Universitat de Lleida

Estudio longitudinal de la carga externa en partidos de fútbol profesional de 1ª y 2ª división española durante 4 temporadas, para la optimización del rendimiento condiconal del jugador

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TESI DOCTORAL

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Memoria presentada para optar al título de Doctor por la Universidad de Lleida
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RESUM

Una de les majors preocupacions per a gran part de la comunitat científica de l'entrenament del futbol, és conèixer i controlar la càrrega externa. És a dir, saber quants quilòmetres, metres, velocitats, esprints, acceleracions, desacceleracions, etc. realitza el futbolista durant l'entrenament i la competició. Es diu que el futbol és molt diferent del futbol de fa 10-15 anys. Una de les diferències més comentades és que totes les accions del joc es realitzen de manera més freqüent i amb més intensitat. Aclarir aquesta afirmació és un dels motius que ens ha motivat a desenvolupar aquesta tesi: analitzar l'evolució de la càrrega externa. Valorar des d'una perspectiva longitudinal, la possible evolució de la càrrega externa i alhora aportar coneixements actuals a tots els tècnics dels equips de futbol. Per aquest motiu, hem realitzat un estudi de la competició oficial espanyola de futbol durant 4 temporades (2015/16-2018/19) amb tots els equips de la 1a divisió de la Lliga Santander (LL1) i 2a divisió de la Lliga Smartbank (LL2). Hem analitzat la càrrega externa utilitzant les variables locomotores, que segons (Fernández et al., 2016) cobreixen totes les dades de desplaçaments realitzats pel jugador com: la distància total, distàncies entre 14-21 km/h, 21-24 km/h i distàncies superiors a 24 km/h. El nombre d'esprints entre 21 i 24 km/h i a més de 24 km/h entre d'altres.
Al mateix temps, ens va interessar examinar les possibles diferències entre les dues categories (1a i 2a Divisió) i les diferències entre cadascuna de les parts de 45 minuts. Aquest estudi s'ha realitzat utilitzant la tecnologia video-tracking System (VTS) a través d'un sistema de seguiment multicàmera anomenat Mediacoach. Hem analitzat també la correlació entre els sistemes, actualment utilitzats en el futbol professional, pel control de càrrega externa. Ens referim al VTS de Mediacoach, que s'utilitza durant els partits i el sistema de Geolocalització de Posicionament Global (GPS), d'ús més comú en les sessions d'entrenament. Aquest estudi de correlació s'ha realitzat mitjançant la comparació de variables locomotores i mecàniques. Aquest grup de variables mecàniques inclou segons Fernández et al., (2016), les acceleracions i les desacceleracions realitzades pel jugador en diferents rangs de velocitat. Aquesta recerca comparativa i de correlació s'ha dut a terme amb dades de partits oficials perquè les dades d'ambdós sistemes es poguessin interrelacionar. La pretensió final d'aquesta tesi és donar a conèixer els fonaments i les principals característiques de la metodologia l'Entrenament Optimitzador (EO). A partir dels resultats dels diferents estudis presentats s'ha objectivat una disminució de la distància total i un augment de les distàncies d'alta intensitat i el nombre d'esprints realitzats; encara que es percep una tendència més clara en la LL1. Al mateix temps afirmem que tots dos sistemes VTS i GPS es poden utilitzar per analitzar la càrrega externa dels jugadors en el futbol professional. La informació es pot compartir amb els beneficis que això comporta per a professionals i investigadors a l'hora de controlar la càrrega externa.
Incorporar els resultats d'aquestes investigacions permetrà una intervenció més precisa en tots els àmbits del futbol: entrenament, recuperació, nutrició, prevenció de lesions.

Paraules clau: Futbol, Longitudinal, Càrrega Externa, GPS, VTS, Entrenament Optimitzador.

RESUMEN

Una de las mayores inquietudes para gran parte de la comunidad científica del entrenamiento en el fútbol es conocer y controlar la carga externa. Es decir, saber cuántos kilómetros, metros, velocidades, esprintes, aceleraciones, desaceleraciones, etc. realiza el jugador de fútbol durante los entrenamientos y la competición. Además, en la actualidad, se afirma que el fútbol es muy diferente al de hace 10-15 años. Una de las diferencias más mencionadas es que todas las acciones del juego se realizan de manera más frecuente y a mayor intensidad. Esclarecer dicha afirmación es una de las razones que nos ha motivado a desarrollar esta tesis: analizar la evolución de la carga externa. Valorar, desde una perspectiva longitudinal, la posible evolución de la carga externa y a su vez aportar conocimiento actual a todos los técnicos de los equipos de fútbol. Por este motivo, hemos llevado a cabo un estudio de la competición oficial de futbol española durante 4 temporadas (2015/16-2018/19) con todos los equipos de la 1ª división de la Liga Santander (LL1) y 2ª división de la Liga Smartbank (LL2). Hemos analizado la carga externa mediante las variables locomotoras que, según Fernández et al.,(2016), abarcan todos los datos de desplazamientos que realiza el jugador como: la distancia total, distancias entre 14-21 km/h, 21-24 km/h y distancias superiores a 24 km/h. El número de esprintes entre 21 y 24 km/h y superiores a 24 km/h entre otros. Al mismo tiempo se ha examinado la existencia de posibles diferencias entre las dos categorías (1ª y 2ª División) y la variación entre cada una de las partes de 45 minutos. Este estudio ha sido realizado utilizando la tecnología Vídeo Tracking System (VTS) a través de un sistema de seguimiento de multicámaras llamado Mediacoach. Hemos analizado también la correlación entre los sistemas empleados actualmente en el fútbol profesional, para el control de la carga externa. Nos referimos al sistema de VTS de Mediacoach, que se utiliza durante los partidos y el sistema de Geolocalización Global Position System (GPS), de uso más común durante las sesiones de entrenamiento. Este estudio de correlación se realizó comparando las variables locomotoras y mecánicas. Este último grupo de variables abarca según Fernández et al., (2016) las aceleraciones y desaceleraciones que realiza el jugador en sus diferentes rangos de velocidad. Esta investigación comparativa y de correlación se ha desarrollado con datos de partidos oficiales, con el fin de que los datos de ambos sistemas se pudiesen interrelacionar. La pretensión final de esta tesis es dar a conocer los fundamentos y características principales de la metodología del Entrenamiento Optimizador (EO). A partir de los resultados de los diferentes estudios presentados se ha podido demostrar una disminución en la distancia total y un aumento en las distancias de alta intensidad y en el número de esprintes realizados, aunque se percibe una tendencia más clara en la LL1. Afirmamos también que ambos sistemas VTS y GPS se pueden utilizar para analizar la carga externa de los jugadores en el fútbol profesional y compartir la información. Con los beneficios que conlleva, para profesionales e investigadores, en el momento de controlar la carga externa. Incorporar los resultados de estas investigaciones permitirá tener una intervención más precisa en todos los ámbitos del fútbol: entrenamiento, recuperación, nutrición, prevención de lesiones.

Palabras clave: Fútbol, Longitudinal, Carga externa, GPS, VTS, Entrenamiento Optimizador.

ABSTRACT

One of the biggest concerns for the large part of the scientific community of football training is knowing and controlling the external load, that is, knowing how many kilometers, meters, speeds, sprints, accelerations, slowdowns, etc. performs the football player during training and competition. In addition, football is said to be very different from football 10-15 years ago. One of the most mentioned differences is that all the actions of the game are performed at greater intensity and are more frequent. Under this concern and concern one of the reasons that has motivated us to develop this thesis, is to analyze whether the external load, from a longitudinal perspective, is changing or not and being able to bring current knowledge to all the technical bodies of football teams. For this reason, the fundamental objective of this thesis has been to carry out a study of the competition for 4 seasons (2015/16-2018/19) with all teams of the 1st Division of the Santander (LL1) League and 2nd Division of the Smartbank (LL2) League of Spanish football. Analyzing the external load using the locomotive variables, which according to (Fernández et al., 2016) covers all the travel data made by the player such as: the total distance, distances between 14-21 km/h, 21-24 km/h and distances greater than 24 km/h, the number of sprints between 21 and 24 km/h and greater than 24 km/h among others. At the same time, it was in the interest of examining the possible differences between the two categories (1st and 2nd Division) and the variation between each of the 45-minute parts. This study has been conducted using Video Tracking System (VTS) technology through a multi-camera tracking system called Mediacoach. A second and third objective was to analyze the correlation between the systems currently used in professional football, for external load control, we refer to the Mediacoach (VTS), which is used during matches and the Global Position System (GPS) geolocation system, is more common to use in training sessions. This correlation study was carried out through the comparison of locomotive and mechanical variables, this last group of variables covers according to(Fernández et al., 2016), accelerations, slowdowns performed by the player in their different speed ranges. This comparative and correlation research has been carried out with data from official parties so that data from both systems can be interrelated. As the ultimate objective of this thesis is to publicize the fundamentals and main characteristics of the Optimizer Training (EO) methodology. From the results of the different studies presented it can be concluded that longitudinally it has been possible to demonstrate a decrease in the total distance and an increase in the distances of high intensity and the number of sprints performed, although a clearer trend is perceived in the (LL1). At the same time as both systems VTS and GPS can be used to analyze the external load of players in professional football and information can be shared with the benefits involved for professionals and researchers when controlling external loading.
Incorporating the results of these research will allow for more accurate intervention in all areas around football: training, recovery, nutrition, injury prevention.

Keywords: Football, Longitudinal, External Charging, GPS, VTS, Optimized Training.

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ACC: Aceleraciones

FCB: Futbol Club Barcelona

CV: Coeficiente de variación

CE: Cualidades específicas

DEC: Desaceleraciones

EE: Entrenamiento Estructurado

EO: Entrenamiento Optimizador

EPTS: Electronic Performance and Tracking Systems

FIFA: Federation International of Football Association

GPS: Global Positioning System

GNSS: Global Navigation Satellite System

HIRD: High Intensity Running Distance. Distancia entre 14-21km/h.

HDR: High Dynamic Range

Hz: Frecuencia de muestreo

ICC: Intraclass Correlation Coefficient

Km/h: Kilómetros por hora.

LPS: Local Positioning System

LL1: La Liga 1ª división, Liga Santander LL1

LL2: La Liga 2ª división, Liga Smartbank

SHD: Ser humano deportista

SpD: Sprinting Distance. Distancia a más de 24km/h.

SpVHIR : Number of Very High Intensity Running Sprints.
Número de esprintes entre 21 y 24 km/h.

SP: Número de esprintes a más de 24km/h

SHD: Ser humano deportista

SSP: Situaciones Simuladoras Preferenciales

SWC: Smallest Worth White Change

TD: Distancia Total Recorrida

TEE: Typical Error of Estimate

VICOM: Sistema de Captura de Movimientos Ópticos

VID: Video Technology

VTS: Video Tracking Systems

VHIRD: Very High Intensity Runnig Distance. Distancia recorrida entre 21 i 24 km/h

VAR: Video arbitraje

1. INTRODUCCIÓN

Desde una perspectiva evolutiva, los seres humanos coexisten en una sociedad que está en continua transformación. Nosotros, como parte de esta sociedad, nos adaptamos a ella todos los días.

El futbol de élite ha experimentado transformaciones a lo largo de su historia. Desde modificaciones reglamentarias, mejorías de los terrenos de juego, cambios metodológicos de entrenamiento, sistemas de juego cada vez más exigentes, implementación de la tecnología, … Y un factor fundamental en los últimos años ha sido, y es, la dependencia de los clubes profesionales de las televisiones debido a los elevados contratos económicos que ofrecen los entes televisivos. Estos compromisos obligan a jugar los partidos en los horarios y los días que marcan las televisiones, sin respetar muchas veces las 72 horas de recuperación entre 2 partidos (Hader et al., 2019) y tampoco los periodos de planificación de las pretemporadas jugando partidos de alta exigencia con muy pocos días de preparación (Calleja-Gonzalez et al., 2020), con el consecuente riesgo que esto conlleva para el jugador.

Trasladando este concepto evolutivo social al mundo del entrenamiento y más específicamente al fútbol de élite, sucede como dicen Nassis et al., (2020) que el fútbol de élite moderno es cada vez más exigente en términos de número de partidos jugados durante la temporada. Lo que conlleva una carga física y mental adicional a los jugadores. Un equipo europeo de primer nivel jugó casi 50 partidos en la temporada 2008/2009, y este número aumentó a 60 en la temporada 2018/2019. Además, para los jugadores más destacados, debemos añadir los partidos internacionales. Lo que implica más de 70 partidos jugados por temporada. Se considera que el número de partidos jugados durante una temporada deportiva probablemente aumentará sustancialmente en el futuro (Nassis et al., 2020).

Además de este aumento en el número de partidos también debemos considerar otros factores como los mostrados en los estudios realizados en la Premier League por (Barnes et al., 2014). Presentan un estudio de variables condicionales y variables técnicas a lo largo de 7 temporadas donde se verificó, que la distancia total cubierta durante un partido fue un 2% menor en 2006-2007 en comparación con 2012-13, mientras que la distancia de carrera y las acciones de alta intensidad aumentaron un 30% y un 50%, respectivamente. O que la distancia en esprín y el número de esprines aumentaron un 35% y un 85%. A todo ello hay que añadir otro factor según el estudio de Ekstrand et al., (2016) realizado con primeros equipos a nivel europeo: el hecho de que la intensidad de las sesiones de entrenamiento ha aumentado, ya que muchos entrenadores quieren que la intensidad de la competición se refleje en los entrenamientos. Ello ha generado un aumento de la carga de trabajo en los jugadores.

Ante estos aumentos, de la intensidad de las sesiones, de los datos de alta intensidad de los partidos y del número de encuentros durante la temporada, los clubes han empezado a incrementar el número de jugadores en sus plantillas. También ha aumentado el número de jugadores presentes en el banquillo. Un claro ejemplo es la Serie A italiana donde se permiten

12 jugadores sentados en el banquillo. A todo ello hay que añadir las nuevas iniciativas organizativas promovidas en el último año por la Federation International of Football Association (FIFA), como poder hacer 5 sustituciones a lo largo del partido. Consideramos que todos estos aspectos tendrán un impacto significativo en las demandas físicas y psicológicas de los jugadores.

Todo ello conlleva a la necesidad de controlar y gestionar la carga externa condicional del jugador de una manera muy precisa con el objetivo de optimizar el rendimiento y ayudar a prevenir lesiones derivadas de tanta acumulación de partidos y a tanta intensidad.

Entendemos el concepto de carga externa en el fútbol como las exigencias físicas necesarias para practicar la actividad. Exigencias cuantificadas generalmente con parámetros de tipo físico tales como: la distancia total recorrida, la distancia recorrida a diferentes velocidades, los esprines realizados y sus intensidades, aceleraciones y desaceleraciones, etc. (Gómez-Carmona et al., 2019; Impellizzeri et al., 2019; Recuenco Serrano & Juárez Santos-García, 2015; Rojas-Inda, 2018).

En los últimos años el fútbol ha sido el deporte más estudiado, con casi 14.000 citas en Pubmed y casi un 60% más de artículos que el siguiente deporte más estudiado, como se puede ver en el estudio presentado por Kirkendall (2020). Ello ha facilitado que los preparadores físicos dispongan de información más objetiva y científica para el control de la carga externa. Y a su vez, ha permitido combinar preparación física, tecnología y ciencia.

Este escenario nos genera una inquietud, que es el objetivo fundamental de esta tesis: identificar, cuantificar, objetivar y analizar la evolución de la carga externa en la liga profesional española de futbol durante los últimos años. Para ello hemos realizado un registro, cuantificación, evaluación y análisis longitudinal de la carga externa durante 4 temporadas competitivas (2015/16-2016/17-2017/18-2018/19) con todos los equipos de la LL1 y LL2 del fútbol español. Al mismo tiempo, los datos registrados nos han permitido observar las diferencias entre categorías y posibles variaciones de rendimiento entre la primera y segunda parte de los partidos. (Pons et al., 2021). Todo ello con la finalidad de disponer de una visión actualizada de las necesidades del fútbol de élite español, que permita una toma de decisiones más científica. Al tiempo que generamos los contenidos y tareas en las sesiones de entrenamiento con más objetividad; con el fin de optimizar el rendimiento y prevenir las lesiones del jugador de fútbol.

Esta investigación de la carga externa se ha desarrollado, en gran medida, gracias a la implementación de la tecnología. Actualmente en la Liga Española el sistema de seguimiento de imágenes que está instalado en todos los campos de la 1ª y 2ª división española es el sistema Vídeo Tracking System (VTS) que registra lo que sucede durante el partido a través de un sistema de seguimiento multicámara llamado Mediacoach, de la que se extraen los datos métricos de carga externa de cada partido (Castellano & Casamichana, 2015; Valter Di Salvo et al., 2009; Owen et al., 2017) . Este sistema solo funciona durante los partidos. Mientras que la tecnología que se utiliza en las sesiones de entrenamiento, para el control de la carga externa en la mayoría de los clubes profesionales, es el sistema de geolocalización Global Position System (GPS).

Otro de los objetivos de la tesis ha sido demostrar que ambos sistemas de medición de la carga externa VTS más habitual en partidos y GPS más habitual en entrenamientos miden la carga externa con valores prácticamente idénticos. La comprobación de esta correlación entre ambos sistemas de medición se ha realizado durante partidos de competición oficial en los que se han empleado ambos sistemas a la vez. Por una parte realizando el análisis de correlación de los datos de carga externa Pons et al., (2019) que constituyen el grupo de variables locomotoras según Fernández et al., (2016). Por otra parte, hemos realizado el estudio (**en revisión**) de correlación de los 2 sistemas tecnológicos mediante el grupo de datos de carga externa, que pertenecen al grupo de variables mecánicas según la categorización de Fernández et al., (2016). Ambos estudios persiguen la pretensión de dotar de una seguridad objetiva a los cuerpos técnicos para interpretar los datos con la misma fiabilidad en ambos sistemas y permitir un análisis ecuánime de los resultados para el diseño de las sesiones de entrenamiento y el control imparcial de la carga externa de los jugadores.

Esta tesis presenta, aprovechando los resultados obtenidos en los artículos redactados, una metodología de entrenamiento: el Entrenamiento Optimizador (EO) (Pons et al., 2020) que forma parte de la trilogía que configura el Entrenamiento Estructurado (EE) (Tarragó et al., 2019) Dicha metodología de entrenamiento utilizada en el Futbol Club Barcelona ha tenido en cuenta los datos de carga externa generados por estas tecnologías a lo largo de prácticamente toda la última década.

1.1. Evolución de la preparación física en el fútbol

Existen diferentes factores a considerar en la evolución de la preparación física en el fútbol. Uno es el aumento de la exigencia condicional en el fútbol desde la década de 1960 hasta la actualidad. Otro factor es la implementación de la tecnología para el control del rendimiento de los jugadores, que ha mejorado las prestaciones de rendimiento del jugador durante la competición. Un tercer elemento es el número de licencias federativas, siendo el deporte que dispone de más licencias a nivel mundial y a su vez el deporte más estudiado, según el estudio de Kirkendall (2020). Hecho que pone a disposición de los preparadores físicos más información objetiva y científica.

