorded, the data can go through a process of data reduction using algorithms, producing software-derived data (Malone et al., 2017). However, GIS is an external complement that manufacturers add to their software and uses different data processing. In general, due to its limited capacity to process data, GIS manufacturers limit the capacity to import data. For example, if an EPTS records data at 10 Hz, 10 data points per second are available for kinematic analysis (e.g. velocity or time motion), but only 1 data point per second is allowed in GIS. Since the data available in GIS may not be enough for collective tactical behaviour analysis, the manufacturers make available some options to add data. To date, the impact of inserting data on the measurement of collective tactical behaviour has not been assessed.

Hypothesis and aims of the doctoral thesis

Hypothesis:

- ✓ The limitation to import positional data to Geographical Information Systems influences the quality of the measurement of collective tactical behavior variables.

Aims:

- ✓ To assess the impact of the amount of inserted data per second in the measurement of the *geometrical center position* (*cGCp*) and the *total area* (*TA*) in the Geographical Information System (GIS) during controlled tasks.

- ✓ To assess the impact of the amount of inserted data per second in the measurement of the *geometrical center position* (*cGCp*), mean distance between players (*mean*-DbP) and the *total area* (*TA*) in the Geographical Information System (GIS) during a soccer match.

Method

Subjects

Preliminar study (study 1)

Data was collected from sixteen young male soccer players (under 16 years) (age 15.6 ± 0.8, height 1.70 ± 0.1 m, weight 65.6 ± 10.2 kg) who belonged to the Torre Pacheco Soccer School (Spain). These players also participated in the cadet category of the Autonomous League of the region of Murcia during the 2018-2019 season. The team's staff gave their consent for their participation in this study. A written consent was signed by their legal guardians and players gave their assent to participate. The study, which was conducted according to the Declaration of Helsinki (2013), was approved by the Bioethics Commission of the University (Reg. Code 67/2017).

Soccer match (study 2)

Participants were sixteen well-trained youth soccer players (age: 15.9 ± 0.4, height: 170.1 ± 7.1 cm, weight: 57.9 ± 8.3 kg) with at least 6 years of experience in soccer training and competition. Players belonged to the same team, performed three training sessions per week (75–90 min) and played an official game during the weekend at a regional level (Navarre Regional Community, U15 Spanish League) during the 2018-2019 season. A written consent was signed by their legal guardians and players gave their assent to participate. The study, which was conducted according to the Declaration of Helsinki (2013), was approved by the Institutional Review Board of the University (Reg. Code 132/2018).

Procedure

Preliminar study (study 1)

Two teams of eight players participated in the exercises on a field of 30x40 meters (Coutinho et al., 2018). They were asked to execute three different controlled tasks for about 5 minutes each: i) players walked along the line that described the perimeter of the area arranged (see Figure 17a) ii) players walked along the perimeter line and after the coach's signal they ran to the centre of a smaller area placed in the middle of the total area and then scattered towards the perimeter line again continuously (see Figure 17b), and iii) players walked along the perimeter line and after the coach's signal they ran to the corners of a smaller area placed in the middle of the total area and then scattered towards the perimeter line again continuously (see Figure 17c).

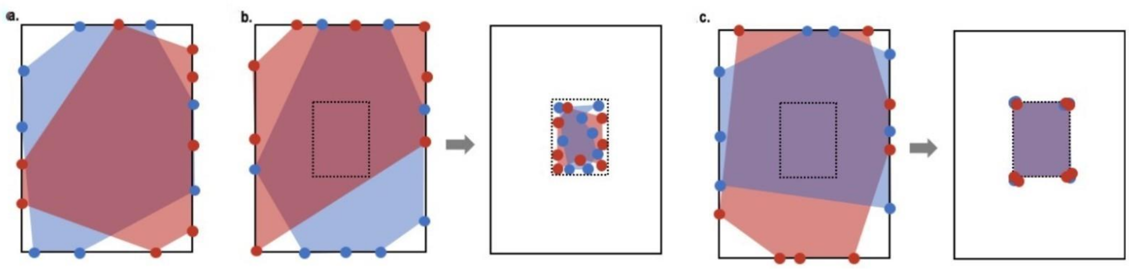


Figure 17. Positioning during task

Soccer match (study 2)

Tactical variables were assessed during a 7+GK vs 7+GK soccer match played on an artificial-turf pitch (60 m length x 40 m width) using 7-v-7 goals (7 x 2.5 m) (150 m^2 per player). The technical staff divided the players into two balanced teams according to the tactical/technical level and the playing position of the players (Casamichana & Castellano, 2010). Both teams used the same game system (1-3-3-1) and the participants played the match in the same playing position during the two bouts. The official game rules, including the offside rule at the middle of the pitch, were applied during the game. The match was composed of two bouts of 5 min interspersed with 4 min of passive recovery. The players were not replaced between bouts. Several balls were placed around the field to ensure replacement as fast as possible. No feedback was allowed before or during the game.

Collective tactical behaviour variables

We measured and analyzed the following variables: (1) preliminary study (study 1); the change in *GC* position (*cGCp*) of the team and the *total area* (i.e. *TA*) of the team, and (2) soccer match (study 2); the change in *GC* position (*cGCp*) of the team, the mean distance between players (*mean-DbP*) and the *total area* (i.e. *TA*) of the team. For the soccer match, the three variables were measured in both teams and considering both bouts together (i.e., 10 min in total). *cGCp* (m) was defined as the distance in meters between two consecutive measured points of the centroid as the mid-point of the polygon. The m*ean-DbP* (metres) = considered all outfielder players (Gonçalves et al., 2017). *TA* (m^2) was defined as total square meters of a polygon described by players at its vertex point.