Antes de los años 60 no se tenía muy en cuenta la preparación física en el futbol español (Domínguez, 2014). El progreso se inicia a partir de la década de 1960 y 1970 con la aportación de especialistas rusos como Ozolin, Matveyev, Vorobjev, Verchoshanski, etc. Es un momento de la evolución que giró en torno a la perfección y desarrollo de la técnica (Domínguez, 2014). En la década de los años 1970-1980, la preparación física está influenciada por las metodologías de entrenamiento de los países de la Europa oriental bajo la influencia de Matveyev (1978-1982), donde propone la periodización del entrenamiento con el objetivo principal de las 3 bases de entrenamiento: desarrollo (base) relacionado con el período preparatorio, conservación (lograr y estabilizar) relacionada con el período competitivo y período de pérdida. Todo este proceso se basó en la teoría del síndrome general de adaptación de Seyle en busca de la supercompensación (Bompa, 2019). La aparición del libro "*La preparación física del fútbol basado en el atletismo*" de Carlos Álvarez del Villar en 1983 marcó un antes y un después en los preparadores físicos españoles de la época. El entrenamiento condicional era priorizado con tareas como carrera continua, series de velocidad y ejercicios analíticos. Las intervenciones del preparador físico durante las sesiones sucedían de manera analítica y separada del juego.

En los años 90 hay una priorización por el trabajo táctico, mientras que van aumentando las exigencias a nivel condicional debido a la presencia de enfoques tácticos que priorizan la presión. El jugador empieza a adquirir la cultura de la importancia de la preparación física, tal vez como afirma Domínguez, (2014) es el momento de mayor evolución de la preparación física, debido al gran aumento de estudios científicos y del comienzo del estudio de la carga externa, gracias a la implementación de sistemas de análisis de movimiento (Carling et al., 2008). En los años 90 se inicia la influencia de la corriente fisiológica del norte de Europa con Jens Bangsbo al frente. Se empieza a pensar más en la intensidad vinculada con el agotamiento de glucógeno para retrasar la fatiga, se inicia el control de la frecuencia cardíaca y a extraer muestras de lactato. Se genera la necesidad de controlar tanto la carga externa como la interna. A nivel de contenidos, el entrenamiento de la fuerza comienza a estar muy presente con la aparición de técnicos de fútbol italianos y sus preparadores físicos: comienza la influencia de la escuela italiana como la de Carmelo Bosco. También influye la escuela francesa a través de Gilles Cometti con los entrenamientos pliométricos, de contrastes, todos vinculados al concepto de transferencia de la fuerza (Domínguez, 2014). A pesar de la evolución de estos años, los estímulos físicos y técnico-tácticos siguen funcionando por separado, pero el aumento de los estudios de carga interna y externa hace que las tareas planteadas se acerquen más a las necesidades de competición (Domínguez, 2014). Durante los años 90, surgieron los modelos de planificación contemporánea con Verkhosansky al frente, con el modelo de planificación de bloques y más tarde el modelo A.T.R (Acumulación, Transformación, Realización) siendo un tipo de planificación aun vigente en el fútbol español.

En esta evolución de la preparación física del fútbol tiene una contribución clave Tudor Bompa en 1994, quien propone un modelo de periodización para los deportes de equipo con un objetivo crucial en la planificación: mantener el nivel de alta forma competitiva durante los meses de la competición. Se empieza a realizar estudios de carga externa con tareas en las que se incluye la pelota, ya que poco a poco se está estableciendo la metodología de un entrenamiento integrado que incluye el trabajo técnico, táctico y condicional con aspectos específicos del juego. Es necesario hacer una mención especial a la contribución de Paco Seirul·lo (Seirul·lo, 1993; Seirul·lo Vargas, 1998). Quien pone en práctica el entrenamiento integrado, del que surge la metodología de entrenamiento específico para los deportes colectivos. Se considera que el jugador está configurado por diferentes estructuras: bioenergética, condicional, cognitiva, emotivo-volitiva, coordinativa, expresivo-creativa y mental (Tarragó et al., 2019). Y, el jugador, es el más importante dentro del proceso de entrenamiento con diferentes niveles de aproximación: general, dirigido, especial y competitivo. Y con cualidades físicas específicas a desarrollar: desplazamiento, lucha, salto y acciones con el balón (Pons et al., 2020; Seirul·lo Vargas, 1998). Todas estas cualidades tienen una relación directa con la cualidad física de la fuerza, al mismo tiempo influenciadas por las aportaciones de Verkhosansky y Bondarchuck, quienes proponen la concentración de la carga a través de la microestructura semanal que ha evolucionado hasta el día de hoy con el microciclo estructurado (Martín-García et al., 2018; Seirul·lo Vargas, 1998). Esta metodología de entrenamiento está vinculada a la corriente sistémica desde una perspectiva de la teoría de los sistemas complejos. En esta corriente de entrenamiento hay aportaciones de Balagué et al. (2014) entre otros, donde se deja de ver el entrenamiento de forma lineal e incorpora una visión mas holística desde la complejidad del juego.

Hay un punto de inflexión sin lugar a duda en esta evolución de la preparación física en el fútbol, sucede en la década de los años 90 al año 2000, como dice (Domínguez, 2014). Es la aparición de los sistemas de "*Time Motion Analysis*" con las compañías Amisco y Prozone. Sistemas de registros mediante cámaras instaladas en los estadios, que generan información sobre los datos de carga externa de la competición, que hasta ahora no se habían podido obtener de manera tan detallada y además de todo el equipo, con poco tiempo de espera tras la competición. Esta información se utiliza en todas las metodologías de entrenamiento, lo cual permite una preparación física mucho más específica ante las necesidades de la competición. Esta tecnología ha permitido investigar en el fútbol, en las últimas dos décadas, de una manera significativa. Todo ello ha generado la publicación de artículos científicos, que hablan de la evolución de las manifestaciones de carga externa en la competición Lago Peñas, (2014), o presentan un estudio evolutivo realizado en la Premier League por Barnes et al., (2014), donde se estudian las variables condicionales y variables técnicas a lo largo de 7 temporadas y se verifica que la distancia total cubierta durante un partido fue un 2% menor en 2006-2007 en comparación con 2012-13. Mientras que la distancia de carrera y las acciones de alta intensidad aumentaron en un 30% y un 50% respectivamente; o que la distancia en esprín y el número de esprines aumentaron en un 35% y un 85%. Aprovechando el estudio de Barnes et al., (2014), Bradley et al., (2016) analizan las variables condicionales anteriores dependiendo de las posiciones ocupadas por los equipos en la tabla de clasificación. Estas aportaciones permiten desarrollar una preparación física más próxima a las necesidades de los equipos y particularmente a las del jugador de fútbol.

En esta evolución del entrenamiento de preparación física dentro del fútbol español hay que tener en cuenta que a principios de la década del 2000 surge la corriente de la periodización táctica, generada por el profesor de la facultad de Deporte de Oporto, Víctor Frade, en 1980. Esta influencia a nivel de entrenamiento en España es más significativa a principios del año 2000 (Domínguez, 2014).

Nassis y colaboradores (2020) destacan que en el fútbol de élite cada vez se disputan más partidos. Por lo tanto, los futbolistas jugarán más partidos por temporada, con mayores intensidades, con períodos más frecuentes y densos de esfuerzos de alta intensidad. En un futuro no muy lejano esto generará un aumento fisiológico y psicológico adicional. Lo que requerirá por parte de todos los preparadores físicos mayor precisión en la planificación y el diseño de sesiones y ejercicios de carácter físico. Con el objetivo de que el jugador rinda al más alto nivel durante todo el periodo de competición y se pueda prevenir la aparición de lesiones.

1.2. Implementación de la tecnología en el fútbol

La necesidad de cuantificar aspectos de la competición para mejorar la planificación del entrenamiento ha sido el objetivo de los científicos deportivos y entrenadores durante muchos años. Recientemente, ha habido un aumento en el interés científico debido a los avances tecnológicos y a las mejoras para cuantificar las actividades del entrenamiento. (M Cardinale & Varley, 2017).

La recogida de información, a través de la monitorización, puede ayudarnos a entender los cambios en el rendimiento de los jugadores y determinar aquellos que están preparados para afrontar las demandas de la competición, aunque la interpretación de los datos pueda resultar compleja (Tapia López, 2017).

Ante una retrospectiva histórica constatamos que en los inicios de la observación e investigación de lo que sucedía durante los partidos, los métodos tradicionales de análisis del movimiento eran muy exigentes en mano de obra, ya que los registros se hacían a mano y se limitaban en gran medida a proyectos de investigación universitarios (Carling et al., 2008). En aquella época, el uso de estos métodos generó observaciones científicas esenciales. Pero la complejidad y el tiempo necesario para codificar, analizar e interpretar los datos constituían barreras para su uso por parte de los analistas de rendimiento. Además, las técnicas originales tenían otra limitación debido a que se limitaban a un solo jugador.

En relación con el estudio de Carling et al., (2008), observamos que el principal avance tecnológico significativo en estudios posteriores fue el uso de cámaras de mejor calidad y métodos de codificación más avanzados, como resultado de los programas informáticos más modernos. En este punto podemos destacar el avance de Bloomfield, que utilizó la instalación 'PlayerCam' (Sky Sports Interactive Service, British Sky Broadcasting Group, Reino Unido) para proporcionar imágenes de vídeo de primer plano de alta calidad centradas en los movimientos y acciones de un solo jugador (Carling et al., 2008). Después se da un paso más con el sistema de observación versión 5.1 (Noldus Information Technology, Países Bajos), con el análisis del movimiento del tiempo computarizado. Estos métodos basados en vídeo utilizados para medir manualmente las acciones de trabajo mostraron cierta fiabilidad. Sin embargo, la falta de objetividad y validez podía surgir debido a errores humanos al introducir datos inexactos (Reilly, 1976). Además, la codificación manual y la determinación de los requisitos condicionales en los estudios de la "*Premier League*" inglesa fueron extremadamente largos y lentos. Se llegó a la conclusión de que esta información no era del todo útil, ya que la densidad competitiva estaba empezando a ser elevada para los clubes, los cuales querían que la información estuviera disponible dentro de las 24 a 36 horas tras el partido (Carling et al., 2008). Otros enfoques contemporáneos se basan esencialmente en un método original diseñado por (Ohashi et al., 1987) que utilizó el cálculo de la posición y la velocidad de los jugadores utilizando técnicas trigonométricas, pero todavía tenía el problema de que sólo podía analizar a un jugador. Un nuevo avance tecnológico en este campo fue el desarrollo del sistema "*Trakperformance*" (Sportstec, Warriewood, NSW, Australia), pero también se limitaba a rastrear a un jugador; aunque esta tecnología empezó a permitir los seguimientos en tiempo real.

Los progresos continuaron y los avances tecnológicos incluyeron la introducción de sistemas de análisis de movimiento cada vez más sofisticados que ahora se utilizan en el fútbol de élite. Estos sistemas permiten completar el análisis simultáneo de todos los jugadores en un período relativamente corto y proporcionar un valioso conjunto de datos que informan a los cuerpos técnicos y puede influir en el diseño de las sesiones diarias (Carling et al., 2008). La implementación de los sistemas informáticos potenció avances que ofrecían una mayor amplitud de análisis, con procedimientos matemáticos para el monitoreo automático. Lo que supuso un salto importante en comparación con métodos más tradicionales que requerían mucha mano de obra.

En 1995 surge un nuevo punto de inflexión para el control de la carga externa en los jugadores de fútbol con la aparición de *AMISCO Pro* desarrollado por *Sport-Universal Process* en colaboración con la Federación Francesa de Fútbol. Se trata del primer sistema que logra el análisis simultáneo de la velocidad de desplazamiento de todos los jugadores de un equipo durante todo el partido (Carling et al., 2006; Valter Di Salvo et al., 2007). Tres años más tarde, en 1998, aparece *Prozone* otro sistema de seguimiento que fue creado en Leeds (Reino Unido). Son dos sistemas de seguimiento de vídeo basados en tecnología informática y permiten el seguimiento de todos los jugadores al mismo tiempo. Ambos sistemas requieren la instalación permanente de varias cámaras en los estadios, fijadas en posiciones calculadas de forma óptima, para cubrir toda la superficie del terreno de juego.

A medida que todo evoluciona, la tecnología aplicada al fútbol no es una excepción. A principios de la década del 2000, los sistemas de seguimiento automático basados en vídeo como DatatraX y el sistema de seguimiento de imágenes TRACAB comenzaron a salir al mercado. Generaron técnicas mejoradas para el procesamiento de imágenes de vídeo y el uso de algoritmos matemáticos diseñados originalmente para rastrear objetos guiados, proceso derivado de la industria militar, los cuales ofrecen el análisis en tiempo real (Carling et al., 2008). Actualmente, en el 2021, el mundo de los sistemas de seguimiento de imágenes permite a cualquier club tener acceso a los datos a través de numerosos proveedores como son: *Opta - Estadísticas*, *INSTAT*, *StatsBomb*, *Tracab-Chyronhego*, entre otros. Por lo tanto, es un gran avance para toda la comunidad científica del fútbol.

La principal ventaja de estos sistemas es que proporcionan a los entrenadores un alto nivel de detalles disponibles al instante sobre el rendimiento del partido, en aspectos físicos, tácticos y técnicos que permiten tomar decisiones durante el partido que pueden influir en el resultado final (Barnes et al., 2014; Valter Di Salvo et al., 2009). Otra gran ventaja que tienen estos sistemas es que los jugadores no necesitan llevar ningún dispositivo de transmisión electrónica para ser valorado. Si bien, su principal desventaja, reside en los altos costes y la necesidad de instalar varias cámaras en los estadios de fútbol y una red informatizada con al menos un operador dedicado a organizar la recogida de datos y otros operadores para llevar a cabo el análisis. Hoy en día, en la Liga Española el sistema de seguimiento de imágenes esta instalado en todos los campos de la 1ª y 2ª división española con el sistema TRACAB, realizando el análisis de datos por parte del operador Mediacoach.

Otro paso de gigante en la implementación de la tecnología en el control del rendimiento del jugador aparece en el año 2000, cuando aparece gracias a la compañía australiana *Catapult Sports*, un prototipo experimental (Carling et al., 2008) que funciona mediante el sistema de geolocalización vía satélite, son los conocidos dispositivos GPS. Actualmente es una tecnología ampliamente utilizada en todos los equipos de fútbol de élite, para el control de la carga externa e interna. El sistema de posición global GPS con sistema global de navegación por satélite GNSS, son dispositivos que los jugadores llevan dentro de un peto, ajustado al cuerpo para que la información reportada sea lo más precisa posible. Esta tecnología ha evolucionado de forma muy rápida. Se emplea para el control de los esfuerzos realizados por el jugador, habitualmente en las sesiones de entrenamiento, aunque también se puede utilizar en los partidos. Hay diferentes compañías que han desarrollado esta tecnología como *Statsports, Gpsports, Catapult o Wimu*, etc. A diferencia de otros sistemas, que dependen del vídeo y de una instalación más compleja, el GPS es mucho más independiente. La expansión de esta tecnología se aceleró en marzo de 2015, cuando la FIFA dio luz verde al uso de accesorios tecnológicos durante los partidos. El mundial femenino de Canadá, celebrado ese mismo año 2015, se convirtió en la primera competición oficial en aplicar esta tecnología.

Parte de los estudios de esta tesis se ha desarrollado con dispositivos GPS Wimu Pro, de la empresa española *Realtrack Systems* (Almería). Hay muchos clubes de LL1 y LL2 que utilizan estos dispositivos todos los días y se ha convertido en una herramienta de vital importancia. Además, la compañía firmó recientemente una alianza estratégica con La Liga para permitir a todos los clubes de Primera y Segunda División recibir un informe de rendimiento generado por su tecnología a partir de la información recopilada por Mediacoach y adaptada al software de Wimu Pro con el propósito de combinar la información de los 2 sistemas de control de la carga externa, que como se ha demostrado con los estudios realizados en esta tesis **estudio I** (Pons et al., 2019) y **estudio II** (en revisión) se trata de datos comparables. Por lo tanto, dos tipos de sistemas electrónicos de seguimiento del rendimiento convergen hoy en día: los basados en cámaras de sensores ópticos VTS y los sistemas GPS/GNSS.

En relación al estudio de Ekstrand et al., (2021) donde concluyen que el índice de lesiones en el fútbol ha caído un 3% en los últimos 18 años considero, a modo de reflexión personal, que la implementación de la tecnología en las últimas dos décadas, ha permitido a la comunidad de preparadores físicos del fútbol controlar mejor las cargas de los jugadores durante el entrenamiento y durante la competición. Y, en consecuencia, se ha influido de manera positiva en la prevención de lesiones.

1.3. Validez y fiabilidad de los sistemas de análisis VTS y GPS

Dado el aumento de dispositivos tecnológicos disponibles para el control de carga externa en el deporte, es esencial conocer su fiabilidad y validez para informar de la carga externa del entrenamiento y la competición. Las decisiones en torno a la optimización del entrenamiento de los jugadores pueden basarse en pequeñas fluctuaciones en la carga de entrenamiento, por lo que la fiabilidad y validez de los sistemas es importante para diferenciar entre el cambio real y el error de medición.

Un número considerable de estudios han evaluado la validez y fiabilidad de la tecnología utilizable para su uso en el deporte. Esta temática ha sido ampliamente revisada. (Marco Cardinale & Varley, 2016). En el fútbol, los dos medios más comunes para el control de carga externa son actualmente: el sistema de cámara de vídeo VTS durante la competición y los dispositivos GPS durante el entrenamiento (Buchheit et al., 2014).

En relación a los estudios de validez y fiabilidad de los dispositivos GPS destacamos el análisis con dispositivos de frecuencia de muestreo de 5hz (Casamichana & Castellano, 2015), cuyos resultados indicaron una validez y fiabilidad moderada en las intensidades estudiadas casi a todos los niveles y también para la distancia total. En este sentido López et al., (2017) llegan a la conclusión de que el GPS de Wimu Pro demostró ser válido y fiable para medir esprines a velocidades de más de 20 km/h, además de los movimientos requeridos en los deportes de equipo. Otros estudios que podemos nombrar son el de Bastida-Castillo et al., (2017), donde concluyen que la validez y fiabilidad del GPS depende de la frecuencia de muestreo, velocidad de ejecución, distancia de ejecución y patrón de movimiento; por lo que la frecuencia de muestreo más baja conducirá a una menor validez y fiabilidad del GPS.

Debemos mencionar el estudio de Jackson et al., (2018) que compara la recopilación de datos con el sistema GPS y con el Sistema Global de Navegación por Satélite GNSS. Un término colectivo utilizado para abarcar todos los sistemas de navegación por satélite que proporcionan un posicionamiento geoespacial con cobertura global. Actualmente todos los dispositivos de geolocalización utilizados en el control de carga externa en el fútbol incluyen este sistema GNSS. En relación al estudio realizado por Jackson et al., (2018) con jugadores de hockey, afirman que el sistema GNSS tiene el potencial de medir los patrones de movimiento con mayor precisión. Se encontró que GNSS tenía niveles razonables de fiabilidad entre los dispositivos para la mayoría de las mediciones, excepto para las variables de velocidad y aceleración más altas.

En el caso del sistema de seguimiento con videocámaras destacamos un estudio reciente de Linke et al., (2020) que para evaluar la exactitud del sistema TRACAB, compararon sus mediciones con las mediciones de un sistema de referencia (sistema de captura de movimiento VICON) grabadas simultáneamente. Midieron variables mecánicas y locomotoras (Fernández et al., 2016). Dicho estudio comparativo concluye que el sistema TRACAB puede considerarse como tecnología válida para el análisis de rendimiento específico del fútbol en los parámetros probados. Aunque en determinadas acciones presenta el inconveniente de que tiene que ajustarse manualmente.

1.4. Comparación entre los sistemas VTS y GPS

En relación a los primeros estudios comparativos entre el sistema VTS y GPS debemos mencionar el estudio de Buchheit et al., (2014) en el que realizaron la comparación entre el sistema VTS *Prozone* y los dispositivos GPS, *GPsport* (Camberra, Australia). Se observó que el error típico de la estimación era de magnitud moderada, llegando a la conclusión de que la intercambiabilidad de los diferentes sistemas de seguimiento es posible con las ecuaciones proporcionadas, pero es necesario tener en cuenta su error típico moderado de estimación. Según Buchheit et al., (2014) es necesario ser cauteloso al comparar e interpretar las actividades de entrenamiento y la coincidencia de medidas por diferentes sistemas.

Durante el mismo año Stevens et al., (2014) concluyen que la precisión del seguimiento de vídeo VTS y el seguimiento GPS disminuye sustancialmente, subestimando la velocidad y la velocidad media, midiendo velocidades más altas. Lo mismo ocurre en acciones de corta distancia y no lineales, probablemente debido a un número de muestreo relativamente bajo. En esta línea de estudio, M Cardinale & Varley, (2017) muestra que la correlación mejora en los ensayos de mayor distancia, donde la fase de aceleración se reduce relativamente durante la prueba. Esto explicaría el aumento de errores para los movimientos que requieren cambios rápidos en la velocidad, como el cambio de dirección y las acciones explosivas cortas. Dado que la distancia y la velocidad se calculan de forma independiente y están sujetas al filtrado, es importante que cada técnica de medición y análisis de GPS asociada se valide correctamente.

En relación con el estudio realizado por Felipe et al., (2019) donde evalúan la correlación del sistema VTS de *Mediacoach* con el sistema GPS de *APex* (STATSportsTM, Newry, Irlanda del Norte) durante 38 partidos de LL2 en la temporada 2017-2018, se detectan elevados coeficientes de correlación y regresión. Además, muestra que *Mediacoach* es tan confiable y válido como un sistema GPS y también demuestra una alta precisión en el seguimiento de los movimientos específicos del fútbol de élite.

En la misma línea, Taberner et al., (2019) finaliza su análisis donde compara dispositivos GPS y VTS concluyendo que el intercambio de información entre los 2 sistemas es confiable y que para identificar dónde hay errores, se debe calcular con ecuaciones de regresión y aplicarlas para intercambiar datos con confianza. Esto permitirá a los profesionales combinar datos de entrenamiento y competición para ayudar a planificar adecuadamente estrategias que afectan el rendimiento físico y potencialmente reducir el riesgo de lesiones.

1.5. Carga externa

El deseo de saber cuántos kilómetros, metros, velocidades, esprines, etc.… ha hecho un jugador de fútbol durante los partidos, históricamente ha sido un objetivo para descubrir y controlar por la mayoría de la comunidad científica del entrenamiento del fútbol. A lo largo de los años, los investigadores del deporte han evaluado el análisis del movimiento y los requisitos que implica jugar al fútbol, con el fin de entrenar al jugador, lograr las necesidades físicas que el fútbol requiere y alcanzar la optimización para competir al más alto nivel. Los procedimientos para recopilar esta información han evolucionado, lo que ha llevado a una mejor aproximación al conocimiento de las demandas condicionales requeridas por el juego.

El seguimiento de la carga de los jugadores tanto en el entrenamiento como en la competición se ha convertido en un tema destacado en la ciencia del deporte en la última década. "*Tanto los científicos como los entrenadores supervisan las cargas todos los días a través de enfoques multidisciplinarios, y la búsqueda de las mejores metodologías para capturar e interpretar datos, esto ha producido un aumento significativo en la investigación empírica y aplicada*" escriben Bourdon et al, (2017, p.16). De hecho, este campo de investigación se ha desarrollado tan rápidamente en los últimos años que ha dado lugar a industrias destinadas a desarrollar nuevos paradigmas que permitirán cuantificar con mayor precisión las cargas internas y externas propuestas a los deportistas para ayudarnos dentro de las diferentes metodologías de entrenamiento a preservar de lesiones a los jugadores y a optimizar su máximo rendimiento. En la actualidad el tratamiento y el conocimiento de estos datos de carga externa han facilitado el avance del conocimiento a toda la comunidad científica del entrenamiento.

En el congreso anual del Simposio del Colegio Europeo de Ciencias del Deporte celebrado en Salzburgo, se intentó llegar a un consenso de las definiciones de carga interna y externa. Conceptos que Matveyev ya desarrolló en el año 1986 tal y como describe Mujika (2013) en su libro. En dicho libro identifica los indicadores externos que representan características cuantitativas que pueden ser evaluadas de manera externa como la duración, el número de sesiones, la velocidad de ejecución, el ritmo, etc. Y, además, matiza la carga externa en tres momentos de entrenamiento diferentes que pueden variar significativamente dentro de un programa: la carga esperada antes del inicio de la temporada, la carga diaria diseñada, y la carga real realizada por cada deportista individualmente. Para Mujika, (2013) la carga real es la carga que debe cuantificarse e informarse, no la carga a largo o medio plazo prescrita por el entrenador o investigador

Según M Cardinale & Varley, (2017) la carga externa de entrenamiento se define como el trabajo realizado por el deportista, medido independientemente de sus características internas. Las mediciones de carga externa pueden incluir duración, velocidad, distancia recorrida, desaceleración, aceleración, potencia metabólica y movimientos específicos del deporte. Este aspecto de carga externa (Impellizzeri et al., 2019) da más objetividad al concepto de carga de entrenamiento. Según este autor, se puede describir como externa o interna, dependiendo de si nos referimos a aspectos medibles que suceden interna o externamente al deportista.

En referencia al concepto de carga externa Hernández et al.,(2017), Impellizzeri et al., (2019), Recuenco Serrano & Juárez Santos-García, (2015) se refieren a demandas cuantificadas en general con parámetros físicos como: la distancia total recorrida, la distancia recorrida a diferentes velocidades, los esprines realizados y sus intensidades, aceleraciones y desaceleraciones. Cabe recordar como dice Impellizzeri et al., (2019) que la organización, la calidad y la cantidad del ejercicio planificado determinan la carga externa, que se define como el trabajo físico establecido en el plan de entrenamiento. Por lo tanto, las medidas de carga externa son específicas de la naturaleza del entrenamiento realizado y de la competición. Por ejemplo, en el entrenamiento de fuerza, la carga externa se considera generalmente la carga levantada; sin embargo, también se puede expresar como trabajo realizado o la velocidad generada durante el levantamiento. Del mismo modo, en los deportes de equipo, la carga externa se puede definir mediante mediciones de la distancia total recorrida o por intervalos de velocidad específicos, aceleraciones y desaceleraciones, que se producen en competición y entrenamiento. En esta tesis nos ceñimos a este concepto de carga externa.

La necesidad de individualizar la prescripción del ejercicio en busca del máximo rendimiento individual del deportista y como consecuencia, del rendimiento grupal gracias a la suma de cada una de las personas que componen el equipo, hace indispensable la monitorización de las cargas de entrenamiento y de competición (Castellano & Casamichana, 2015; V Di Salvo et al., 2013). No olvidemos que, por ejemplo, la aplicación de la misma carga externa en dos jugadores de fútbol puede producir diferencias notables en la carga interna, siendo un estímulo apropiado para uno e inapropiado para el otro (Bourdon et al., 2017; Gabbett et al., 2017). Al mismo tiempo obtener un equilibrio adecuado entre entrenamiento y recuperación, facilitará el proceso de mejora del rendimiento en los partidos (Kenta y Hassmén, 1998).

En la misma línea Alexiou & Coutts, (2008) en su estudio concluyen con la idea que la monitorización diaria de la carga de entrenamiento ayuda a los profesionales del deporte a controlar el proceso de entrenamiento y así mejorar el rendimiento (Alexiou & Coutts, 2008) El deporte moderno, especialmente a nivel de élite, es muy competitivo. Un deportista que no se recupera durante las próximas 72 horas de la competición, se puede considerar como un indicador negativo. Por eso cabe destacar la importancia de un proceso de recuperación cuidadosamente monitorizado. (Kenttä & Hassmén, 1998).

Es por ello por lo que la tecnología VTS y el GPS son herramientas que actualmente son útiles para evaluar la carga externa de manera detallada. Impellizzeri et al., (2019) señalan como resultado de la mayor disponibilidad de esta tecnología, que la atención de entrenadores, preparadores físicos y científicos del entrenamiento parece haberse desviado hacia el examen de la carga externa en lugar de evaluar la respuesta psicofisiológica real, es decir, la carga interna. La posibilidad de combinar ambas informaciones en el día a día repercutirá en un mejor control de la carga. Además, la ventaja de obtener más información sobre la carga externa nos permitirá realizar una planificación más precisa de la misma.

1.6. Importancia de las variables de alta intensidad

Según Hader et al., (2019) la distancia total es probablemente la variable más controlada en el fútbol de élite. No está asociada con cambios significativos en marcadores relacionados con la fatiga después del partido. Este investigador realiza un estudio de meta análisis donde descubre, la gran correlación existente entre la distancia recorrida durante el partido entre 21-24Km/h (VHIR) y los marcadores de fatiga. En él determina que la distancia recorrida entre 21-24Km/h (VHIR) fue identificada como la única variable de monitorización que se correlacionó en gran medida con marcadores bioquímicos y neuromusculares. *"Prácticamente, después de más de 24 horas, por cada 100 m. de distancia recorrida entre 21-24Km/h VHIR, la actividad de Creatine Kinasa (CK) aumentaría un 30% y la de potencia máxima de salto en un test de contra movimiento (CMJ) disminuiría un 0,5%. Por lo tanto, debemos tener en cuenta que la distancia en VHIR, al menos cuando se evalúa durante las primeras 24 horas del proceso de recuperación, representa la variable de monitorización más sensible para representar cargas bioquímicas y neuromusculares resultantes del partido de fútbol".* (Hader et al.,2019, p.13).

Resultados a considerar por parte de la comunidad científica del entrenamiento en el fútbol, sobretodo por la alta densidad competitiva actual, donde prácticamente los equipos de élite juegan partidos cada dos o tres días.

1.7. Grupos de variables analizadas

Las mejoras tecnológicas del fútbol de élite nos han permitido analizar con gran detalle el rendimiento de jugadores y equipos. El volumen y la disponibilidad inmediata de esta información permite a los entrenadores deportivos y científicos tomar decisiones más documentadas sobre las necesidades actuales y futuras, aumentando así el potencial de rendimiento de los equipos.

En el fútbol, durante esta última década, se está incorporando mucha tecnología. Lo que ha generado el "*Big Data*", un número muy alto de datos y variables que ofrece muchos beneficios, pero al mismo tiempo puede causar confusión para llegar a conclusiones objetivas.

Cada vez hay más publicaciones científicas (Fernández et al., 2016; Gaudino et al., 2014; Gómez-Carmona et al., 2019; Oliva Lozano et al., 2020) que seleccionan y clasifican los datos que la tecnología nos ofrece. En este sentido, en esta tesis nos fijaremos en el estudio de Fernández et al., (2016) que distribuye y selecciona la infinidad de variables de carácter condicional que nos proporciona la tecnología GPS, mediante la agrupación en 3 grupos de las variables más significativas para el control de la carga externa: variables locomotoras, variables metabólicas, y variables mecánicas. A partir de estos tres grupos analizamos la carga externa con una categorización mucho más precisa para valorar el tipo de esfuerzo realizado por el jugador. En los diferentes estudios realizados durante la elaboración de esta tesis empleamos dicha categorización de las variables.

En las siguientes líneas mostramos las variables que configuran cada grupo según Fernández et al., (2016):

- **Variables metabólicas**: son variables asociadas con el gasto y esfuerzo de energía incluyendo valores de potencia metabólica media (AMP), alta carga de distancia metabólica (HMLD), altos esfuerzos metabólicos (HEF), distancia metabólica equivalente (EMD), porcentaje de carga (POR) y intensidad de la velocidad (SPI). Este grupo de variables **no se utiliza** en esta tesis; aunque también se puede emplear para el control de la carga externa.

- **Variables mecánicas**: son variables relacionadas con acciones de impactos como saltos y aterrizajes. También se relacionan con cambios de intensidad en acciones cortas de desplazamiento, como los cambios de dirección, acciones de alta exigencia neuromuscular y mecánica articular. Fernández et al. (2016), incluyen como variables mecánicas las aceleraciones (ACC) en diferentes rangos de velocidad calculado en m/s^2. Según Gaudino et al. (2014), la actividad de aceleración se mide sobre el cambio en los datos de velocidad. Para contarse como una aceleración, el aumento de la velocidad debe producirse durante al menos medio segundo. La aceleración termina cuando el jugador deja de acelerar. Del mismo modo, en este grupo también se incluyen las desaceleraciones (DEC) en diferentes rangos de velocidad calculado en m/s^2, (Gaudino et al., 2014). Al igual que en la actividad de aceleración, la disminución de la velocidad debe producirse durante al menos medio segundo para que una actividad se cuente como una desaceleración. Este tipo de acciones se deben tener muy presentes al controlar la carga, como se puede leer en el estudio de (Harper & Kiely, 2018, pp.1,2): "*los factores estresantes mecánicos, implícitos en las actividades de desaceleración, son mediadores críticos que actúan como potentes impulsores tanto de la fatiga neuromuscular como del daño tisular, el aumento del volumen o la intensidad de la actividad de desaceleración contribuye a un círculo vicioso de fatiga cada vez mayor*". Por último, hay que comentar que dentro de este grupo de variables mecánicas también encontramos, la carga dinámica de tensión (DSL), el índice de fatiga (FAI), la carga de velocidad (LSL) y la carga total (TL).

- **Variables locomotoras**: son las que tradicionalmente han sido analizadas a lo largo del tiempo por la comunidad científica del fútbol para evaluar la carga externa. En el estudio realizado por Fernández et al. (2016), encontramos desplazamientos en diferentes rangos de velocidad como, distancia total recorrida (TD), distancia recorrida a mayor velocidad de 5,8 m/s (HSR), velocidad máxima (Max Speed), distancia caminando de 0-6 km/h (Walking), distancia trotando de 6-12 km/h (Jogging), distancia corriendo de 12-18km/h (Running), distancia recorrida entre 14-21km/h (HIRD), distancia recorrida entre 21-24 Km/h (VHIRD), distancia recorrida a velocidad mayor de 24km/h (SpD). En la categorización de las acciones en esprín sucede lo mismo. Se diferencia entre las acciones en las que el jugador supera la velocidad de 5.83m/s (SPR), los esprines realizados entre 21-24Km/h (SpVHIR) y los esprines realizados a velocidad mayor de 24Km/h (Sp).

A continuación presentamos de manera ordenada por tablas las variables analizadas en esta tesis, según la clasificación de Fernández et al. (2016) y agrupadas en función de los estudios en que se emplean:

Tabla 1 *Variables locomotoras de los estudios I y II*

Acrónimo / Nombre	Significado	Rango de velocidad	Unidades de medida
TD	Distancia Total Recorrida		m
Walking	Distancia Caminando	Entre 0-6	Km/h
Jogging	Distancia Trotando	Entre 6-12	Km/h
Running	Distancia Corriendo	Entre 12-18	Km/h
HIRD	Distancia Carrera	Entre 14-21	Km/h
VHIRD	Distancia Carrera en Alta Intensidad	Entre 21-24	Km/h
SpD	Distancia en Esprín.	Mayor de 24	Km/h
SpVHIR	Esprines en Alta Intensidad.	Entre 21-24	Km/h
Sp	Esprines Realizados	Mayor de 24	Km/h

Tabla 2 *Variables mecánicas, utilizadas en el estudio II*

Acrónimo / Nombre	Significado / Descripción	Rango Velocidad / Unidad de Medición
ACC	Aceleración	Entre 0 a $1 m/s^2$
ACC	Aceleración	Entre 1 a $2 m/s^2$
ACC	Aceleración	Entre 2 a $3 m/s^2$
DEC	Desaceleración	Entre 0 a $-1 m/s^2$
DEC	Desaceleración	Entre -1 a $-2 m/s^2$
DEC	Desaceleración	Entre -2 a $-3 m/s^2$
Distancia ACC	Suma de metros que se acumulan en acciones de aceleraciones en diferentes rangos.	
Distancia DEC	Suma de metros que se acumulan en acciones de desaceleración en diferentes rangos.	

1.8. Diferentes concepciones metodológicas del entrenamiento

Las metodologías de entrenamiento a lo largo de la historia han experimentado una transformación comparable a la evolución del ser humano inmerso en una sociedad globalizada influenciada por todo lo que nos rodea.

Desde una perspectiva temporal, las metodologías de entrenamiento se pueden ubicar a partir de las corrientes de entrenamiento del siglo XX, donde predominan las bases de las teorías conductuales y mecanicistas. Donde se entrenaba por un lado la práctica física y por otro lado se entrenaba el deporte. Se entrenaba al deportista de una manera no especifica y luego se entrenaba el deporte con un objetivo claro de crear una amplia base cuantitativa en el deportista y luego, mejorar en él valores cualitativos. Todo desde una perspectiva mucho más tradicional y no específica del juego. Una vez inmersos en el siglo XXI, estas metodologías han ido incorporando nuevas teorías a partir de una visión más compleja del ser vivo. Como las teorías de los sistemas dinámicos que se implementan en el deporte, considerando a los deportistas como una estructura hipercompleja configurada a través de interacciones entre sus estructuras. Este nuevo enfoque del entrenamiento genera una nueva concepción del jugador.

Esta contextualización histórica de la metodología de entrenamiento en general también ha estado y está presente en el fútbol. Si nos referimos a las diferentes metodologías de entrenamiento a lo largo de la historia en el fútbol, debemos tener en cuenta que al principio todo estaba muy interrelacionado con metodologías tradicionales y muy influenciados por los métodos de entrenamiento de los deportes individuales y más específicamente por deportes como el atletismo con tareas lineales. Sin embargo, esto no significa que estas metodologías estén equivocadas. Ya que actualmente en el fútbol, se utilizan y permiten conseguir títulos al igual que otras metodologías con procedimientos de entrenamiento diferentes.