Data collection

Positional data were collected using a commercial EPTS (WIMU PRO^{TM}, RealTrack Systems, Almeria, Spain). Each device contains a 10 Hz GPS and an 18 Hz UWB (Ultra-wideband), as well as other sensors (three 3-axis gyroscopes, a 3-axis magnetometer, four 3-axis accelerometers, etc.). For data collection TA (m^2) and CCP

(m) were measured at 18 Hz sampling frequency for raw data by radio ultra-wide band (UWB) sensor. The UWB system is composed of two sub-systems: (1) the reference system and, (2) the devices tracked (carried by the players) that are transmitters and receivers of the radio-frequency signals. The reference system was composed of eight antennae placed around the field and devices that were attached to the players in a special vest in a pocket placed between the scapulae at the T2-T4 level and prior to in-field exercises following previous study protocols (Reche-Soto et al., 2019).

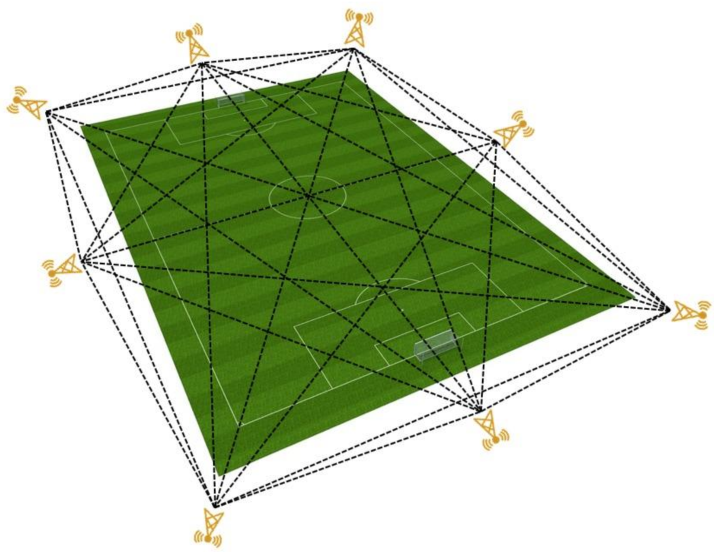


Figure 18. Antennae placed around the field

The antennae (mainly the master antenna) computerize the position of the devices that are in the play area, while the devices receive that calculation (Bastida-Castillo, Gómez-Carmona, De la Cruz-Sánchez, et al., 2019). The TDOA algorithm was used to estimate positioning. The UWB occupies a very large frequency band (i.e. at least 0.5 GHz), as opposed to more traditional radio communications that operate on much smaller frequency bands (Alarifi et al., 2016). 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). This UWB system has recently been validated for collective tactical behaviour variables (Bastida-Castillo, Gómez-Carmona, De La Cruz Sánchez, et al., 2019).

Data processing

To investigate the accuracy of the UWB system for monitoring players´ positions on the court, the data were transformed into raw position data (x and y coordinates) using a software (S PRO, RealTrack Sytems, Almeria, Spain). In this study GIS was proposed as the reference system (Bastida-Castillo, Gómez-Carmona, De la Cruz-Sánchez, et al., 2019). 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. This GIS complement allows the importation of 1 data point per second, but sPRO software allows the insertion of additional data from raw information. Four different amounts of data were inserted per second according to the previous and subsequent data recorded by the device: 10 data samples per second (GIS at 10Hz), 4 data samples per second (GIS at 4Hz), 2 data samples per second (GIS at 2Hz) and 1 data sample per second (GIS at 1Hz). And then, the x and y coordinate data of the UWB system were introduced and compared. Subsequently, we assessed the impact of the inserted data on the measurement of the CCP and TA. For statistical analysis purposes, the datasets corresponding to each sampling frequency were balanced in order to calculate the intraclass correlation coefficient and Bland Altman agreement. The balancing was performed by downsampling each dataset, calculating the mean of the data every 2 (GIS at 2 Hz), 4 (GIS at 4 Hz) and 10 (GIS at 100 Hz) values in order to have the same amount of data in each dataset.

Statistical analysis

Preliminar study

The data are presented as means with standard deviation. For the preliminary study (study 1), the Shapiro Wilk test was applied to confirm the normality of the data, while for the soccer match study (study 2) Kolmogorov-Smirnoff test was used to confirm the normality of the data, verifying the feasibility of using parametric inference. The different amounts of data were balanced using means for each second to allow evaluation of the inserted data. Following previous study principles (Kottner & Streiner, 2011; Zaki et al., 2012), we analyzed the agreement among the different amounts of inserted data per second. We used these tests: 1) intraclass correlation coefficient (ICC) with a mixed two-way model and a 95% CI; 2) one sample t-test of the differences using the Bland and Altman (1986) method to assess bias and agreement, 3) r-Pearson to explore linear correlation between the different amounts of inserted data per second; 4) t-test to explore significant differences between variable amounts of inserted data per second. Moreover, the magnitude of the significance was assessed using Cohen's *d* effect size, qualitatively rated as follows: < 0.2 *trivial*, 0.2-0.6 *small*, 0.6-1.2 *moderate*, 1.2-2 *large*, and 2.0-4.0 *very* large (Hopkins et al., 2009). ICC was interpreted following previous proposed ranks as: 0 *poor*, 0.01-0.20 *trivial*, 0.21-0.4 *regular*, 0.41-0.6 *moderate*, 0.61-0.8 *substantial* and 0.81-1 *almost perfect* (Kramer & Feinstein, 1981). Statistical differences were considered significant if $p < 0.05$. Statistical analyses were developed using SPSS and Figures were drawn using Graph Prism software.