Las metodologías de entrenamiento de fútbol más contemporáneas, del siglo XXI, han ido incorporando nuevas teorías a partir de una visión más compleja del ser vivo (jugador). Como las teorías de los sistemas dinámicos complejos (Balagué et al., 2014) que se implementan en el deporte, desde la visión de considerar al jugador como una estructura hipercompleja configurada a través de interacciones entre sus estructuras (Tarragó et al., 2019). Es una nueva concepción del jugador como un "*todo*". Con ella el entrenamiento adquiere una nueva dimensión desde una perspectiva holística. El entrenamiento holístico es una propuesta metodológica basada en la combinación de conceptos de entrenamiento deportivo y los conceptos de la teoría de la complejidad. Se basa en el diseño de ejercicios con respuesta no lineal. La incertidumbre es la base creativa del proceso. Fundamentos del juego y de su complejidad, no se pueden llevar a cabo en entornos ajenos a la realidad de la complejidad del juego donde el Ser Humano Deportista (SHD) (Tarragó et al., 2019) debe actuar.

Como consecuencia de esta nueva tendencia se crea el Entrenamiento Estructurado (EE) (Tarragó et al., 2019) frente a las necesidades metodológicas que requieren los deportes de equipo: "*el entrenamiento estructurado nace con el objetivo de adaptarse a las necesidades específicas de los deportes de equipo, basado en la especificidad, individualización, enfoque global y aprendizaje diferencial, respetando las diferentes estructuras que componen el ser humano deportista*" (Tarragó et al.,2019, p.103). Esta metodología de entrenamiento se configura con dos paradigmas o formas de acción. Por un lado, hablábamos del EO (Pons et al., 2020) como la base de la "*planificación, diseño, ejecución y control de las tareas de su deporte, cuyo objetivo es optimizar el rendimiento de SHD en todas las competiciones en las que participes a lo largo de tu vida deportiva*" (Tarragó et al., 2019, p.105). Fundamentalmente este entrenamiento lo que hace es preparar al jugador para competir al máximo. Por otro lado, dentro del EE está el "*Entrenamiento Coadyuvante formado por todas aquellas prácticas que permiten al deportista no sólo disfrutar de un estado de bienestar y protección de la salud, sino que le permitan llevar a cabo diariamente las tareas propuestas por el Entrenamiento Optimizador*" (Tarragó et al., 2019, p.106).

Desde una perspectiva más actual según Gómez et al., (2019) el entrenamiento coadyuvante, se podría decir que prepara fundamentalmente para poder entrenar y al mismo tiempo para mejorar las estructuras y sistemas que permitirán construir el rendimiento, desde elementos y entornos que en parte o en su totalidad no son específicos del juego.

Basándose en esta concepción metodológica de entrenamiento, el área de rendimiento del Futbol Club Barcelona (FCB) hace años decidió hacer una apuesta basada en la especificación, la individualización, la variabilidad, el enfoque global y el aprendizaje diferencial, siendo hoy plenamente válida y aceptada por todos los profesionales responsables de la preparación física del club. Como consecuencia de esta apuesta, por parte del área de rendimiento del FCB se ha querido profundizar con el EO de ahí la publicación del **estudio IV** de esta tesis (Pons et al., 2020), donde se da a conocer una metodología de entrenamiento para deportes colectivos. Este EO en los últimos años ha tenido en cuenta los valores de carga externa de la competición del primer equipo del FCB con el fin de diseñar las sesiones de entrenamiento, de manera continuada, con el objetivo de optimizar a los jugadores para poder competir y rendir al más alto nivel durante todo el periodo de competición.

Siguiendo este paradigma más contemporáneo de metodologías de entrenamiento de fútbol hay que mencionar la periodización táctica de Vítor Frade creada en Portugal. Es una propuesta de entrenamiento en el mundo del fútbol que propone trabajar siempre en especificidad, sin dar lugar a ejercicios analíticos y descontextualizados. Por eso rechaza el entrenamiento físico o técnico separado del modelo de juego, ya que ello conduce a una inespecificidad en el proceso de entrenamiento con consecuencias posteriores.

Por último, las diferentes metodologías de entrenamiento en el fútbol a las que nos hemos referido en este punto se pueden beneficiar de los estudios realizados en esta tesis en relación con la carga externa para planificar las temporadas, diseñar las sesiones y elegir los ejercicios.

1.9. Objetivos de la tesis.

El objetivo principal de esta tesis ha sido cuantificar, analizar, comparar, conocer y objetivar la evolución de la carga externa de la 1ª y 2ª división del fútbol profesional de la Liga Española durante 4 temporadas 2015-2016, 2016-2017, 2017-2018 y 2018-2019.

El cuerpo principal de la presente tesis lo constituyen 4 artículos originales presentados (tres publicados y uno en revisión) en revistas indexadas, los cuales dan respuesta a los objetivos planteados. Cada uno de estos artículos se presenta como capítulos individuales en el formato solicitado por cada revista para su admisión.

A continuación, se detallan los objetivos específicos que corresponden a los cuatro artículos que conforman el cuerpo de esta tesis:

- Estudio I: Comprobar y determinar la correlación de las mediciones existentes de las variables locomotoras entre el sistema VTS del servidor Mediacoach y el sistema GPS de la marca Wimu Pro utilizados para el control de la carga externa del jugador de fútbol profesional. Este estudio conforma al artículo titulado "*A comparison of a GPS device and a multi-camera video technology during oficial soccer matches: Agreement between Systems*". El artículo ha sido publicado en la revista: Plos One.

- Estudio II: Comprobar y determinar la correlación de las mediciones existentes de variables mecánicas entre el sistema VTS del servidor Mediacoach y el sistema GPS de la marca Wimu Pro utilizados para el control de la carga externa del jugador de fútbol profesional. Este estudio ha generado el artículo titulado: "*Integration video tracking and GPS to quantify accelerations and decelerations in elite soccer*". Artículo enviado a la revista, Springer Nature Scientific Reports actualmente **en revisión**.

- Estudio III: Determinar, mostrar, identificar, conocer y objetivar la evolución carga externa a lo largo de las 4 temporadas (2015/2016-2016/2017-2017/2018-2018-2019) y objetivar identificar diferencias entre las dos categorías del futbol profesional español. Este estudio ha permitido la elaboración del articulo presentado con el titulo: "*A Longitudinal Exploration of Match Running Performance during a Football Match in the Spanish La Liga: A 4-Season Study"* publicado en la revista: International Journal of Environmental Research and Public Health.

- Estudio IV: Dar a conocer una metodología de entrenamiento válida para la optimización del jugador de futbol la cual utiliza los datos obtenidos en los estudios anteriores con el fin de planificar y mejorar el rendimiento condicional del futbolista profesional para la competición. Esta aportación corresponde al artículo: "*Training in Team Sports: Optimising Training at FCB*", publicado en la revista Apunts, Physical Education and sport.

2. METODOLOGIA

2.1. Participantes

En los diferentes estudios participaron jugadores de futbol de la LL1 y LL2 del fútbol español, en los siguientes apartados se detallan los grupos que conforman cada estudio.

2.1.1. Participantes del estudio I y II

Incluimos a los 26 futbolistas profesionales masculinos del equipo filial de un club de 1ª división española, que jugaban en la Liga Smartbank (2ª división) con una edad media de 20,38 ± 2,03 años; altura 180,00 ± 7,47 cm; peso 73,81 ± 5,65 kg. Se excluyeron a los porteros, debido a los requisitos específicos de esta posición. Registramos los datos de los jugadores a lo largo de todos los partidos de la 2ª División Española 2017/18 (n = 42), mediante los sistemas de Mediacoach y Wimu Pro registrando un total de 759 mediciones simultáneas.

2.1.2. Participantes Estudio III

Los participantes del Estudio III corresponden a todos los jugadores de los equipos de la 1ª división de La Liga Santander, y de la 2ª división de La Liga Smartbank, del fútbol español. La exposición incluyó observaciones de todos los partidos jugados durante cuatro temporadas en 1ªdivision de La Liga Santander y 2ª división de La Liga Smartbank durante las temporadas (2015/2016, 2016/2017, 2017/2018 y 2018/2019). Los datos nos fueron facilitados por La Liga y el estudio recibió la aprobación ética de la Universidad de Extremadura, Vicerrectorado de Investigación, Transferencia e Innovación — Delegación de la Comisión de Bioética y Bioseguridad (número de protocolo: 153/2017).

2.2. Sistemas de análisis

Los sistemas tecnológicos utilizados para realizar las investigaciones de carga externa de los jugadores para los tres estudios fueron los sistemas Mediacoach y Wimu Pro.

El sistema Mediacoach consiste en una serie de cámaras Super 4K High Dynamic Range basadas en un sistema de posicionamiento (Tracab — ChyronHego VTS) que graba y analiza las posiciones X e Y de cada jugador desde varios ángulos, proporcionando así seguimiento tridimensional en tiempo real y los datos se graban a 25 Hz. Mediacoach ha demostrado ser fiable y válido y se ha utilizado en estudios anteriores (Felipe et al., 2019; Rivilla-García et al., 2019).

El dispositivo Wimu Pro (RealtrackSystems, Almería, España) ha sido previamente validado en otros estudios (Bastida-Castillo et al., 2017, 2018) y también se utilizó para la recopilación de datos. El dispositivo integra diferentes sensores: cuatro acelerómetros 3D que funcionan a diferentes escalas: ± 16G, ± 16G, ± 32G y ± 400G; tres giroscopios, de dos a ± 2000°/s a 1000Hz y uno a ± 4000°/s a 1000Hz; un imán 3D ± ocho Gauss a 160 Hz; y un barómetro ± 1200 mbar a 100 Hz. Sensores que permiten la grabación de posicionamiento espacial, velocidad y aceleración basándose en ell sistema global de navegación por satélite y sistema de posición global GNSS/GPS a 10Hz (número de satélites = 8,96; SD = 1,56), compatible con Galileo. Los datos grabados se almacenan en una memoria "flash" interna de 16 GB. El dispositivo tiene una batería interna que dura cuatro horas, pesa 70 g y sus dimensiones son de 81x45x16 mm. Encontrarán una explicación más detallada en el estudio I (Pons et al., 2019 pp. 3-4), (estudio II En Revisión pp. 7-8) y en el estudio III (Pons et al., 2021 p.3).

2.3. Procedimientos

2.3.1. Procedimientos de los estudios I y II

Para el estudio I y II donde se correlacionó los 2 sistemas de registro de carga externa VTS y GPS, los procedimientos fueron los siguientes:
En el estudio I para permitir la comparación de datos de los dos sistemas y evitar errores de valoración, se registraron las muestras de cada una de las dos partes por separado. Específicamente, los datos del GPS de Wimu Pro se ajustaron con respecto al sistema VTS de Mediacoach es decir, se ajustaron las grabaciones GPS de acuerdo con los registros VTS, siempre al principio de cada parte. Además, los datos de algunas coincidencias se eliminaron porque, al descargar los datos sin procesar (Raw Data) desde el dispositivo GPS Wimu Pro o la cámara de seguimiento óptico, se detectó una pérdida intermitente de señal. En concreto, se eliminaron las mediciones de los partidos pertenecientes a las jornadas 29 y 39 porque estos errores de medición se encontraron en dispositivos GPS Wimu Pro se hallaron datos atípicos en algunos jugadores y los partidos de las jornadas 5 y 10 fueron eliminados debido a problemas técnicos visuales detectados en VTS Mediacoach. También se utilizaron los siguientes criterios de exclusión para las medidas: los jugadores que tuvieron un problema de desconexión en el dispositivo GPS Wimu Pro durante el juego fueron excluidos además de los porteros que también fueron retirados del estudio. Un total de 91 medidas fueron eliminadas por estas razones, y el número promedio de jugadores de fútbol analizados por partido fue de 8,88 (SD = 2,17).

Se registraron un total de 759 medidas VTS Mediacoach y GPS Wimu Pro, de las cuales 374 mediciones en la 1ª parte y 385 en la 2ª parte. Además, con la técnica de reconfiguración, explicada en el artículo I se minimiza el error de validación, facilitando la interpretación de los datos. Se muestra una explicación mas detallada en el articulo (Pons et al., 2019 pp. 2,3).

En el estudio II para sincronizar ambos sistemas con todos los jugadores del equipo (incluidos los jugadores reemplazados), hemos utilizado una técnica de reconfiguración descrita por Carling (2013). Además, para permitir la comparación de datos entre ambos sistemas y evitar errores de valoración, se registraron muestras de cada mitad de los partidos por separado (n = 347 primera mitad; y n = 332 segunda mitad). Siguiendo el mismo procedimiento que en el estudio I suavizamos los datos de velocidad y aceleración utilizando una media móvil central de seis y cuatro valores, respectivamente. La señal GPS durante la recopilación de datos era de 10 Hz (10 fotogramas por segundo, o un punto de datos cada 100 ms). Mientras que con el sistema VTS la recopilación de datos era de 25Hz. Debemos de señalar que el proceso de registro de desaceleraciones de alta intensidad fue el mismo que el empleado por el del sistema Mediacoach. Además, se eliminaron los datos de algunos partidos porque se detectó una pérdida intermitente de señal cuando se descargaron datos sucios del dispositivo GPS o de la cámara de seguimiento óptico. Se excluyeron un total de 91 medidas (13,4%), lo que supuso un total de 679 medidas analizadas. De la misma manera que en el estudio I, los partidos pertenecientes a la jornada 29 y 39 fueron eliminados, ya que estos errores de medición se encontraron en dispositivos GPS y las jornadas 5 y 10 fueron también eliminadas debido a problemas técnicos visuales detectados en el VTS. Del mismo modo que en estudio I se puede ver una explicación más detallada en el estudio II, (**en revisión** p. 5).

2.3.2. Procedimientos del estudio III

Se hicieron dos observaciones por partido y una por equipo. En la tabla 3 se puede observar el número de observaciones realizadas en cada categoría y temporada.

Tabla 3 *Número de observaciones realizadas en LL1 y LL2 durante las 4 temporadas analizadas (2015-2019)*

Categoría	Observaciones Incluidas	Temporada
LL1	752	2015-2016
	744	2016-2017
	723	2017-2018
	731	2018-2019
LL2	700	2015-2016
	744	2016-2017
	870	2017-2018
	731	2018-2019

Además, se excluyeron 784 observaciones debido a problemas técnicos en el sistema de recolección de datos o condiciones meteorológicas adversas durante el partido, lo que llevó a un total de 5952 observaciones. El procedimiento del estudio II tiene la explicación más detallada en (Pons et al., 2021, p.3).

2.4. Métodos estadísticos

Los métodos estadísticos utilizados en esta tesis siguen diferentes procedimientos como resultado de los datos utilizados. En el estudio III el procedimiento es diferente a los dos anteriores estudios como consecuencia de la solicitud de los revisores de la revista de este estudio III.

2.4.1. Método estadístico del estudio I

En el estudio I, el tratamiento estadístico de los datos se realizó con el programa IBM SPSS statistics 24.0 y Microsoft Excel. Mediante el método estadístico de Will Hopkins. Las pruebas estadísticas empleadas las hallaran detalladamente en las paginas cuatro, cinco y seis del articulo (Pons et al., 2019, pp. 4-6).

2.4.2. Método estadístico del estudio II

Los datos se analizaron mediante spss statistics 23.0 y software de Microsoft Excel con una hoja de cálculo personalizada de la metodología de Will Hopkins. Encontraran la explicación más detallada en las paginas de la 9 a la 11 de dicho estudio II, (**en revisión**).

Durante la elaboración de los estudios I y II las compañías realizaron una aportación muy interesante da esta investigación. El desarrollo de ecuaciones predictivas que permiten el intercambio de datos de los dos sistemas diferentes. Pocas investigaciones han sido capaces de generar esta ecuación con una muestra de referencia y desde una perspectiva ecológica. Esto implica una intercambiabilidad del sistema adicional como un punto importante para los profesionales de los clubes, que a menudo utilizan dos sistemas diferentes a lo largo de la semana. Más concretamente, se realizó un análisis de regresión lineal utilizando los datos de la mitad de la muestra aleatoria, y a partir de los resultados se obtuvo la siguiente ecuación de regresión, que estima el valor de Wimu Pro cuando entramos en los datos de Mediacoach para cada variable:
*Y (datos Wimu Pro) = (pendiente * X (datos de Mediacoach)) + interceptar (errores residuales)*

Donde Y es el valor estimado de Wimu Pro y X es el valor Mediacoach para una variable determinada. La interceptación representa los errores residuales en: metros (variables de distancia) o km / h (variables de velocidad), número de ACC y DEC y distancias cubiertas en m/s^2. Explicación más detallada del método estadístico en el estudio I (Pons et al., 2019, p.6) y en el estudio II (**en revisión** p.13).

2.4.3. Método estadístico del estudio III

En el método estadístico del estudio III, se empleó el programa estadístico SPSS 25.0 (Armonk, NY: IBM Corp, 2017) para analizar y procesar los datos. Al mismo tiempo se utilizó un análisis bidireccional de la variante (ANOVA) junto con su extensión (MANOVA). Información detallada del proceso estadístico del estudio III (Pons et al., 2021, p. 3).

3. ARTICULOS QUE CONSTITUYEN LA TESI

Estudio I: A comparison of a GPS Device and a multi-camera video Technology during official soccer matches: Agreement between Systems.

Pons, E., García-Calvo, T., Resta, R., Blanco, H., del Campo, R., Díaz García, J., & Pulido, J. J. (2019). A comparison of a GPS device and a multi-camera video technology during official soccer matches: Agreement between systems. PLOS ONE, 14(8), 1–12. https://doi.org/10.1371/journal.pone.0220729

RESEARCH ARTICLE

A comparison of a GPS device and a multi-camera video technology during official soccer matches: Agreement between systems

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Abstract

The aim of this study was to compare the agreement of the movement demands data during a soccer match (total distance, distance per minute, average speed, maximum speed and distance covered in different speed sectors) between an optical tracking system (Mediacoach System) and a GPS device (Wimu Pro). Participants were twenty-six male professional soccer players (age: 21.65 ± 2.03 years; height: 180.00 ± 7.47 cm; weight: 73.81 ± 5.65 kg) from FC Barcelona B, of whom were recorded a total of 759 measurements during 38 official matches in the Spanish second division. The Mediacoach System and the Wimu Pro were compared using the standardized mean bias, standard error of estimate, intraclass correlation coefficients (ICC), coefficient of variation (%), and the regression equation to estimate data for each variable. In terms of agreement between systems, the magnitude of the ICC was *almost perfect* (> 0.90–1.00) for all variables analyzed. The coefficient of the variations between devices was close to zero (< 5%) for total distance, distance per minute, average speed, maximum speed, and walking and jogging, and between 9% and 15% for running, intense running, and sprinting at low and at high intensities. It can be observed that, compared to Wimu Pro the Mediacoach System slightly overestimated all the variables analyzed except for average speed, maximum speed, and walking variables. In conclusion, both systems can be used, and the information they provide in the analyzed variables can be interchanged, with the benefits implied for practitioners and researchers.

Introduction

The quantification of athletes' external load has two main objectives: to improve performance and reduce a player's risk of injury [1, 2]. Hence, the use of technology is an important aid for the analysis of load in sports [3]: (i) to better understand practice sessions (evaluation of demands of any training session or match); (ii) to help program the optimal training load; (iii) and to make decisions about individual players' training programs [4].

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There are different options to quantify team-sport athletes' external load [5]. The recent exponential advancement of match analysis systems such as semi-automatic multiple-camera video technology (VID), radar-based local positioning system (LPS), and the Global Position System (GPS) has enabled the evaluation of players' external load [6]. In this study, we shall focus on the comparison of the data obtained by two of these innovative technologies (VID and GPS) during official soccer matches.

VID is a methodology for analyzing external load based on multiple high-definition cameras that track players placed around the soccer field. This system produces the trajectories of players around the pitch throughout the game, and allows researchers with access to the trajectory data to study the movements of individual players and teams and the interactions between them [7].

In recent years, numerous works have analyzed the competition load through the VID system [8, 9]. However, the main problem is VID validity, and for this reason, some researchers suggest that it is necessary to carry out validity studies and compare the degree of agreement of the VID with other assessment systems [10, 11]. In this sense, GPS technology has experienced exponential growth in recent years in its use for the quantification and control of external load in soccer training and matches. This is possible because in 2015, FIFA [12] amended its rules to allow the use of electronic performance and tracking systems (EPTS) in competitive matches [13].

Thus, many investigations have analyzed the capacity of these systems to evaluate conditional variables in training sessions to improve performance or avoid injuries [14, 15]. In addition, recent studies are quantifying these variables in match situations [13, 16, 17] but, to date, we have no knowledge of studies that have compared VID and GPS data in official matches.

Despite this, some investigations have compared the two technologies in training situations or in specific tests [11]. Specifically, these studies have shown that multiple camera semiautomatic systems tend to report slightly-to-moderately [18] and moderately-to-largely [16] greater distances covered at medium and high intensity than GPS technology [10], and demonstrated that ProZone (VID) tended to report greater distances at high speed than the GPS systems. However, most studies have been carried out in non-ecological environments by creating circuits that try to simulate real competition conditions [19], and this may be one of the keys to the results found.

As has been observed, VID and GPS are widely used technologies in research, but researchers have reported the lack of works that compare the results obtained by both methods and have stated that is necessary to continue working to reach high levels of agreement in the conditional parameters between the systems [11, 20, 21, 22]. Therefore, studies that prove the interrelation between these variables with a more ecological perspective are necessary.

Thus, the objective of this work will be the comparison of the Mediacoach conditional variables with the same data obtained from a GPS device (i.e., Wimu Pro). This comparison will be focused on physical parameters. Specifically, the degree of agreement between the two systems in distances covered and speeds will be determined. In addition, a second objective of the study will be to create equations that allow exchanging data between the two models [10].

Materials and methods

Participants and procedure

Twenty-six male professional soccer players (age: 21.65 ± 2.03 years; height: 180.00 ± 7.47 cm; weight: 73.81 ± 5.65 kg) from the FC Barcelona B team participated in this study. They had no injuries at the time of data collection. The measurements were recorded in twenty-two different stadiums (depending of the location of the match) during official matches (n = 42) of the Spanish second division in the 2017/2018 regular season (LaLiga 123).

To allow data comparison from the two systems and avoid valuation errors, samples were registered from each of the two halves of the matches separately. Specifically, the datasets from the GPS were adjusted with respect to the VID system (i.e., adjusting the GPS recordings according to the VID registers, always at the beginning of each half). In addition, data of some matches were eliminated because, when downloading the raw data from the GPS device or the optical tracking camera, an intermittent signal loss was detected. Specifically, the measurements of the matches belonging to the 29th and 39th rounds were eliminated because these measurement errors were found in the GPS devices (i.e., outlier data in some players), and 5th and 10th rounds were eliminated due to visual technical problems detected in the VID.

The following exclusion criteria were also used for the measurements:

- Players who had a disconnection problem in the GPS device during the game were excluded.
- Goalkeepers were also excluded from the study.

A total of 91 measurements were deleted for these reasons, and the average number of soccer players analyzed per match was 8.88 (SD = 2.17). An ANOVA analysis was also conducted to determine whether the differences between the two procedures used were significantly different among the stadiums where the matches were played. No significant differences were found.

Finally, a total of 759 measurements were recorded (GPS and VID), registering 374 measurements in the first half, and 385 in the second half. In addition, with this reconfiguration technique, the validation error is minimized, facilitating the interpretation of the data [23].

The study received ethical approval from the second author´s university; Vice-Rectorate of Research, Transfer and Innovation—Delegation of the Bioethics and Biosafety Commission (Protocol number: 153/2017). Players received verbal and written information regarding the nature of their voluntary participation in the study. In addition, all participants were treated according to the American Psychological Association ethical guidelines regarding consent, confidentiality, and anonymity.

Instrumentation

The movement demands data were collected using two different systems: Mediacoach and Wimu Pro.

Mediacoach system. The Mediacoach System is a series of super 4K-HDR cameras based on a positioning system (Tracab—ChyronHego VID), which records from several angles and analyzes X and Y positions for each player, resulting in three-dimensional tracking in real-time (tracking data was recorded at 25 Hz per second). Mediacoach is also based on data correction of the semi-automatic VID (the manual part of the process). This correction is made by an overlay of the X Coordinate, provided automatically by the system for each player on the real video image of the match. This detects and visually corrects the situations in which the positioning coordinates are erroneous because they move away from the position of the player to whom the data belong.

Wimu Pro. The Wimu Pro device (RealtrackSystems, Almería, Spain) previously validated in other studies [24, 25] was also used for data collection. The device integrates different sensors: four 3D accelerometers operating at different scales: ± 16G, ± 16G, ± 32G and ± 400G; three gyroscopes, two at ± 2000˚/s at 1000Hz and one at ± 4000˚/s at1000Hz; a 3D magnet ± eight Gauss at 160 Hz; and a barometer ± 1200 mbar at 100 Hz. For the registration of the spatial positioning, speed, and acceleration, the device integrates two sensors:

Global Navigation Satellite System and Global Position System GNSS/GPS at 10Hz (numbers of satellites = 8.96; SD = 1.56), compatible with Galileo and Ultra Wave Band (UWB) at 18 Hz; the use of the latter requires the installation of an antenna system around the sports hall. The device has four communication interfaces: WIFI 802.11 b/g/n, Wireless BLUETOOTH, Wireless ANT+, and USB 2.0 (High speed). The recorded data are stored in a 16GB internal flash memory. The device has an internal battery with a four-hour duration, it weighs 70g, and its dimensions are 81x45x16 mm. For collecting, processing, and reporting GPS data, Malone et al.'s [26] applications and considerations were considered (i.e., soccer players should wear the devices in appropriate tight-fitting garments in the upper part of the back to hold the device and minimize unwanted movement; they should also ensure that devices have satellite connection before any data collection [known as GPS lock] and the devices were placed in a clear outdoor space to allow sufficient time to achieve GPS lock).

Measured variables

Data of the following variables related to movements and speeds were collected:

Total Distance: distance covered in meters (m) by a soccer player during a match, regardless of the position occupied on the pitch.

Distance per minute: distance covered per minute (m) during the time a soccer player participates. It is a relative variable indicating load.

Average Speed: average speed (Km/h) at which the soccer player moves during the game time in which he participates in the match.

Maximum Speed: peak speed (Km/h) reached by a soccer player in a match.

In accordance with Carling [24], distance covered at six different intensities were established:

- *Speed 0–6 Km/h*: Walking.
- *Speed 6–12 Km/h*: Jogging.
- *Speed 12–18 Km/h*: Running.
- *Speed 18–21 Km/h*: Intense running.
- *Speed 21–24 Km/h*: Sprinting at low intensity.
- *Speed more than 24 Km/h*: Sprinting at high intensity.

Statistical analyses

All statistics were analyzed using IBM SPSS Statistics 24.0 version and Microsoft Excel. First, the descriptive statistics were calculated for both instruments. Bland-Altman plot was created to assess the agreement between methods and determine the systematic bias ± random error and limits of agreement for each variable [27, 28], analyzing the means difference found between the two systems and their limits of agreement (M+/- SD*1.96). Linear regression of the average of the two measures with respect to the means difference were calculated to determine the proportional bias in differences between the methods.

However, as Hopkins pointed [29], this method can be sensitive to small errors and to the size of the sample. For this reason, a linear regression in the data obtained with Mediacoach with respect to Wimu Pro was conducted, and standardized mean bias (SMB) and typical error of the estimate (TEE) were calculated. The magnitude of the effects was evaluated according to [29]. The SMB was rated as *trivial* (< 0.19), *small* (0.2 to 0.59), *medium* (0.6 to 1.19, or *large* (1.2 to 1.99), and the TEE was rated as *trivial* (< 0.1), *small* (0.1 to 0.29), *moderate* (0.3 to 0.59), or *large* (> 0.59) [29]. Also, based on 95% confidence limits (95% CL), the

Table 1. Differences between Mediacoach System and Wimu Pro data using Bland and Altman's method with 95% confidence limits.

Variables	Wimu	Medicoach	Bias	Estimate (SD*1.96)	Lower CL	Upper CL	*r*	f^2
Total Distance:	4525.7±1309.8	4628.7 ± 1346.5	103.08	167.43	-64.35	270.51	.43	.22
Distance/Minute:	107.8±18.1	110.1 ± 18.5	2.34	3.97	-1.63	6.30	.17	.02
Speed:	6.8±1.0	6.7 ± 1.1	-0.15	-0.39	-0.53	0.24	.38	.16
Maximum Speed:	29.5±3.3	29.2 ± 2.9	-0.39	2.28	-2.66	1.88	.29*	.09
Walking:	1453.5±417.2	1404,7 ± 413.2	-48.75	117.25	-166.01	68.49	.06*	.00
Jogging:	1589.7±578.3	1593.1 ± 579.7	3.44	99.07	-95.62	102.50	.03	.00
Running:	1038.7±437.5	1125.6 ± 466.1	86.92	123.25	-36.33	210.16	.44	.25
Intense Running:	228.8±106.9	256.2 ± 118	27.41	45.85	-18.44	73.26	.48	.30
Sprinting at LI:	124.1±66.4	143 ± 74.9	18.90	34.57	-15.66	53.47	.48	.30
Sprinting at HI:	98.2±64.7	114.5 ± 73.7	16.34	33.15	-16.83	49.50	.57	.46

Notes. LI = Low Intensity; HI = High Intensity.

* = Negative trend.

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agreement between the criterion measures was assessed using an Excel spreadsheet to calculate the mean bias [29].

Next, the degree of agreement between Wimu Pro and Mediacoach was analyzed using the intraclass correlation coefficient (ICC) and the coefficient of variation (%) of each variable. The following criteria were adopted to interpret the magnitude of the ICC: *trivial* ($\leq$ 0.1), *small* (> 0.10 to 0.30), *moderate* (> 0.30 to 0.50), *large* (> 0.50 to 0.70), *very large* (> 0.70 to 0.90), and *almost perfect* (> 0.90 to 1.00). Finally, the regression equation to estimate Wimu Pro data from Mediacoach data for each variable was calculated.

Results

Descriptive statistics of each of the variables analyzed by the two instruments, Mediacoach System and Wimu Pro, are displayed in Table 1. It can be observed that, compared to Wimu Pro, the Mediacoach slightly overestimated average distance, distance per minute, jogging, running, intense running and sprinting at low and at high intensity, whereas it underestimated average speed, maximum speed and walking variables.

In accordance with Bland and Altman's method [27,28], the plots of the all variables were analyzed and systematic errors were found in some variables. The linear regression calculated presents a proportional systematic bias with a positive trend in all the variables, except for maximum speed and distance covered between 0 and 6 km/h (i.e., walking), showing a negative trend in these two variables. Considering the proposal of Cohen [30], the value of f^2 for the size of the effect shows that these differences are small or medium, except for the case of sprinting at high intensity. For this reason, we decided to analyze the concurrent validity between the two measures [29], with the aim of clarifying and giving consistency to the results.

As can be seen in Table 2 all SMBs were rated as *trivial* (< .14), and TEEs were rated as *trivial* (< 0.1) in total distance and jogging, and as *small* (0.1 to 0.29) in distance per minute, average speed, walking, running, intense running, sprinting at low and at high intensities. Finally, TEE was rated as *moderate* (0.3 to 0.59) in the maximum speed variable. The magnitude of the ICC was rated as *almost perfect* (> 0.90 to 1.00) for all variables. The coefficient of the variations between devices were close to zero (< 5%) in total distance, distance per minute, average speed, maximum speed, walking and jogging, and between 9% and 15% for running, intense running, sprinting at low and high intensities.

Table 2. Comparison of each Variable analyzed by Mediacoach System and Wimu Pro Data, including Standardized Mean Bias, Typical Error of Estimate (TEE), intraclass correlation coefficient (ICC), and coefficient of variation (CV), all with 95% confidence limits.

	Total Distance	Distance–Minute	Average Speed	Maximum Speed	Walking	Jogging	Running	Intense Running	Sprinting at low intensity	Sprinting at high intensity
Standardized Mean Bias	-0.02	-0.01	0.12	0.14	-0.12	-0.01	0.02	0.00	0.02	0.02
95% CLs	[-0.04 to -0.01]	[-0.05 to 0.03]	[0.09 to 0.16]	[-0.02 to 0.31]	[-0.16 to -0.08]	[-0.03 to 0.01]	[0.00 to 0.05]	[-0.03 to 0.03]	[-0.02 to 0.05]	[0.00 to 0.05]
	Trivial	*Trivial*	*Trivial*	*Trivial*	*Trivial*	*Trivial*	*Trivial*	*Trivial*	*Trivial*	*Trivial*
Standardized TEE	0.06	0.11	0.17	0.38	0.14	0.09	0.12	0.18	0.22	0.20
95% CLs	[0.05 to 0.06]	[0.10 to 0.12]	[0.16 to 0.19]	[0.35 to 0.41]	[0.13 to 0.16]	[0.08 to 0.09]	[0.12 to 0.13]	[0.17 to 0.20]	[0.21 to 0.24]	[0.18 to 0.21]
	Trivial	*Small*	*Small*	*Moderate*	*Small*	*Trivial*	*Small*	*Small*	*Small*	*Small*
ICC	0.99	0.99	0.98	0.94	0.99	0.99	0.98	0.96	0.94	0.97
95% CL	[0.92 to 1.00]	[0.90 to 1.00]	[0.91 to 0.99]	[0.90 to 0.96]	[0.92 to 0.99]	[0.98 to 1.00]	[0.72 to 0.99]	[0.71 to 0.98]	[0.71 to 0.98]	[0.75 to 0.98]
	Almost Perfect	*Almost Perfect*	*Almost Perfect*	*Almost Perfect*	*Almost Perfect*	*Almost Perfect*	*Almost Perfect*	*Almost Perfect*	*Almost Perfect*	*Almost Perfect*
% CV	1.8	1.8	2.7	4.0	4.2	3.8	6.8	10.4	13.5	14.9

Notes. CLs = Confidence Limits. Distances covered in different speed sectors: Walking = 0–6 Km/h; Jogging = 6–12 Km/h; Running = 12–18 Km/h; Intense Running = 18–21 Km/h; Sprinting at low intensity = 21–24 Km/h; Sprinting at high intensity = > 24 Km/h.

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On the other hand, regarding the proposal to generate an equation that would allow us to validly exchange the data obtained with the two systems, the following procedure was conducted. First, one half of the sample was selected (N = 380) to analyze a linear regression analysis between the two systems. The regression equation to estimate Mediacoach data from Wimu Pro data (Table 3) for each variable is:

$$Y\,(\mathrm{Wimu\ \ data}) = (\mathrm{slope} * X\,(\mathrm{Mediacoach\ \ data})) + \mathrm{intercept}\,(\mathrm{residual\ \ errors}).$$

Where Y is the estimated Wimu Pro datum, and X is the Mediacoach datum for a given variable. The intercept represents residual errors in meters (distance variables) or km/h (speed variables). Next, it was compared with the second half of the sample to examine whether the

Table 3. The regression equations for each variable in the study.

Variables	Equations	ICC	Bias	SMB	TEE
Total Distance	y = 0.971x + 29.653 m	.999	-5.20	0.00	0.06
Distance/Minute	y = 0.977x + 0.115 m	.998	-.05	-0.01	0.10
Speed	y = 0.914x + 0.770 m/s	.992	.05	0.03	0.17
Maximum Speed	y = 1.041x – 0.787 m/s	.966	.05	0.01	.28
Walking	y = 1.002x + 35.458 m	.995	-9.92	-0.04	0.14
Jogging	y = 0.988x + 14.036m	.998	-.77	0.01	0.09
Running	y = 0.927x – 3.756 m	.996	.76	0.01	0.12
Intense Running	y = 0.892x + 1.055 m	.991	.71	0.00	0.19
Sprinting at LI	y = 0.869x + 0.034 m	.988	.10	0.00	0.22
Sprinting at HI	y = 0.858x + 1.059 m	.989	1.12	0.02	0.21

Notes. LI = Low Intensity; HI = High Intensity.

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equation adjusted correctly and to determine whether the application of the values to Mediacoach were valid compared with the values of Wimu Pro.

Discussion

The main aim of this study was to compare two systems designed and developed to measure the movement demands of soccer. Using two different methods [27, 29], and considering the terms of agreement between the systems, similar data were obtained from the Mediacoach System and from the Wimu Pro in the total distance covered, distance per minute traveled, average and maximum speed and covered distance in several speed sectors. These findings are in line with those reported by other authors in different studies focused on analyzing the movement loads during soccer matches [18]. In this sense, very similar results were registered in the total distances covered and the distances traveled in different speed intervals recorded by the two systems compared to other results found in previous research [10].

In according to the results obtained in this study, we highlight that the Mediacoach System systematically overestimated the scores of the distance variables, except for distance covered at 0–6 km/h, compared to the Wimu Pro. Conversely, average speed and maximum speed variables (i.e., variables analyzed in Km/h) reached higher values with the Wimu Pro system than with Mediacoach. Also, after analyzing the values of the regression of the averages with respect to the means differences, a positive systematic error was found in all the variables examined, except for the maximum speed and the distance covered between 0 and 6 km/h (i.e., walking). These results are consistent with the findings of most previous studies [31] concluding that both GPS technology and the computer-based tracking system involve systematic errors, overestimating the distance traveled, although this is the first study focused on evaluating performance indicators with professional soccer players during official matches and in a full season.

We emphasize that these errors are relatively small and predictable, so it is considered that the use of either of these technologies should be promoted in order to monitor players' movements. Thus, the standardized mean bias was *trivial* for all variables, with a *trivial* and *small* TEE, except for maximum speed, where TEE was *moderate*. The ICCs between the two systems were *almost perfect* in all the analyzed variables.