Results

Preliminar study (study 1)

ICC and linear correlation values ranged from 0.07 to 0.79 and from 0.49 to 0.99, respectively, according to the amount of data added (i.e. 10, 4, 2 and 1 data samples per second) and the task. Significant ($p<0.01$) and substantial (ES = *large*) differences were found among the CCP values recorded at different amount of data per second in all tasks (Table 10).

High to *perfect* ICCs (0.91-1) and *high* to *perfect* linear correlations ($r= 0.961$-1; $p < 0.01$) were found among the TA values obtained through all amount of data added (i.e. 10, 4, 2 and 1 data samples per second) derived from the software in the three tasks. No significant ($p> 0.05$) and substantial (ES = *trivial*) differences were found among the TA values obtained with all amount of data samples added in all tasks (Table 11).

Table 10. Intra-class Correlation Coefficient, Linear Correlation and mean comparison of *change in centroid position* (*CCP*) by the amount of inserted data per second

Task	Variable	Amount of inserted data per time period	N	*ICC*	*95% IC*	*BIAS*	*95%IC*	*r* (*p* value)	*t* (*p* value)	Cohen *d (rating)*
Task 1	Change in Centroid (m)	10vs4	300	0.33	0.22; 0.43	-0.18	-0.57; 0.21	0.49 (< 0.01)	-15.07 (< 0.01)	-1.27, *large*
		10vs2	300	0.18	0.07; 0.3	-0.49	-1.33; 0.84	0.49 (< 0.01)	-19.2 (< 0.01)	-1.63, *large*
		10vs1	300	0.1	-0.02; 0.21	-01.11	-2.85; 0.63;	0.5 (< 0.01)	-20.77 (< 0.01)	-1.76, *large*
		4vs2	300	0.79	0.75; 0.83	-0.31	-0.76; 0.14	0.99 (< 0.01)	-21.89 (< 0.01)	-1.85, *large*
		4vs1	300	0.46	0.36; 0.55	-0.93	-2.32; 0.46	0.98 (< 0.01)	-21.82 (< 0.01)	-1.85, *large*
		2vs1	300	0.79	0.74; 0.83	-0.62	-1.56; 0.32	0.99 (< 0.01)	-21.57 (< 0.01)	-1.83, *large*
Task 2	Change in Centroid (m)	10vs4	300	0.69	0.62; 0.76	-0.09	-0.2; 0.02	0.96 (< 0.01)	-19.58 (< 0.01)	-1.66, *large*
		10vs2	300	0.34	0.21; 0.45	-0.24	-0.53; 0.07	0.82 (< 0.01)	-18.85 (< 0.01)	-1.6, *large*
		10vs1	300	0.15	0.02; 0.28	-0.52	-1.21; 0.17	0.72 (< 0.01)	-18.73 (< 0.01)	-1.59, *large*
		4vs2	300	0.65	0.57; 0.73	-0.15	-0.4; 0.1	0.82 (< 0.01)	-14.99 (< 0.01)	-1.27, *large*
		4vs1	300	0.37	0.25; 0.48	-0.43	-1.04; 0.18	0.79 (< 0.01)	-17.59 (< 0.01)	-1.49, *large*
		2vs1	300	0.42	0.3; 0.52	-0.27	-0.89; 0.35	0.52 (< 0.01)	-10.85 (< 0.01)	-0.92, *moderate*
Task 3	Change in Centroid (m)	10vs4	300	0.49	-0.055; 0.75	-0.081	-0.19; 0.03	0.98 (< 0.01)	-21.46 (< 0.01)	-1.82, *large*
		10vs2	300	0.20	-0.07; 0.43	-0.21	-0.51; 0.09	0.92 (< 0.01)	-21.13 (< 0.01)	-1.79, *large*
		10vs1	300	0.07	-0.04; 0.18	-0.45	-1.16; 0.26	0.66 (< 0.01)	-19.59 (< 0.01)	-1.66, *large*
		4vs2	300	0.61	0.003; 0.83	-0.13	-0.31; 0.05	0.96 (< 0.01)	-20.46 (< 0.01)	-1.73, *large*
		4vs1	300	0.21	-0.04; 0.42	-0.37	-1; 0.26	0.73 (< 0.01)	-18.02 (< 0.01)	-1.53, *large*
		2vs1	300	0.54	0.12; 0.75	-0.24	-0.71; 0.23	0.85 (< 0.01)	-15.23 (< 0.01)	-1.29, *large*

Hz: Hertz; M: metres; p: p value; r: Pearson r; t: t test; %: percentage

Table 11. Intra-class Correlation Coefficient, Linear Correlation and mean comparison of *total area* (*TA*) by the amount of inserted data per second

Task	Variable	Amount of inserted data per time period	N	*ICC*	*95% IC*	*BIAS*	*95%IC*	*r* (*p* value)	*t* (*p* value)	Cohen *d (rating)*
Task 1	Total Area (m^2)	10vs4	300	0.96	0.95; 0.97	2.61	131.18; 125.97	0.96 (< 0.01)	0.66 (=507)	0.06, *trivial*
		10vs2	300	0.96	0.95; 0.97	2.7	130.35; 124.95	0.96 (< 0.01)	0.69 (=.489)	0.06, *trivial*
		10vs1	300	0.96	0.95, 0.97	3.71	125.54; 119.18	0.96 (< 0.01)	0.82 (=.411)	0.07, *trivial*
		4vs2	300	1	1; 1	0.09	6.4; 6.22	1 (< 0.01)	0.48 (=.635)	0.04, *trivial*
		4vs1	300	0.99	0.99; 0.99	0.57	22.19; 21.05	0.99 (< 0.01)	0.86 (=.389)	0.07, *trivial*
		2vs1	300	0.99	0.99; 0.99	0.47	15.25; 14.29	0.99 (< 0.01)	0.91 (=.362)	0.08, *trivial*
Task 2	Total Area (m^2)	10vs4	300	1	1; 1	-47	-11.34; 10.4	1 (< 0.01)	-1.09 (=.278)	-0.09, *trivial*
		10vs2	300	0.99	0.99; 0.99	462.3	107.73; 1032	0.998 (< 0.01)	0.12 (=.907)	0.01, *trivial*
		10vs1	300	0.993	0.99; 0.99	453.7	120.4; 1028	0.993 (< 0.01)	-1.11 (=.267)	-0.09, *trivial*
		4vs2	300	0.99	0.99; 0.99	0.66	-42.9; 44.24	0.997 (< 0.01)	0.38 (=.708)	0.03, *trivial*
		4vs1	300	0.99	0.99; 0.99	-2.51	-58.7; 53.68	0.995 (< 0.01)	-1.12 (=.266)	-0.09, *trivial*
		2vs1	300	0.99	0.99; 0.99	-3.19	-90.83; 84.45	0.988 (< 0.01)	-0.90 (=.369)	-0.08, *trivial*
Task 3	Total Area (m^2)	10vs4	300	1	1; 1	-0.05	-4.92; 4.82	1 (< 0.01)	-0.3 (=.765)	-0.03, *trivial*
		10vs2	300	0.99	0.99; 0.99	-0.13	-13.1; 12.84	0.99 (< 0.01)	-0.29 (=.769)	-0.03, *trivial*
		10vs1	300	0.99	0.99; 0.99	-0.41	-29.88; 29.06	0.99 (< 0.01)	-0.42 (=.674)	-0.04, *trivial*
		4vs2	300	0.99	0.99; 0.99	-0.36	-8.51; 7.79	0.99 (< 0.01)	-0.29 (=.772)	-0.03, *trivial*
		4vs1	300	0.99	0.99; 0.99	-0.36	-25.01; 24.29	0.99 (< 0.01)	-0.45 (=.657)	-0.04, *trivial*
		2vs1	300	0.99	0.99; 0.99	-0.28	-16.87; 16.31	0.99 (< 0.01)	-0.52 (=.605)	-0.04, *trivial*

Hz: hertz; M^2: square metres; p: p value; r: Pearson r; t: t test; %: percentage

As an example, Figure 19 shows the *cGCP* and *TA* values for each amount of data added (i.e. 10, 4, 2 and 1 data samples per second) in Task 1.

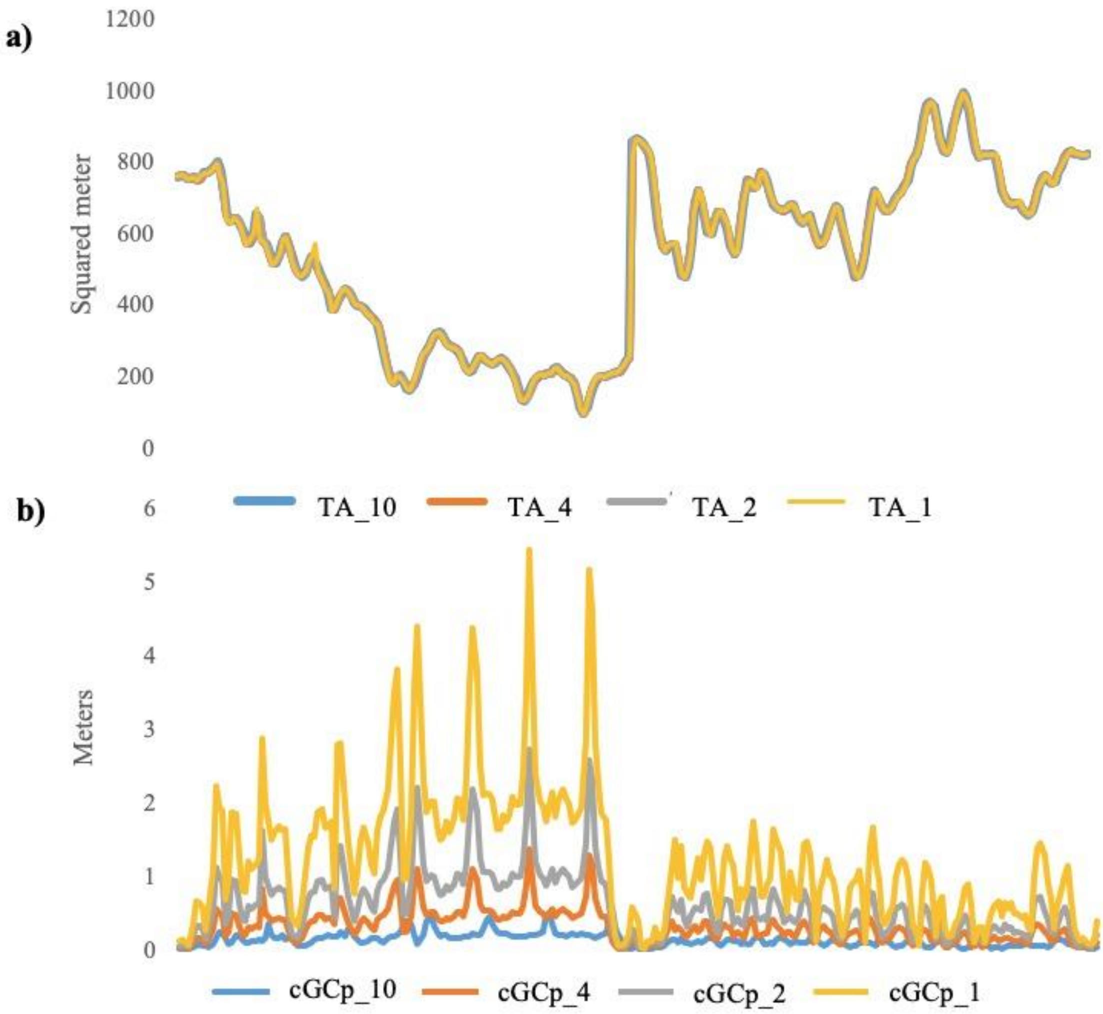


Figure 19. Differences between different amount of data inserted

Soccer match (study 2)

Descriptive data of *cGCp*, *mean-Dbp* and *TA* for each team are shown in Table 12.