Other studies have shown that multiple camera semiautomatic systems tend to report slightly-to-moderately [18] and moderately-to-largely [32] greater distances covered at medium and high intensity than GPS technology. In these investigations, results highlighted that all the systems similarly detected the fatigue produced during the match, and there were differences between the instruments in the estimation of the distances traveled in each of the speed categories. Greater total distances were recorded (around 1 km) with VID and 5-Hz GPS systems than with 1 Hz GPS devices, and the video system [10] demonstrated that, whereas there were small between-system differences in total distance, ProZone (VID) tended to report greater distances at high speed than the other three systems.

Linke, Link, and Lames [11] also assessed the measurement accuracy of the most commonly used tracking technologies in professional team sports (i.e., semi-automatic multiple-camera video technology, LPS and GPS), concluding that differences between technologies were not as pronounced in distances and speeds, but all technologies had in common that the magnitude of the error increased as the speed of the tracked object increased. Results revealed technology-dependent accuracy variations in the video tracking system. As the movement direction of the shuttle run was conducted on the vertical (perpendicular) camera axis (Y-axis), video tracking tended to overestimate the peak speed during shuttle runs. In our case, differences between the two systems were smaller than in previous studies, possibly due to the technological advances of the two information collection procedures. In recent years, a huge effort has been made to improve GPS technologies [24, 33] and to increase the number of cameras to have greater coverage of the stadium from more angles and to improve the resolution quality of the cameras to automatically detect and track each player by his identification number [34].

On another hand, most studies have been carried out in non-ecological environments by creating circuits that simulate real competition conditions [19]. However, it is interesting to note that this is the first time that a VID is compared with real tracking data during official matches using a GPS device. Moreover, we highlight that the measurements were taken in very different environmental situations, stadiums in different geographical locations at different times, compared to other studies that have been carried out in a single stadium at a specific time [35].

Another very interesting finding of this research is the development of predictive equations that allow interchanging data from the two different systems. In this line, Buchheit and Simpson [4] consider that the ideal system does not yet exist, and that all systems have advantages and disadvantages. To allow for an adequate evaluation of a player's overall movement load, and to integrate the data from different systems accordingly, practitioners are recommended to use calibration equations. In our case, we have confirmed the equations that allow us to determine the distances and speeds that players would reach in the Wimu Pro when collected through the Mediacoach System or vice versa. Few researches have been able to generate this equation with a referent sample and from an ecological perspective. This implies added system interchangeability as an important point for practitioners in professional clubs, who often use two different systems over the week [10].

Limitations and practical applications

Some limitations were detected during the development of this study. Despite comparing some movement demands in the two systems to understand players' workload during the match, it would also have been interesting to analyze accelerations and decelerations variables [4]. Finally, we point out that the systems used are not totally accurate, so it would be interesting to compare them with the VICOM system to determine the degree of agreement [11].

The development of this kind of study can also generate several interesting benefits and practical applications for professionals and researchers. Firstly, the use of these advanced approaches furthers our understanding of specific position work-rate profiles of soccer players and their fitness requirements, the intensities of discrete activities during the match, and the occurrence of a reduced work-rate among players [36]. In addition, knowledge of these variables related to players' physical load volume and intensity during the match can be provided from a scientific perspective in order to better understand game situations, improve task training from these situations, and design models that allow us to improve performance or prevent injuries, and optimize the control and quantification of loads for the individualization of training [4].

On another hand, as we have established the equations that allow interchanging data between the two systems analyzed, many clubs could benefit from this. The multi-camera video Mediacoach System is a non-intrusive method, avoiding various problems that may arise in the players. Also, this study can resolve the problems that the GPS appears to have in certain stadiums or climatic conditions that block the signal, and data from competitions can be obtained that can be used later by coaches and researchers. However, and taking into account all the above, we are aware that we must be cautious about the interchangeability of the data and continue to improve the accuracy of GPS. In the future, this could be applied to other systems of analysis.

In this line, the Mediacoach System also allows analyzing technical-tactical behaviors (e.g., the specific position of the ball) that occur during the game, or players' specific technical actions, a matter that has been considered essential in the latest contributions of performance analysis [3, 37]. Many authors have proposed the need to integrate all these variables to gain complex knowledge of individual and collective behavior during matches, which can be used to make objective decisions to structure the training elements and for subsequent match preparation [22, 23, 38].

Finally, as the Mediacoach System registered the last 10 seasons in the LaLiga competitions (First and Second Division), studies that allow us to longitudinally compare the evolution of the game demands can be performed. This can help coaches and researchers to improve their knowledge of the game of soccer and enable closer monitoring of aspects such as the evolution of the physical demands over time [8]. In addition, this device will enable us to analyze specific performance demands related to other variables such as high speed running distance, high metabolic load distance, acceleration and deceleration. . . even considering different match situations.

To sum up, we highlight the advantages and disadvantages of using the two systems to determine in greater depth the characteristics and demands of this sport in real situations. GPS contributes precision, immediacy and informational richness about external and internal load [22], but it also presents some problems in the estimate measurements [11], and cannot be used with court-based sports held indoors, due to the lack of satellite reception [39]. On another hand, VID is a technology which does not require players to have any equipment attached to them and allows researchers with access to the trajectory data to study movements of individual players and teams and the interactions between them [8]. However, VID does not allow access to internal variable information. Due to all these issues, we consider that these technologies are not opposed and that they offer many possibilities of collaboration.

Conclusion

This study reveals a good agreement in the comparison of two systems designed to analyze each player's movement demands in professional soccer performance. Specifically, the Mediacoach System slightly overestimates the variables analyzed in meters such as total distance covered, distance per minute, and distance covered in several speed sections (except for *walking*), whereas the Wimu Pro overestimates variables measured in Km/h such as average speed and maximum speed. Therefore, these data provide high ecological relevance to analyze real match situations related to physical demands. In addition, the bases have been established to generate predictive equations that allow exchanging data with other analytical devices, with the benefits that this can imply for practitioners and researchers.

Permissions statements

The authors declare that all appropriate permissions have been obtained from Mediacoach System and Wimu Pro for the use of these systems in this research and in subsequent publications.

Supporting information

S1 File. Data Mediacoach and Wimu.xls.
(XLS)

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Estudio II: Integrating video tracking and GPS to quantify accelerations and decelerations in elite soccer. (**En Revisión**)

Eduard Pons, Tomás García-Calvo, Francesc Cos, Ricardo Resta, Hugo Blanco, Roberto López del Campo, Jesús Díaz García, and Juan José Pulido (2021). Integreation vídeo tracking and Gps to quantify accelerations and decelerations in elite soccer (En Revisión)

Integrating video tracking and GPS to quantify accelerations and decelerations in elite soccer

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Abstract

The aim of this study was to analyze the degree of agreement comparing number and distances covered in different acceleration and deceleration sections registered by a video tracking system (MEDIACOACH) and a GPS device (WIMU PRO) during official competition. Data during an overall season from a Spanish professional club were registered. First, the descriptive statistics presented more bursts of accelerations and decelerations in WIMU PRO than in MEDIACOACH, whereas the distances covered recorded by both systems were similar. Second, negative relationships were found (i.e., negative bias) comparing WIMU PRO with MEDIACOACH in the number of accelerations and decelerations between 0/1 m/s^2 and ½ m/s^2 ($p < .05$), and in the distances covered in accelerations and decelerations ($p < .05$) between 0/1 m/s^2 and in accelerations and decelerations registered between 2/3 m/s^2 and more than 3 m/s^2. Moreover, the different in means (i.e., standardized mean bias) across the two devices were *trivial* (>0.19) and *small* (0.2-0.59) for most variables. The standardized typical error of the estimate (TEE) were *moderate* (0.3-0.59) and *small* to *moderate* (0.1-0.29 - 0.3-0.59), respectively. Also, the Intra class Correlation Coefficients (ICCs) for agreement and consistency between systems showed *good* and *excellent* values (>0.90). The magnitude of change in means (%) between systems, defined as the percentage change between the numbers or values, was below 14% and 7% for number and distances covered, respectively. All scores in the smallest worthwhile change were lower than 9% and in the coefficients of variation were lower than 9 and 15%, respectively. Thus, both systems demonstrated an acceptable agreement and could be useful to analyze players' acceleration demands in professional soccer. However, caution is required when interpreting the results and a comparison with a gold standard is required to valid the both systems.

***Keyword*s**: accelerometry, GPS, agreement, performance, soccer, video tracking system.

Introduction

The quantification of the competition demands allows to improve the specificity of the training load and indicates the subject's capacity to adapt to the demands of competition. In recent years, many studies have compared physical demands in professional soccer by analyzing the distances covered at varying thresholds of speed intensity [1, 2]. However, assessing soccer performance only with these variables may underestimate a player's true workload during soccer match due to a lack of consideration of the physiological and biomechanical data associated with acceleration and deceleration. [3]. In this line, the proposal of this study was to quantify accelerations and decelerations in professional soccer matches using two systems, in order to exchange the data obtained.

The challenge of obtaining data on accelerations and decelerations can be addressed using three main technological approaches: i) Global Positioning System (GPS), ii) Local Positioning System, and iii) semi-automatic multiple-camera Video Tracking Systems [4]. GPS is used to measure external load, which is the psychophysiological responses of players to the efforts, via accelerations, both in training and in matches [5]. However, GPS lacks the accuracy required to measuring explosive accelerations, which may be because the commonly used threshold cutoff of $0.6m/s^2$ results in low acceleration counts [6], although newer GPS models allow greater analytical filtering [7]. Video Tracking System is used to analyze load variables, such as meters traveled and speeds reached [8]. There has been limited research into the use of Video Tracking Systems to record accelerations in soccer, but some evidence supports the validity of using Video Tracking Systems to record accelerations [1, 9].

Various studies have compared accelerometry data from GPS and Video Tracking Systems in the training setting. For instance, Randers et al. [10] showed significantly differences between systems, where GPS tended to provide lower values than Video Tracking Systems in high-acceleration races, while this trend was reversed in low acceleration situations. These conclusions are supported by the findings of other research comparing PROZONE and GPS devices [11, 12]. Finally, Linke and Lames [13] found that neither GPS nor Video Tracking Systems provide valid data for measuring high intensity activity.

Based on aforementioned, it seems necessary to continue investigating the relationship between two devices to quantify the external load of professional soccer players with the objective to understand better the sport demands. More specifically, using MEDIACOACH and WIMU PRO it would be possible to quantify acceleration and deceleration when assessing the external load because of its importance as a biomechanical stress (e.g., impacts) and its importance at the intramuscular and eccentric level (e.g., ability to sustain high force output and attenuation) [14]. In this sense, not only the number of accelerations or decelerations shows the external load caused by these efforts, and other parameters like the distances covered with certain acceleration or deceleration values allow describing more precisely a profile of acceleration/deceleration efforts [14]. In addition, this study was developed in real soccer competition, different to the majority of the previously studies that have been developed in non-ecological environments that merely simulate competition conditions [15].

Therefore, the objective of this study were to compare the specified accelerations and decelerations values obtained during official competitions by two devices, the MEDIACOACH and WIMU PRO. Specifically, we evaluated the degree of agreement between these systems in the number of accelerations and decelerations and the distances covered in each. As a secondary outcome, we also developed mathematical functions that allow us to exchange data between these models.

Materials and methods

Subjects

This study included all 26 professional male soccer players from FC Barcelona B team (mean ± SD age 20.38 ± 2.03 years; height 180.00 ± 7.47 cm; weight 73.81 ± 5.65 kg) (except goalkeepers, due to the specific demands of this position). We recorded the data of the players in the course of all the matches of the 2017/18 Spanish 2nd division (n = 42), and a total of 759 measurements were captured by MEDIACOACH and WIMU PRO at the same time.

Recordings and Procedure

To synchronize both systems with all the players in the team (including substituted players), we used a reconfiguration technique described by Carling [16]. Specifically, before fitting players with the WIMU PRO unit, the device was calibrated and synchronized according to the manufacturer's recommendations: i) we turned on the device, ii) waited for ~30 seconds, iii) and once the operating system had initialized, we pressed the record button to start recording, and iv) placed the devices on the player.

In addition, to allow the comparison of data between both systems and to avoid valuation errors, samples were recorded from each half of the matches separately (n = 347 first half; and n = 332 second half). Due to soccer characteristics, many players remove/change their shirts at half-time and there are signal losses that make synchronization between the two devices not possible during this period of time. More specifically, the datasets from the GPS were adjusted with regard to the VID system (i.e. adjusting the GPS recordings according to the VID registers, always at the beginning of each half). Moreover, data from some matches were deleted because an intermittent signal loss was detected when the raw data were downloaded from the GPS device or the optical tracking camera. A total of 91 measurements were excluded (13.4%), resulting in a total of 679 measurements analyzed. More specifically, the matches pertaining to the 29th and 39th rounds were eliminated since these errors of measurement were found in the GPS devices (i.e. outlier data in some players), and the 5th and 10th rounds were eliminated due to visual technical problems detected in the VID.

The procedure was carried out in accordance with relevant guidelines and regulations. Specifically, the study received ethical approval from the second author's university; Vice-Rectorate of Research, Transfer and Innovation - Delegation of the Bioethics and Biosafety Commission (Protocol number: 153/2017) of University of Extremadura, Spain. Players received verbal and written information regarding the nature of their voluntary participation in the study and informed consent was obtained from all of them. In addition, all participants were treated according to the American Psychological Association ethical guidelines regarding consent, confidentiality, and anonymity.

Instruments

MEDIACOACH. The MEDIACOACH system (Mediapro, Barcelona, Spain) consists of a series of super 4K- High Dynamic Range cameras based on a positioning system (Tracab - ChyronHego Video Tracking System) that record from several angles and analyze X and Y positions for each player, thus providing real-time three-dimensional tracking. This device is also based on the correction of the semi-automatic Video Tracking Systems (the manual part of the process). This adjustment is made by overlaying the X-coordinate provided automatically by the system for each player onto the actual video image of the match. MEDIACOACH detects and corrects situations in which the positioning coordinates are erroneous because they do not correspond to the position of the corresponding player.
If position datum is completely noise-free, these performance metrics can be computed directly: distance can be recorded frame by frame and the changes in numerical position provides the acceleration values. In the present study, the position data generally contained noise, so this direct approach overestimates distance and speed such that the data need to be filtered to attenuate the effect of noise on the results. To achieve this, we calculated acceleration as the derivative of speed, and applied a smoothing speed signal with a central moving average (rolling average) of two values. After obtaining the acceleration curve, we applied smoothing with a central moving average of 25 values. The MEDIACOACH signal during data collection was 25 Hz (25 frames per second, or 1 data point every 40 ms), so values above $3 m/s^2$ were defined as accelerations. If there was more than one value above the threshold in the same acceleration curve, we retained the highest value. The procedure for recording high-intensity decelerations was the same, but the threshold was $-3 m/s^2$.

WIMU PRO PRO. The WIMU PRO device (Realtrack Systems, Almería, Spain) is comprised of different sensors, including four accelerometers, three gyroscopes, a magnetometer, a global navigation satellite system chip (GNSS; *M* = 8.96; *SD* = 1.56) and a UWB chip. It also has a microprocessor, 8 GB of flash memory, a high-speed USB interface to record, store, and share data for further analysis, and an internal battery with four hours of autonomy. It weighs 70 grams and measures 81x45x16 mm. WIMU PRO uses two devices to determine location, and these can be used simultaneously to record the player's position. In our study (i.e. outdoor conditions), the GNSS determines the position (coordinates) in relation to the time of emission and reception of the signal by radiofrequency on a bandwidth above 500 MHz. The GNSS sampling frequency was 10 Hz. Location technology [17] and accelerometers [18] allow us to obtain the distance covered and speed directly, while the other variables analyzed are manually calculated or obtained from other variables. We smoothed the speed and acceleration data using a central moving average of six and four values, respectively. The GPS signal during data collection was 10 Hz (10 frames per second, or 1 data point every 100 ms), so values higher than $3 m/s^2$ (for 100 ms) were considered to be acceleration. Again, if the acceleration curve had more than one value above the threshold, we retained the highest value. Finally, the process of recording high-intensity decelerations was the same used for MEDIACOACH. Also, vests designed specifically to hold the devices, located in the player's upper torso, and anatomically adjusted to each player, as previously described, were used [19].

Measured Variables

We collected data on the number of accelerations and decelerations for each player during each match, and the distances they covered. We collected data for all player positions, and for each of the following ranges [20] we recorded the number of accelerations and decelerations and the distance covered in meters (m):

Acceleration from 0 to 1 m/s^2 and deceleration from 0 to -1 m/s^2.
Acceleration from 1 to 2 m/s^2 and deceleration from -1 to -2 m/s^2.
Acceleration from 2 to 3 m/s^2 and deceleration from -2 to -3 m/s^2.
Acceleration from > 3 m/s^2 and deceleration from > -3 m/s^2.

Statistical analysis

Data were analyzed using the SPSS Statistics 23.0 software [21] and Microsoft Excel with a customized spreadsheet from Hopkins [22]. Firstly, the descriptive variables were expressed as the mean and standard deviation (see Table 1). Subsequently, using the Bland and Altman procedure [23], MEDIACOACH and WIMU PRO statistics were calculated to detect systematic bias ± random error in the sample, and Standard Error of Measurement (SEM) = standard deviation of the sample/√ (sample size) and 95% CLs = Mean ± (SEM x 1.96). Moreover, in order to determine the proportional bias between the methods, we fit a linear regression of the average of the data collection from the two devices with regard to the differences between means, testing β and Cohen's f^2 method of effect size (see Table 2) [24].

However, as Hopkins has pointed out [25], this method could be sensitive to small errors and sample size. Thus, according to Hopkins' recommendation, a linear regression analysis to compare the error and differences between the systems was conducted to test the validity between the systems. Consequently, we calculated the standardized mean bias (SMB) and the typical error of the estimate (TEE). We rated the SMB as *trivial* (<0.19), *small* (0.2-0.59), *medium* (0.6-1.19), or *large* (1.2-1.99). We also rated the TEE as *trivial* (<0.1), *small* (0.1-0.29), *moderate* (0.3-0.59), or *large* (> 0.59). We assessed the level of agreement between the measured criteria by calculating the mean bias [21] based on 95% CLs (see Table 3 and Table 4).

In addition, we analyzed the reliability between the WIMU PRO and MEDIACOACH data using the intraclass correlation coefficient (ICC; 3,1). Values less than 0.5 are indicative of *poor* reliability, values between 0.5 and 0.75 indicate *moderate* reliability, values between 0.75 and 0.9 indicate *good* reliability and values above 0.9 indicate *excellent* reliability [26]. We also calculated the percentage least-square means difference (WIMU PRO -MEDIACOACH) and qualitative magnitude-based inference [25]. The magnitude of changes was interpreted as follows: <0.20 *trivial*, 0.20-0.59 *small*, 0.60-1.19 *moderate*, 1.20-1.99 *large*, 2.0-3.9 *very large*, >4.0 *extra-large* [25]. The typical error percent coefficient of variation (CV) and the Smallest Worthwhile Change (SWC) for each variable were also estimated.