Table 12. Descriptive data of the *change in geometrical center position* (*cGCp*), the mean distance between players (*mean-DbP*) and the *total area* (*TA*) by team

Variable	Amount of inserted data per second	n	Team A	Team B
cGCp (m)	10	600	0.11 ± 0.06	0.11 ± 0.06
	4	600	0.26 ± 0.15	0.28 ± 0.15
	2	600	0.53 ± 0.31	0.55 ± 0.31
	1	600	1.03 ± 0.62	1.07 ± 0.63
Mean-DbP (m)	10	600	19.19 ± 6.6	18.44 ± 5.61
	4	600	19.19 ± 6.65	18.46 ± 5.63
	2	600	19.19 ± 6.6	18.44 ± 5.61
	1	600	19.2 ± 6.67	18.45 ± 5.62
TA (m^2)	10	600	407.3 ± 135.05	384.67 ± 120.27
	4	600	407.32 ± 135.04	384.6 ± 150.17
	2	600	407.53 ± 135.3	384.65 ± 120.2
	1	600	407.56 ± 135.29	384.72 ± 120.44

Significant (p<0.001) and substantial (ES = moderate-large) differences were found among the *cGCp* values recorded at different amount of data per second during the task and both teams (Tables 13 and 14). Moreover, agreement and reliability values were regular to substantial (Tables 13 and 14).

Except for 10vs1 data samples per second (p <0.05), no significant (p>0.05) and trivial-small differences were found in *mean-DbP* values among the different amounts of inserted data per second Team A (Table 13). In addition, except for 10vs1 and 10vs4 data samples per second (p <0.01), no significant (p>0.05) and trivial-moderate differences were found in the *mean-DbP* values among the different amounts of inserted data per second for Team B (Table 14). Agreement and reliability values ranged from trivial to substantial for both teams (Tables 13 and 14).

There were no significant (p> 0.05) and substantial (ES = trivial) differences in the *TA* values of the Team A (Table 13) and Team B (Table 14) among the different amounts of inserted data per second. In addition, agreement and reliability values were perfect for *TA* (Tables 13 and 14).

Table 13. Intra-class Correlation Coefficient, Linear Correlation and mean comparison of *change in geometrical center position* (*cGCp*), the mean distance between players (*mean-DbP*) and the *total area* (*TA*) by the amount of inserted data per second (Team A)

Variable	Amount of inserted data per second	N	*ICC*	*95% CI*	*BIAS*	*95%IC*	*r* (*p* value)	*t* (*p* value)	Cohen *d (rating)*
cGCp (m)	10vs4	600	0.65	0.601; 0.694	-0.16	-0.11; -0.43	0.946 (<0.01)	-39.663 (<0.01)	-1.62, *large*
	10vs2	600	0.306	0.231; 0.377	-0.42	-0.29; -1.12	0.8 (<0.01)	-39.288 (<0.01)	-1.6, *large*
	10vs1	600	0.152	0.073; 0.229	-0.93	-0.64; -2.5	0.777 (<0.01)	-39.594 (<0.01)	-1.62, *large*
	4vs2	600	0.592	0.537; 0.642	-0.26	-0.18; -0.7	0.946 (<0.01)	-29.131 (<0.01)	-1.19, *moderate*
	4vs1	600	0.357	0.285; 0.425	-0.77	-0.53; -2.07	0.741 (<0.01)	-36.778 (<0.01)	-1.62, *large*
	2vs1	600	0.563	0.506; 0.615	-0.51	-0.35; -1.37	0.746 (<0.01)	-27.157 (<0.01)	-1.11, *moderate*
Mean-DbP (m)	10vs4	600	0.412	0.053; 0.677	-0.03	-0.09; 0.029	0.413 (0.029)	-1.478 (0.151)	-0.28, *small*
	10vs2	600	0.313	-0.061; 0.61	-0.03	-0.09; 0.029	0.313 (0.105)	-1.19 (0.245)	-0.22, *small*
	10vs1	600	0.408	0.048; 0.674	-0.05	-0.15; 0.05	0.408 (0.031)	-2.273 (0.031)	-0.43, *small*
	4vs2	600	-0.08	-0.43; 0.298	0.04	-0.04; 0.118	-0.078 (0.694)	0.120 (0.906)	0.02, *trivial*
	4vs1	600	0.617	0.323; 0.802	-0.02	-0.06; 0.02	0.617 (<0.01)	-1.03 (0.312)	-0.19, *trivial*
	2vs1	600	0.347	-0.023; 0.63	-0.02	-0.06; 0.02	0.348 (0.07)	-0.923 (0.364)	-0.17, *trivial*
Total Area (m^2)	10vs4	600	0.996	0.996; 0.997	-0.02	-0.01; -0.06	0.996 (<0.01)	-0.049 (0.961)	0, *trivial*
	10vs2	600	0.973	0.968; 0.977	-0.23	-0.16; -0.63	0.973 (<0.01)	-0.182 (0.855)	0.01, *trivial*
	10vs1	600	0.995	0.994; 0.996	-0.23	-0.16; -0.63	0.995 (<0.01)	-0.458 (0.647)	0.02, *trivial*
	4vs2	600	0.955	0.947; 0.962	-0.21	-0.15; -0.57	0.955 (<0.01)	-0.127 (0.899)	0.01, *trivial*
	4vs1	600	0.993	0.991; 0.994	-0.23	-0.16; -0.63	0.993 (<0.01)	-0.349 (0.727)	0.01, *trivial*
	2vs1	600	0.97	0.965; 0.974	-0.02	-0.02; -0.06	0.97 (<0.01)	-0.016 (0.987)	0, *trivial*

cGCp = change in the geometrical centre position.; Mean-DbP = mean distance between players

Table 14. Intra-class Correlation Coefficient, Linear Correlation and mean comparison of *change in geometrical center position* (*cGCp*), the mean distance between players (*mean-DbP*) and the *total area* (*TA*) by the amount of inserted data per second (Team B)

Variable	Amount of inserted data per second	N	*ICC*	*95% CI*	*BIAS*	*95%CI*	*r* (*p* value)	*t* (*p* value)	Cohen *d (rating)*
cGCp (m)	10vs4	600	0.661	0.614; 0.704	0.16	-0.11; -0.43	0.963 (<0.01)	-41.67 (<0.01)	-1.7, *large*
	10vs2	600	0.247	0.17; 0.32	-0.44	-0.3; -1-18	0.649 (<0.01)	-38.758 (<0.01)	-1.58, *large*
	10vs1	600	0.133	0.053; 0.21	-0.96	-0.66; -2.58	0.692 (<0.01)	-39.642 (<0.01)	-1.62, *large*
	4vs2	600	0.56	0.502; 0.612	-0.27	-0.18; -0.73	0.702 (<0.01)	-28.77 (<0.01)	-1.17, *moderate*
	4vs1	600	0.343	0.270; 0.412	-0.8	-0.55; -2.15	0.746 (<0.01)	-36.838 (<0.01)	-1.5, *large*
	2vs1	600	0.374	0.303; 0.441	-0.53	-0.37; -1.43	0.473 (<0.01)	-23.025 (<0.01)	-0.93, *moderate*
cGCp (m)	10vs4	600	0.489	0.149; 0.726	-0.07	-0.21; 0.067	0.491 (<0.01)	-4.125 (<0.01)	-0.78, *moderate*
	10vs2	600	0.184	-0.197; 0.52	-0.03	-0.09; 0.03	0.185 (0.346)	-1. 033 (0.311)	-0.19, *trivial*
	10vs1	600	0.46	0.112; 0.71	-0.06	-0.178; 0.06	0.462 (0.013)	-3.271 (<0.01)	-0.62, *moderate*
	4vs2	600	0.023	-0.35; 0.39	0.04	-0.04; 0.12	0.024 (0.905)	1.825 (0.079)	0.34, *small*
	4vs1	600	0.328	-0.04; 0.62	0.08	-0.08; 0.24	0.333 (0.084)	0.395 (0.696)	0.02, *trivial*
	2vs1	600	0.073	-0.302; 0.43	-0.04	-0.12; 0.04	0.073 (0.71)	-1.435 (0.163)	-0.28, *small*
Total Area (m^2)	10vs4	600	0.999	0.998; 0.999	0.08	0.06; 0.22	0.999 (<0.01)	0.302 (0.762)	0.01, *trivial*
	10vs2	600	0.955	0.947; 0.961	0.02	0.01; 0.05	0.955 (<0.01)	0.012 (0.99)	0, *trivial*
	10vs1	600	0.992	0.99; 0.993	-0.04	-0.03; -0.1	0.992 (<0.01)	-0.069 (0.945)	0, *trivial*
	4vs2	600	0.965	0.96; 0.971	-0.06	-0.04; -0.16	0.965 (<0.01)	-0.045 (0.964)	0, *trivial*
	4vs1	600	0.99	0.988; 0.992	-0.12	-0.08; -0.32	0.99 (<0.01)	-0.173 (0.862)	-0.01, *trivial*
	2vs1	600	0.94	0.93; 0.949	-0.06	-0.04; -0.16	0.94 (<0.01)	-0.037 (0.971)	0, *trivial*

cGCp = change in the geometrical centre position; Mean-DbP = mean distance between players

Discussion

Preliminar study (study 1)

To our knowledge, no study has assessed the influence of the amount of data samples on the measurement of tactical positioning variables using GIS in team sports. For this reason, the aim of the present study was to assess how the amount of data samples (i.e. 10, 4, 2 and 1 data samples per second) affected the outcomes of the CCP and TA during tactical analysis in sports. We found significant and large differences between the values of CCP measured at different amount of data. However, we did not find significant and substantial differences between TA values measured at different amounts of data during three controlled tasks. These results suggested that the amount of data could indeed affect the outcomes of tactical positioning variables, requiring different amounts of data for each variable.

Significant and large differences, from 0.07 to 0.79 ICC values and 0.49 to 0.99 association values, respectively, were found between the CCP values measured at different amount of data per second (i.e. 10, 4, 2 and 1 data samples) during the three controlled tasks. This suggested that the CCP values in the three controlled tasks depended on the amount of inserted data. Furthermore, using GIS at low frequencies (i.e. low amount of data per second) obscured relevant data. As for TA, team sports studies have used a sampling frequency for software-derived data that ranged from 0.4 to 30 Hz (Clemente et al., 2013; Frencken et al., 2011; Frencken, 2009; Palucci Vieira et al., 2018; Yue et al., 2008) to measure the centroid. However, there is not reported the use of GIS. Thus, further studies explore even higher amounts of inserted data per second to determine the optimal parameters to measure the centroid in the assessment of team sports behaviour using GIS.