The CV is considered to be the noise of the signal and the SWC the change due to the signal. The recommendation is for the CV to be lower than 10%, although this depends on the context and the data [25]. It is recommended that the SWC be greater than the CV [25] (see Table 3 and Table 4).

Finally, a function that would allow us to interchange the data obtained by the two systems was generated. More specifically, a linear regression analysis was conducted using the data from half of the randomized sample, and from this obtained the following regression equation, which estimates the WIMU PRO value that would be expected when we input data from MEDIACOACH for each variable: Y (WIMU PRO data) = (slope * X (MEDIACOACH data)) + intercept (residual errors), where Y is the estimated WIMU PRO value and X is the MEDIACOACH value for a given variable. The intercept represented residual errors in meters (distance variables) or number of accelerations and decelerations (variables). Moreover, another part of the randomized sample was used to test the cross-validation (see Table 5).

Table 1. *Descriptive statistics comparing the data obtained by Mediacoach and Wimu systems.*

	Number of Acc 0 to 1 m/s²	**Number of Acc 1 to 2 m/s²**	**Number of Acc 2 to 3 m/s²**	**Number of Acc > 3 m/s²**	**Number of Dec 0 to -1 m/s²**	**Number of Dec -1 to -2 m/s²**	**Number of Dec -2 to -3 m/s²**	**Number of Dec > -3 m/s²**
Mediacoach®	857.6 ± 243.4	147.7 ± 41.4	63.7 ± 18.9	31.7 ± 2.31	868.6 ± 243.5	136.6 ± 69.7	55.2 ± 17.7	36.4 ± 12.1
Wimu Pro™	1041.0 ± 272.8	159.8 ± 45.7	63.6 ± 18.9	29.9 ± 1.98	1033.9 ± 269.7	167.6 ± 70.6	57.9 ± 17.8	34.6 ± 11.7
	Distance Acc 0 to 1 m/s²	**Distance Acc 1 to 2 m/s²**	**Distance Acc 2 to 3 m/s²**	**Distance Acc > 3 m/s²**	**Distance Dec 0 to -1 m/s²**	**Distance Dec -1 to -2 m/s²**	**Distance Dec -2 to -3 m/s²**	**Distance Dec > -3 m/s²**
Mediacoach®	1052.7 ± 262.4	877 ± 253.5	512 ± 143.3	286.7 ± 98.2	1087.6 ± 273.4	612.9 ± 174.5	268.2 ± 89.0	167.1 ± 63.2
Wimu Pro™	1078.8 ± 269.2	858.5 ± 249.6	498.9 ± 146.9	262.2 ± 95.1	1016.5 ± 253.2	601 ± 170.2	266.4 ± 84.8	173.5 ± 62.9

Notes. Acc. = Accelerations; Dec. = Decelerations.

Results

Table 1 summarizes the descriptive statistics comparing the data obtained by the two systems. Regarding the number of accelerations and decelerations recorded at different intensities, WIMU PRO recorded more accelerations and decelerations at low intensities, whereas MEDIACOACH recorded a slightly higher number of accelerations and decelerations at high intensities. With regard to the distances covered in different accelerations and decelerations, WIMU PRO recorded a slightly greater distance in accelerations between 0 and 1 m/s^2 and in decelerations higher than -3 m/s^2, whereas MEDIACOACH recorded slightly greater distances traveled in accelerations and decelerations in the remaining ranges.

In Table 2, according to Bland and Altman [23], the linear regression presents a proportional (i.e. not constant) bias in some variables. More specifically, negative biases were found in the number of low-intensity acceleration (0/1 m/s^2, $\beta = -.34$, $p < .05$; and 1/2 m/s^2, $\beta = -.21$, $p < .05$), and deceleration sections (0/-1 m/s^2, $\beta = -.32$, $p < .05$; and -1/-2 m/s^2, $\beta = -.30$, $p < .05$), whereas negative biases were found in 0/1 m/s^2 in distance covered and in all high-intensity acceleration and deceleration sections. This indicates that the measurement error decreases as the recorded score increases in most variables. Also, the effect size calculated for the f^2 value ranged between .00 and .12 in the number of acceleration and deceleration sections and between .00 and .08 for the distance covered in each one, all considered small [24].

Table 2. *Bland and Altman 95% confidence limits of the number and the distance covered in different accelerations and decelerations sections.*

Variables	Bias	Estimate (sd*1.96)	Lower CL	Upper CL	β	f^2
Number of Acceleration-Deceleration						
Acceleration 0/1m/s²	-181.31	167.06	-348.37	-14.25	-.34*	.12
Acceleration 1/2m/s²	-12.08	40.06	52.15	27.98	-.21*	.04
Acceleration 2/3m/s²	0.14	17.45	-17.31	17.59	.00	.00
Acceleration >3m/s²	1.79	10.14	-8.36	11.93	-.02	.00
Deceleration 0/-1m/s²	-165.31	161.74	-327.06	-3.57	-.32*	.11
Deceleration -1/-2m/s²	-31.17	46.05	-77.23	14.88	-.30*	.09
Deceleration -2/-3m/s²	-2.66	16.92	-19.58	14.27	-.01	.00
Deceleration >-3m/s²	1.81	11.63	-9.82	13.44	.07	.00
Distance in Acceleration-Deceleration						
Acceleration 0/1m/s²	-25.83	119.08	-144.91	93.25	-.10	.01
Acceleration 1/2m/s²	18.44	138.71	-157.15	120.26	.05	.00
Acceleration 2/3m/s²	-13.09	128.43	-141.52	114.34	-.03	.00
Acceleration >3m/s²	-24.50	93.43	-117.94	68.93	-.06	.00
Deceleration 0/-1m/s²	71.15	134.04	-205.19	62.89	.29*	.08
Deceleration -1/-2m/s²	11.98	111.57	123.55	99.59	.07	.00
Deceleration -2/-3m/s²	-1.82	86.64	-88.47	84.82	-.09	.01
Deceleration >-3m/s²	-5.49	56.82	-50.33	63.30	.01	.00

Comparing the number of accelerations [22, 25, 26] detected by the two instruments (Table 3), we found a *trivial* and *small* differences in SMB, except for the differences recorded in the number of accelerations from 0 to 1 m/s^2 and decelerations below ± 2 m/s^2 (i.e. *moderate*). Regarding the standardized TEE, all variables presented *moderate* scores. The ICC presented good agreement between both systems, with values above or close to 0.90, classified as *good* (i.e. in the number of accelerations and decelerations at more than 3 m/s^2), and as *excellent* (i.e. in the other acceleration and deceleration ranges). The magnitude of change in means (%) was *moderate* at low-intensity accelerations and decelerations and *small* to *trivial* at high-intensity accelerations and decelerations. The SWC (%) obtained scores ranging between 7.6-8.3%. Finally, the % of CV for all variables was between 6-13.7%.

Table 3. *Comparison of each variable in the number of acceleration/deceleration in different sections analyzed by Mediacoach and Wimu data, including Standardized Mean Bias, Typical Error of Estimate (TEE), Intraclass Correlation Coefficient (ICC), % Change Mean, % Smallest Effect and % Coefficient of Variation (CV), of all with 95% confidence limits.*

	Number of Acc. 0 to 1 m/s²	**Number of Acc. 1 to 2 m/s²**	**Number of Acc. 2 to 3 m/s²**	**Number of Acc. > 3 m/s²**	**Number of Dec. 0 to -1 m/s²**	**Number of Dec. -1 to -2 m/s²**	**Number of Dec. -2 to -3 m/s²**	**Number of Dec. > -3 m/s²**
Agreement Analysis								
Standardised Mean Bias	-0.66	-0.26	0.01	0.17	-0.61	-0.68	-0.15	0.15
95% CLs	[-0.68 to -0.64]	[-0.29 to -0.23]	[-0.02 to 0.04]	[0.14 to 0.21]	[-0.63 to -0.59]	[-0.72 to -0.65]	[-0.18 to 0.12]	[0.12 to 0.18]
	Moderate	*Small*	*Trivial*	*Trivial*	*Moderate*	*Moderate*	*Trivial*	*Trivial*
Standardised TEE	0.32	0.50	0.51	0.57	0.32	0.36	0.54	0.55
95% CLs	[0.31 to 0.35]	[0.47 to 0.54]	[0.48 to 0.58]	[0.53 to 0.61]	[0.30 to 0.34]	[0.33 to 0.38]	[0.51 to 0.58]	[0.52 to 0.59]
	Moderate	*Moderate*	*Moderate*	*Moderate*	*Moderate*	*Moderate*	*Moderate*	*Moderate*
ICC	0.98	0.92	0.92	0.90	0.98	0.92	0.92	0.90
95% CLs	[0.97 to 0.98]	[0.91 to 0.93]	[0.91 to 0.93]	[0.89 to 0.91]	[0.97 to 0.98]	[0.91 to 0.93]	[0.91 to 0.93]	[0.89 to 0.91]
	Excellent	*Excellent*	*Excellent*	*Good*	*Excellent*	*Excellent*	*Excellent*	*Good*
% Change Means	-12.8 *Moderate*	-7.1 *Small*	0.5 *Trivial*	6.8 *Trivial*	-11.3 *Moderate*	- 13.2 *Moderate*	-4.8 *Trivial*	4.1 *Trivial*
% Smallest Effect	8.1	7.6	8.2	8.3	8.0	7.6	8.2	8.3
% Typical Error (CV)	6.1	7.3	9.6	13.4	6.0	7.4	9.8	13.7

Notes. Acc. = Acceleration; Dec. = Deceleration; CLs = Confidence Limits.

Table 4 describes the data for each variable in distances covered in different acceleration/deceleration zones analyzed by MEDIACOACH and WIMU PRO [23, 25, 26].
We observed that the mean distances covered in accelerations or decelerations showed only a *trivial* difference between the two systems, with the exception of a *small* difference for decelerations of 0 to -1 m/s^2. As for the standardized TEE, all variables for distances covered in accelerations and decelerations varied between *small* (in higher acceleration and deceleration intervals) and *moderate* (in smaller acceleration and deceleration intervals). The ICC presented good agreement between both systems, with values above 0.90 for all variables (i.e. *excellent*). The magnitude of change in mean (%) ranged from small to *trivial* or *small* in all variables. The SWC (%) oscillated between 7.4 and 8.6%. Finally, a CV (%) of between 4.3% and 14.3% was obtained for all variables.

Table 4. *Comparison of each variable in distances covered in different acceleration/deceleration sections analyzed by Mediacoach and WIMU data, including Standardized Mean Bias, Typical Error of Estimate (TEE), Intraclass Correlation Coefficient (ICC), % Change Mean, % Smallest Effect and % Coefficient of Variation (CV), all with 95% confidence limits.*

	Distance Acc. 0 to 1 m/s²	**Distance Acc. 1 to 2 m/s²**	**Distance Acc. 2 to 3 m/s²**	**Distance Acc. > 3 m/s²**	**Distance Dec. 0 to -1 m/s²**	**Distance Dec. -1 to -2 m/s²**	**Distance Dec. -2 to -3 m/s²**	**Distance Dec. > -3 m/s²**
Agreement Analysis								
Standardised Mean Bias	-0.10	0.07	0.09	0.25	0.28	0.07	0.02	- 0.10
95% CLs	[-0.11 to -0.08]	[0.05 to 0.09]	[0.07 to 0.12]	[0.22 to 0.28]	[0.26 to 0.30]	[0.05 to 0.09]	[0.00 to 0.05]	[-0.13 to -0.07]
	Trivial	*Trivial*	*Trivial*	*Trivial*	*Small*	*Trivial*	*Trivial*	*Trivial*
Standardised TEE	0.23	0.27	0.48	0.54	0.25	0.24	0.53	0.50
95% CLs	[0.22 to 0.25]	[0.25 to 0.29]	[0.45 to 0.51]	[0.51 to 0.58]	[0.24 to 0.27]	[0.22 to 0.27]	[0.50 to 0.56]	[0.47 to 0.53]
	Small	*Small*	*Moderate*	*Moderate*	*Small*	*Small*	*Moderate*	*Moderate*
ICC	0.99	0.97	0.94	0.96	0.98	0.96	0.93	0.95
95% CLs	[0.98 to 1.00]	[0.96 to .98]	[0.93 to 0.95]	[0.95 to 0.97]	[0.97 to 0.99]	[0.95 to .97]	[0.92 to 0.94]	[0.94 to 0.96]
	Excellent	*Excellent*	*Excellent*	*Excellent*	*Excellent*	*Excellent*	*Excellent*	*Excellent*
% Change Means	-2.4 *Trivial*	2.1 *Trivial*	-2.8 *Trivial*	-7.0 *Small*	6.1 *Small*	2.0 *Trivial*	-0.2 *Trivial*	-4.1 *Trivial*
% Smallest Effect	8.1	7.6	8.2	8.3	7.6	7.4	8.6	8.3
% Typical Error (CV)	4.3	6.3	9.3	13.5	4.7	6.4	9.1	14.3

1 *Notes*. Acc. = Acceleration; Dec. = Deceleration; CLs = Confidence Limits.

As we pointed out in the statistical analysis section, a function that would allow us to interchange the data obtained by the two systems was generated:
Y (WIMU PRO data) = (slope * X (MEDIACOACH data)) + intercept (residual errors), where Y is the estimated WIMU PRO value and X is the MEDIACOACH value for a given variable. The results showed (Table 5) that equation adjusted correctly and determine that the application of the values to MEDIACOACH were valid compared with the values of WIMU PRO.
Moreover, a cross-validation equation that would allow us to validly exchange the data obtained with the two systems was produced. First, we tested a linear regression analysis with one half of the randomized sample (n = 380). The regression equation for estimating MEDIACOACH data from WIMU PRO data (Table 5) for each variable is:
Y (WIMU PRO data) = (slope * X (MEDIACOACH data)) + intercept (residual errors).
Where Y is the estimated WIMU PRO datum and X is the MEDIACOACH datum for a given variable. The intercept represents the residual errors of the number of accelerations and decelerations and distances covered in m/s^2. This was then compared to the second half of the randomized sample to examine whether the equation fit correctly and to determine whether the application of the values to MEDIACOACH was valid compared to the WIMU PRO values. Finally, Table 5 also shows the ICC, SMB and TEE of the number and distances covered in different acceleration and decelerations sections. More specifically, the ICC ranged from .95 to .99 for the number of accelerations/decelerations and from .95 to .99 for the distance covered. The SMB oscillated between -0.39 and 0.02 and between -0.13 and 0.41, respectively. Finally, the TEE was below 0.51 in the number of accelerations/decelerations and below 0.48 for the distance covered in different acceleration/deceleration sections.

Table 5. *The regression equations and cross-validation in distance covered and number of accelerations and decelerations in different sections.*

Number of Acceleration and Deceleration	ICC	SMB	TEE	*Distance Covered*	ICC	SMB	TEE
Deceleration 0/-1m/s²: Y = 1.06x + 115.28	.97	-0.39	0.21	*Deceleration 0/-1m/s²*: Y = 1.05x + 23.86	.99	0.41	0.18
Deceleration -1/-2m/s²: Y = 1.01x + 29.07	.95	-0.02	0.46	*Deceleration -1/-2m/s²*: Y = 0.97x + 30	.99	0.07	0.27
Deceleration -2/-3m/s²: Y = 0.88x + 4.72	.96	-0.17	0.43	*Deceleration -2/-3m/s²*: Y = 0.92x + 24.27	.97	0.01	0.46
Deceleration >-3m/s²: Y = 0.85x + 3.86	.95	0.02	0.48	*Deceleration >-3m/s²*: Y = 0.89x + 11.66	.95	-0.13	0.47
Acceleration 0/1m/s²: Y = 1.07x + 126.1	.97	0.02	0.25	*Acceleration 0/1m/s²*: Y = 0.95x + 28.02	.98	-0.12	0.16
Acceleration 1/2m/s²: Y = 0.99x + 14.09	.99	0.01	0.32	*Acceleration 1/2m/s²*: Y = 0.97x + 40.10	.98	0.11	0.22
Acceleration 2/3m/s²: Y = 0.89x + 7.01	.98	0.01	0.42	*Acceleration 2/3m/s²*: Y = 0.92x + 54.39	.99	0.01	0.38
Acceleration >3m/s²: Y = 0.87x + 2.09	.95	-0.02	0.51	*Acceleration >3m/s²*: Y = 0.90x + 52.59	.96	0.02	0.48

Notes. ICC = Intraclass Correlation Coefficient; SMB = Standardized Mean Bias; TEE = Typical Error of the Estimate.

Discussion

The aim of this study was to compare the accelerations and decelerations values obtained during official competitions recorded in a team by MEDIACOACH and WIMU PRO, examining the degree of agreement between these systems in the number of accelerations and decelerations and the distances covered in meters. The results showed an adequate degree of concordance between WIMU PRO and MEDIACOACH for all variables measured, although caution is still required when interpreting accelerations/decelerations > 3m/s^2.

First, taking the variables analyzed in this study into account, to our knowledge this is the first work that analyzes accelerations in the ranges proposed here. García-Unanue et al. [27] defined, using GPS, the number of high-intensity accelerations as anything above 2.75 m/s^2, and obtained an average of ~30 high-intensity accelerations per game. Other authors [28] also found 597.43 ± 31.68 (numbers, in defenders) and 610.75 ± 32.06 (numbers, in midfielders) accelerations over 1.5 m/s^2 in a Bundesliga analysis, and these results are similar to those obtained in this study with WIMU PRO and MEDIACOACH.

Regarding the results obtained comparing both systems in the number of accelerations and decelerations in the different intensities sections, WIMU PRO provides higher values than MEDIACOACH at low intensities (<2 m/s^2). In contrast, MEDIACOACH recorded slightly higher values than WIMU PRO in high-intensity accelerations and decelerations. This difference has also been reported by other authors [11, 12], and could be because the systems differ in considering when the acceleration starts. While MEDIACOACH only records movements (and therefore accelerations) when there has been a minimum displacement of one meter, WIMU PRO records an acceleration when there is a specific difference in the speed derivative [28]. For this reason, WIMU PRO could overestimate acceleration values in the medium and low range [29].

Regarding the level of agreement, we found an adequate level of agreement in SMB and in the number of accelerations from 0 to 1 m/s^2 and decelerations below ± 2 m/s^2. More agreement problems were showed between instruments, but it is over the minimum statistics threshold. Again, the overestimation of WIMU PRO in low intensities is noteworthy. These results are in line with previous research [30] comparing different GPS devices. This study showed that the change of mean was greater at low intensities compared to high intensities in the number of accelerations and decelerations recorded. Thus, while we can understand that the change of means above 10% could be high for the agreement between the instruments, this could easily be remedied by modifying the procedure to account for the start of an acceleration. On the other hand, GPS presented poor accuracy at high-intensity acceleration/deceleration [31], which can generate more noise and difficulty in interpreting the signal

Regarding the distances covered in different ranges of acceleration and deceleration, WIMU PRO recorded a slightly greater distance in accelerations of 0 to 1 m/s^2, and in decelerations above -3 m/s^2, whereas MEDIACOACH slightly overestimated the distance for the other accelerations and decelerations. For all of the distances covered in accelerations and decelerations, there were *agreement* between the means for MEDIACOACH and WIMU PRO showed, except decelerations of 0 to -1 m/s^2, which showed a *small difference*. Our results are consistent with previous findings [29]. The results presented a better agreement between the systems in distance covered than in number in all acceleration and deceleration sections. Most research and applications focus on analyzing distances covered in meters instead of the number of accelerations and decelerations recorded in official matches, which is why the degree of agreement between both systems facilitates the interpretation from this perspective.