On the contrary, we found only trivial differences between TA values that were measured at different amounts of data samples (i.e. 10, 4, 2 and 1 data samples per second) during the three controlled tasks (Table 2). The high to perfect ICC values and linear association suggested that the addition of just one data sample per second is sufficient to accurately measure TA in these types of tasks. The structural traits and training tasks of each team sport considerably affect the values of TA (Clemente et al., 2013; Frencken et al., 2011; Timmerman et al., 2017) and the magnitude of the data could affect the outcomes of the tactical variables. Therefore, in further studies, the impact of the frequencies used in GIS on TA values should be expanded to several team sports and training drills. If the results of these future studies were similar, less data would be helpful in the practical setting where a rapid evaluation of training/competition loads is necessary to assess performance and inform exercise prescription (Malone et al., 2017).

Positional data for collective analyses has become an important topic in team sport analysis (Low et al., 2020; Rico-González et al., 2020). In this way, GIS offers wide opportunities for these analyses, and has been gaining more attention and is increasingly being used in sport research (Bastida-Castillo, Gómez-Carmona, De la Cruz-Sánchez, et al., 2019). However, there is a lack of emphasis on the limitations of GIS and how they should be addressed. Usually, although do not indicate if they use GIS, researchers apply the same sampling frequency to measure all tactical variables in their studies (Rico-González et al., 2019). Based on our results, we recommend that researchers and technical staffs should indicate if they inserted data or how they have avoided the limitation of GIS applications. Moreover, they should not consider the same amount of data per second to assess all tactical variables. This can result in a loss of relevant data for some tactical variables (e.g. CCP in this study) but, simultaneously, a superfluous amount of data to measure others (e.g. TA). In case of CCP, one would lose relevant data and in the TA case, the excessive data could delay the analysis of the report resulting in difficultly to respond to a complex calendar, which requires rapid performance analysis (Malone et al., 2017).

Soccer match (study 2)

In the preliminary study, we found that the amount of inserted data per time period (10, 4, 2 and 1 inserted data samples per second) does not affect the measurement of *TA* but does affect the change in *GC* position (*cGCp*) measurement during three controlled tasks. These results suggested that the use of different amounts of inserted data per second may differentially affect the measurement of *total area* (*TA*) and the *cGCp* in team sports. However, these studies did not assess the impact of the amount of inserted data per second in specific team sports tasks and only with node and area geometric primitives (Ibáñez & Hoehne, 2010). Therefore, the aim of the present study was to assess how the amount of inserted data per second affects the measurement of the several types of team behaviour variables (i.e., point: *cGCp*; line: inter-player distance; polygon: *TA*) during soccer match as an example of team sports. The main findings were that the amount of data samples per second affected the outcomes of the *cGCp* and the *mean-DbP* but did not affect the outcome of the *TA*. These results demonstrated the value of studying how different amounts of inserted data samples per second to measure affected each tactical variable (i.e. *cGGp*, *mean-DbP*, *TA*) during soccer training. Specifically, it seems that a higher amount of data sample per second, at least 10 data samples per second, is necessary for the accurate measurement of the *cGCp* and the *mean-DbP*, but a lower amount of data sample per second, 1 data samples per second, is enough for the *TA*.

Several studies have assessed the accuracy of the EPTS to measure derivate variables of velocity as acceleration or deceleration, suggesting that the low sampling frequencies will be not enough to measure these external training load parameters (Scott et al., 2015; Winter, 2009). However, few studies have analysed the impact of the software-derived data frequencies (Duarte et al., 2010) or the amount of data samples per second on the outcomes of positional data (preliminar study). In the preliminary study, we found that the amount of inserted data differentially affected the outcomes of the *cGCp* and *TA* in three controlled tasks. Thus, we suggested the use of different amounts of inserted data per second to measure these two types of tactical variables (i.e. *point* and *polygon*) in team sports. However, this study did not carry out during a soccer specific training task (i.e. Long-Sided Game [LSGs]) and did not consider a tactical variable of the geometric primitive *line*. In a similar way as in the preliminary study, we found that the impact of the amount of inserted data is unique to each tactical variable. Specifically, the amount of data samples per second (i.e. 10, 4, 2 and 1 inserted data samples per second) affected the outcomes of the *cGCp* and the *mean-DbP* (i.e. dyads), but did not affect the outcome of the *TA* (i.e. area).

The sampling frequency used to measure *cGCp* in team sports varies considerably between studies (Bueno et al., 2018; Clemente et al., 2013; Moura et al., 2011). To our knowledge, no previous study has assessed the impact of the amount of inserted data samples per second on the values of *cGCp* during team sport tasks and matches using GIS. A previous study found significant and substantial (ES = large) differences between the *cGCp* values measured at different amount of data samples per second (i.e. 10, 4, 2 and 1 data samples per second) during three controlled tasks. Similarly, we found significant and substantial (ES = moderate-large) differences during

GK+7 vs 7+GK soccer match for both teams (Tables 13 and 14), suggesting the beneficial use of a high amount of data samples per second to measure *cGCp* in LSGs. Until further studies assess of the impact of more than 10 inserted data samples per second, we suggest the use of at least 10 data samples to measure the *cGCp* in soccer training.

As for *cGCp*, there is a lack of consensus on what software-derived data should be used to measure the distance between dyads (Coutinho et al., 2017; Duarte, Araújo, Freire, et al., 2012; Duarte et al., 2010; Folgado, Duarte, et al., 2014b; Olthof et al., 2018; Ric et al., 2016; Vilar et al., 2014) an the *TA* (Bueno et al., 2018; Clemente et al., 2013; Moura et al., 2011; Palucci Vieira et al., 2018). In addition, no previous study has assessed the impact of the amount of inserted data samples per second on the values of these tactical variables during team sport tasks and matches. To our knowledge, for the first time, our study has assessed the impact of the amount of inserted data per second on distance values. Taking together the results of the two teams, several significant and substantial (ES = small-moderate) differences were found in *mean-DbP* values between "10 data samples per second" and the rest (i.e. 4 and 1 data samples per second). These results suggest the use of at least 10 data samples per second to measure the *mean-DbP* in soccer training. Interestingly, these differences were more and higher (ES = moderate) in the Team B than in Team A. The magnitude of the average (18.45 vs 19.19 m) and *ds* (5.62 vs 6.6) values of the *mean-DbP* in the Team B in comparison to Team A could explain the differences between both teams. Thus, further studies should assess the impact of the amount of inserted data per second in other types of dyads and in team sports in which the magnitude of the distance varies considerably (Bartlett, Button, Robins, Dutt-Mazumder, & Kennedy, 2012; Clemente, Couceiro, Martins, & Mendes, 2013; Silva, Vilar, Davids, Araújo, & Garganta, 2016; Yue et al., 2008).

A previous study showed no significant and trivial differences between the *TA* values using different amount of inserted data per second (i.e. 10, 4, 2 and 1 data samples) during three controlled tasks. Similar to that study, we did not find significant and substantial (ES = trivial) differences between *TA* values recorded at from 10 to 1 data samples per second during a 7+GK vs 7+GK soccer match. Thus, our study suggests that 1 data sample per second is sufficient to measure *TA* in soccer training, allowing sports scientist to get accurate information about this team behaviour variable with less amounts of data.

Conclusions, limitations and future lines of research

The use of different amounts of inserted data per time period determined the outcomes of the collective tactical behaviours: the amount of inserted data affected the outcomes of the *cGCp* and *mean-DbP*, but did not affect the *TA*. Thus, we recommend the use of different amounts of inserted data per time period to measure the collective tactical behaviours in team sports. Specifically, we recommend the use of at least 10 inserted data samples per time period to measure the *cGCp* (i.e. *point*) and the *mean-DbP* (i.e. *line*, dyad), but we suggested that the insertion of more than one data per time period did not provide more precision in measure the *TA* (i.e. *polygon*) during soccer training.

Since the magnitude of the values of each collective tactical behavior variable (i.e., GC, dyad, area) can vary depending on the characteristics of each sport, the training tasks and the competitive level of the players, the impact of the insertion of data per second should be assessed in other sports, other training tasks and with players of different competitive levels.

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Appendix

Table 15. Quality criteria standard check sheet for assessing collective variables using radio-frequency technologies in sports

Quality Index Item Number	Criteria			
GC	*General criteria*			
GC1	Was the process to avoid technology lock explained?	Yes = 1	No = 0	
GC2	Was the data download moment mentioned?	Yes = 1	No = 0	
	Reliability and validity			
GC3	Was the brand/model mentioned?	Yes = 1	No = 0	
GC4	Were the variability and reliability of the model cited? (Multi-player vs single player)	Yes = 1	No = 0	
GC5	Was the model assessed for variability or reliability according to the variables used?	Yes = 1	No = 0	
GC6	How was the validation test performed?	Continuous situations = 2	No continuous situations = 1	Not cited = 0
GC7	Were data exclusion criteria mentioned?	Yes = 1	No = 0	
	Sampling frequency			
GC8	Was the raw data justified?	Yes = 2	No = 1	No appearance = 0
GC9	Was the software-derived data justified?	Yes = 2	No = 1	No appearance = 0
GC10	Was a data reduction method mentioned?	Yes = 1	No = 0	
GC11	Were different Hz values used for each variable reported?	Yes = 1	No = 0	
GC12	Was it mentioned whether the participants wore tight-fitting garments?	Yes = 1	No = 0	
GC13	Was it mentioned whether the participants wore the same garment?	Yes = 1	No = 0	
	Collective variables			
GC14	Was the time synchronization method explained (only for collective measures (i.e. tactical variables))?	Yes = 1	No = 0	

Table 16. Quality criteria standard check sheet for assessing collective variables using GPS/GNSS in sports

Quality Index Item Number	Criteria		
GPS1	Was the satellite number mentioned?	Yes = 1	No = 0
GPS2	Were the HDOP values mentioned?	Yes = 1	No = 0
GPS3	Were weather conditions reported?	Yes = 1	No = 0
GPS4	Was the infrastructure around the field described?	Yes = 1	No = 0

- Total score/ out of 21
- Percentage score/ %

Table 17. Quality criteria standard check sheet for assessing collective variables using LPS in sports

Quality Index Item Number	Criteria		
LPS1	Was the technology mentioned (e.g. UWB, ultrasounds)?	Yes = 1	No = 0
LPS2	Was the temperature reported?	Yes = 1	No = 0
LPS3	Were humidity gradients reported?	Yes = 1	No = 0
LPS4	Was it mentioned whether there was slow air during the sessions?	Yes = 1	No = 0
LPS5	Was it mentioned whether there were any metallic materials around the antennas?	Yes = 1	No = 0
LPS6	Was the installation shape explained?	Yes = 1	No = 0
LPS7	Was the installation height reported?	Yes = 1	No = 0
LPS8	Was the measurement method reported?	Yes = 1	No = 0
• Total score/ out of 25			
• Percentage score/ %			