Note that this is the first study that compares accelerations/decelerations from a Video Tracking System to those from a GPS system using real tracking data in official competitions. Most previous studies have been carried out in non-ecological environments that merely simulate competition conditions [15]. We would like to highlight this point. Although this research demonstrates good agreement between both instruments, the results should also be interpreted with caution, especially at high-acceleration intensities. These findings could be useful for researchers and practitioners to be able to make progress in terms of knowledge and application with data measure from an ecological perspective.

Limitations and practical applications

This study has some limitations that should be considered in order to correctly interpret the results. First, it is difficult to validating accelerations and decelerations [31]. Although the reliability and accuracy of GPS have improved, they still have limitations, particularly in the context of changes of direction or curvilinear movements at high intensities [11, 33]. The present investigation has used different methodological approaches at the statistical level, demonstrating that it is necessary to be cautious with the greater changes in accelerations/decelerations values. Secondly, another important question is that 91 of the 679 measurements had to be excluded. This involved the loss of 13.4% of the total data. Hoppe, Baumgart, Polgleze, and Freinwald

[34] lost 10% and 20% of the measurements with 10 Hz GPS and 18 Hz GPS, respectively. In this regard, Linke, Link, and Lames [35] recorded 6.3% for GPS and 4.6% for VID measurement errors. In this study, errors were found for GPS signals in the 29th and 39th rounds. Siegle, Stevens, and Lames [36] explained that positioning systems can be negatively influenced by weather and stadium characteristics (e.g. high stands). Other problems, such as indoor stadiums, were related to GPS [18], but there were no fully-covered stadiums in the competition analyzed. Moreover, problems with VID in the study were related to visual technical problems in the 5th and 10th rounds. Thus, teams that only use one system regularly should pay attention in stadiums with certain characteristics.

On the other hand, these results could facilitate several interesting applications for researchers and practitioners. Firstly, and as is already stated elsewhere [37], all systems have their advantages and disadvantages, and the ideal tracking system has yet to be developed. Interestingly, here we developed a predictive equation that allows us to exchange data between the two systems used. To adequately evaluate a player's overall movement load, and to integrate data from different systems accordingly, practitioners should use calibration equations. In our study, we validated the equations that allowed us to estimate the number and distances covered in different acceleration and deceleration sections provided by WIMU PRO with data recorded using MEDIACOACH, and vice versa (i.e. cross-validation). The interchangeability of these types of systems is important for practitioners in professional clubs who often use two different systems during the week.

Secondly, although this study is a typical case in a professional football club, many other teams currently have access to MEDIACOACH and/or use WIMU PRO to quantify the external load of their teams during training sessions and matches. More specifically, these two devices have been currently used several professional soccer clubs and national teams in countries like Spain, Mexico or Russia. These data could be essential to the daily work of coaching and medical staff and other professionals involved in looking after athletes' health. In addition, this indirect calculation system (i.e. Tracab Optical Tracking – CHYRONHEGO) related to acceleration and deceleration variables could also be used in the 300 stadiums currently installed in the English Premier League, German Bundesliga and Spanish LaLiga, among other professional soccer leagues (i.e. around 4,500 professional matches a year). Moreover, WIMU PRO PRO is used by several soccer teams in different countries (e.g., Spain, Mexico or Russia).

Additionally, due to the problems presented by GPS in certain conditions, and the fact that soccer players would rather be measured by non-portable instruments [39], the results of this investigation could overcome these limitations. Specifically, the problem reported by players with portable instrument have been in competition´s situations. MEDIACOACH satisfy this problem, however these instrument have measurements problem in certain conditions mentioned. Due to we know which contexts are more difficult for MEDIACOACH measurements we can recommend to coach the use of GPS in these cases and the possibility of interchange the information between systems. Research is currently focusing on comparing related instruments that permit data interchangeability [8, 30, 38, 39]. In this line, FIFA Football Technology Innovation Department is working on the standardization of electronic performance and tracking systems (EPTS), thereby seeking to provide guidance to football stakeholders regarding the use of EPTS in competitive matches [40].

Thirdly, these results could render it possible to fill the gap encountered by strength and conditioning coaches, reconditioning and performance coaches and medical staff during official competitions, helping them to plan training loads based on the accelerations and decelerations made during the competition with a view to optimizing player performance, reducing risk of injury and for the Return To Play process (by a high control of the effort and fatigue of the players). Also, the scientific community could have access to performance data recorded during official matches without the need to simulate situations. It is never possible to reproduce what happens in a real match exactly. Furthermore, the difference found in this comparison could be associated with the error obtained in other research works that have compared other similar instruments [35, 37, 41].
Finally, the equations that allow the exchange of data between the WIMU PRO and MEDIACOACH would allow clubs to incorporate a broader dimension into performance analysis, reducing the loss of information due to technical problems of the instrument and responding to the players and team demands, thus facilitating closer monitoring of aspects such as trends in physical demands over time.

Conclusion

To conclude, this study demonstrated to exceed a minimum threshold of agreement between these two systems (WIMU PRO and MEDIACOACH) used to analyze players' acceleration demands in professional soccer. However, caution is still required when interpreting accelerations/decelerations >3m/s^2. Although WIMU PRO gave slightly higher acceleration and deceleration values at low intensity compared to MEDIACOACH, both systems showed adequate agreement and were considered as useful instruments for recording players' load during official matches. The linear regression showed slightly overestimated values in favor of MEDIACOACH, being consistent with the findings of most of the previous related studies. In addition, using these two instruments it would be possible to quantify the external load variables because of its relevance as a biomechanical stress and its importance at the intramuscular and eccentric level.

Permission statement

The authors declare that the appropriate permission was obtained from MEDIACOACH and WIMU PRO PRO to use these systems in this research and in subsequent publications.

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Author Contributions Statement

EP, TGC & FC. Conception or design of the work.
RR, RLC & HB. Data collection.
JDG & JJP. Data analysis and interpretation.
EP, TGC, JDG & JJP. Drafting the article.
FC, RR, RLC & HB. Critical revision of the article.

Estudio III: A Longitudinal Exploration of Match Running Performance during a Football Match in the Spanish La Liga: A 4-Season Study.

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Article

A Longitudinal Exploration of Match Running Performance during a Football Match in the Spanish La Liga: A Four-Season Study †

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Abstract: This study aimed to analyze and compare the match running performance during official matches across four seasons (2015/2016–2018/2019) in the top two professional leagues of Spanish football. Match running performance data were collected from all matches in the First Spanish Division (Santander; n = 1520) and Second Spanish Division (Smartbank; n = 1848), using the Mediacoach® System. Total distance and distances of 14–21 km·h^{-1}, 21–24 km·h^{-1}, and more than 24 km·h^{-1}, and the number of sprints between 21 and 24 km·h^{-1} and more than 24 km·h^{-1} were analyzed. The results showed higher total distances in the First Spanish Division than in the Second Spanish Division ($p < 0.001$) in all the variables analyzed. Regarding the evolution of both leagues, physical demands decreased more in the First Spanish Division than in the Second Spanish Division. The results showed a decrease in total distance and an increase in the high-intensity distances and number of sprints performed, although a clearer trend is perceived in the First Spanish Division ($p < 0.001$; $p < 0.01$, respectively). Knowledge about the evolution of match running performance allows practitioners to manage the training load according to the competition demands to improve players' performances and reduce the injury rate.

Keywords: longitudinal study; match running performance; professional soccer leagues; sports performance; external load

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1. Introduction

The external load of soccer matches has been studied in depth over the last two decades, which has improved knowledge on its evolution and trends [1]. Thus, different variables have been analyzed, usually related to the distance covered by the players at different intensities [2], and it should be noted that soccer match running performance has evolved, with significant increases in high-intensity actions [3]. Match physical demands can vary depending on the tactical planning, the opposite team's playing style or the tactical–technical demands [4]. Research has also shown that these changes could be related to differences between soccer leagues [5]. However, to the best of our knowledge, there are no updated studies on how efforts have evolved in professional leagues' full seasons. In addition, we found no studies of the analysis and comparison of match running performance from several seasons between two professional soccer leagues to update our knowledge about physical differences at the competitive level and in the evolution of football.

Regarding the comparison of match running performance between professional soccer leagues, a previous study analyzed the external load of the top three leagues in English soccer: the FA Premier League, Championship, and League One [5]. This study concluded that the players in the Premier League, compared to players in the lower leagues such as the Championship and League One, covered less total distance and had fewer high-intensity running distances ($p < 0.01$). A related study collected physical demand data over four seasons (2006–2010) in two top leagues of English soccer, with similar external load data [6]. Players of the Championship League (2nd) covered more total distance than players of the Premier League (1st). In addition, Championship players covered more high-intensity running distance and performed more sprinting-intensity actions than Premiership players. However, recent research has found the opposite results in this area of study. In this way, authors described and compared the match running performance of the teams of the Spanish First and Second Division leagues during the 2015–2016 season, showing that the Spanish First Division teams covered more total distance than the Spanish Second Division teams [7]. There were differences in the distance covered at high intensity and very high intensity, where teams from the First Division covered more meters at these intensities. In this line, similar results were reported in the analysis of the match running performance of three professional soccer leagues in Norwegian football [8]. They found a higher total distance in the Norwegian first league teams, but differences were nonsignificant. Concerning high-intensity running distances, Norway's first league teams covered higher sprinting distances than Norway's second and fourth league teams ($p < 0.05$). Thus, the most recent studies agree on the presence of higher match physical demands (total and at high intensity) in the top professional soccer leagues.

On the other hand, research of the evolution of external load has shown that total distances have been stable over the period from 1967 to 2012 [9]. However, it has also demonstrated that total distance has increased by 2% in the English Premier League over seven consecutive seasons (2006/2007–2012/2013), whereas high-intensity running and sprint distances have increased by 30–50% [3]. Moreover, a longitudinal study of the World Cup final soccer games reported that the soccer game trend evolved towards shorter, higher intensity play periods because players covered a higher sprint distance and they performed sprints more frequently [10]. Although the evolution of match running performance has also been analyzed by ranking tiers, similar trends have been found for all tiers. In this sense, one study reported that, during seven consecutive seasons in the English Premier League, there was an increase in high-intensity running distance (40%) and leading (15%) and explosive (25%) sprints for all tiers, although the average distance covered per sprint decreased [11]. Thus, changes have been observed in the external load of soccer competitions over the last few years. It is difficult to attribute these findings to a single factor. These changes could be explained through the increases in the competition levels of the leagues, the evolution of movement patterns, training specificity based on match physical demand data or a new approach to training [12]. It also could be related to the playing formation or, possibly, the recruitment of players with more explosive characteristics [1,7,11,13].

There are few studies on the evolution of external load over several years. Most of them are outdated and only analyzed the English Premier League. In addition, even if some works compare leagues or analyze the evolution of external load, there are no studies comparing the evolution of leagues of different levels over several years. Therefore, the aim of this study was to analyze and compare the evolution of match running performance between LaLiga Santander (LL1) and LaLiga Smartbank (LL2) across four seasons (2015/2016–2018/2019).

Based on the aforementioned studies [3,7,11], the authors established the following hypotheses. Concerning the match running performance comparison, we expected that the total distances, the distances covered at high intensity, and the number of very high-intensity running efforts would be higher in LL1 than in LL2.

On the other hand, we expected that the total distance, the distances covered at high intensity, and the number of very high-intensity running efforts would increase in both professional soccer leagues across the four seasons analyzed.

2. Materials and Methods

2.1. Participants

The sample included observations of all the matches played over four seasons in LL1 and LL2 (2015/2016, 2016/2017, 2017/2018, and 2018/2019). Two observations were made by match, and one by team. In LL1, 752 team match observations were included in the 2015/2016 season; 744 team match observations were included in the 2016/2017 season; 723 observations were included in the 2017/2018 season and, finally, 731 observations were included in the 2018/2019 season. Similarly, in LL2, 700 team match observations were included in the 2015/2016 season; 744 team match observations were included in the 2016/2017 season; 870 observations were included in the 2017/2018 season and, finally, 731 observations were included in the 2018/2019 season. In addition, 784 observations were excluded due to technical problems in the data collecting system or adverse weather conditions during the match, leading to a total of 5952 team match observations.

2.2. Design and Procedures

Match running performance data were collected by a multicamera tracking system called Mediacoach®. This system assesses the distance covered in meters by teams and the number of high-intensity sprints (LaLiga™, Madrid, Spain). It consists of a series of super 4K-High Dynamic Range cameras based on a positioning system (Tracab—ChyronHego VTS) that records and analyzes X and Y positions for each player from several angles, thus providing real-time three-dimensional tracking (tracking data are recorded at 25 Hz). Mediacoach® has been proven to be both reliable and valid and has been used in previous studies [14–16]. Data were provided to the authors by LaLiga™, and the study received ethical approval from the University of Extremadura, Vice-Rectorate of Research, Transfer and Innovation—Delegation of the Bioethics and Biosafety Commission (Protocol number: 153/2017).

2.3. Study Variables

Similarly to previous studies [17–19], the physical demand variables were recorded for each match: (1) total distance covered by soccer teams in meters (TD); (2) distance covered between 14 and 21 $km \cdot h^{-1}$ (i.e., High-Intensity Running Distance = HIRD); (3) distance covered between 21 and 24 $km \cdot h^{-1}$ (i.e., Very High-Intensity Running Distance = VHIRD); (4) distance covered at more than 24 $km \cdot h^{-1}$ (i.e., Sprinting Distance = SpD). These variables were shown and analyzed by matches and separated by halves (first and second half). In addition, the number of sprints performed was registered, as well as (5) the number of very high-intensity running sprints at 21–24 $km \cdot h^{-1}$ (i.e., SpVHIR), and (6) the number of sprints at more than 24 $km \cdot h^{-1}$ (i.e., SP). All efforts that implied a minimum movement of one meter, which was maintained for a 1 s minimum, were recorded. Any recording at a speed of over 80% of the value of that category (i.e., >24 $km \cdot h^{-1}$) was considered as a single register. All these variables show total team values (i.e., all players who participated in matches, starters, nonstarters and substitutes).

2.4. Data Analysis

The statistical program SPSS 25.0 was used (Armonk, NY: IBM Corp, 2017) to analyze and treat the data. Firstly, a two-way Analysis of Variance (ANOVA) was used to explore the main differences between the two professional soccer leagues for external load variables (i.e., variables related to distances covered and the number of sprints) across matches and halves. Subsequently, a 2 × 4 Multivariate Analysis of Variance (MANOVA) was used to examine the differences between the two professional soccer leagues across four seasons in different subsets of dependent variables. A split file, where data were separated by seasons, was used to carry out a posthoc comparison between the professional soccer leagues, using Bonferroni posthoc analyses. Thus, MANOVA investigated the evolution of the external load variables, where season and league (LL1 or LL2) were independent variables. Statistical significance was set at $p < 0.05$, $p < 0.01$, and $p < 0.001$.

3. Results

Table 1 shows the mean match running performance comparison between LL1 and LL2 across the four league seasons. We observed a higher TD in LL1 than in LL2 ($p < 0.001$). In the analysis of TD by halves, in LL1, TD decreased over the match, as TD was higher in the first half than in the second half, whereas this trend was the opposite in LL2. Similarly, HIRD was higher in LL1 than in LL2 ($p < 0.001$). Concerning the analysis of the HIRD by halves, this variable was higher in the first half than in the second half in both leagues. VHIRD and SpD were also higher in LL1 than in LL2 ($p < 0.001$). These two variables were higher in the second halves for these two leagues. Finally, SpVHIR and SP were higher in LL1 ($p < 0.001$).

Table 1. Differences between both professional soccer leagues in match running performance.

	LL1		LL2		F	*p*
	M (%)	SD	M (%)	SD		
TD (m)	109,135	4355	107,895	4110	126	0.00 (***)
TD 1st Half (m)	54,826 (50.24%)	2390	53,935 (49.99%)	2386	205	0.00 (***)
TD 2nd Half (m)	54,309 (49.76%)	2664	53,960 (50.01%)	2570	26	0.00 (***)
HIRD 14–21 km·h^{-1} (m)	22,436 (20.56%)	2182	21,727 (20.14%)	2005	169	0.00 (***)
HIRD 1st Half (m)	11,395 (10.44%)	1222	10,971 (10.17%)	1129	191	0.00 (***)
HIRD 2nd Half (m)	11,041 (10.12%)	1186	10,756 (9.97%)	1129	89	0.00 (***)
VHIRD 21–24 km·h^{-1} (m)	3019 (2.77%)	385	2838 (2.63%)	378	331	0.00 (***)
VHIRD 1st Half (m)	1504 (1.38%)	230	1409 (1.31%)	223	255	0.00 (***)
VHIRD 2nd Half (m)	1515 (1.39%)	234	1429 (1.32%)	231	202	0.00 (***)
SpD > 24 km·h^{-1} (m)	2905 (2.66%)	490	2687 (2.49%)	481	296	0.00 (***)
SpD 1st Half (m)	1437 (1.32%)	291	1329 (1.23%)	279	209	0.00 (***)
SpD 2nd Half (m)	1467 (1.34%)	304	1357 (1.26%)	299	196	0.00 (***)
SpVHIR 21–24 km·h^{-1}	264 (62.12%)	30	249 (62.41%)	30	354	0.00 (***)
SP > 24 km·h^{-1}	161 (37.88%)	23	150 (37.59%)	22	287	0.00 (***)

Note: *** $p < 0.001$; TD = Total distance, HIRD = High-intensity running distances, VHIRD = Very high-intensity running distances, SpD = Sprinting distance, SpVHIR = Sprints at very high-intensity running, and SP = Sprints at more than 24 km/h; LL1: LaLiga Santander; LL2: LaLiga Smartbank; % = percentage of the total distance covered. The percentage of SpVHIR and SP takes into account the sum of both variables.

Table 2 shows the evolution of TD and HIRD in LL1 and LL2 over these four seasons. We can observe a progressive decrease in TD, especially in LL1. Furthermore, during the second half, TD decreased more in LL2 than in LL1, where it remained more stable. HIRD showed a slight increase in LL1 and a slight decrease in LL2. Concretely, during the first half, HIRD increased slightly in both professional soccer leagues over the four seasons. However, during the second half, HIRD increased in LL1, whereas in LL2, there was a decrease.

Table 2. Multivariate Analysis of Variance (MANOVA) to compare TD and HIRD between seasons and professional soccer leagues.

		LL1		*p*	LL2		*p*	F	Sig.	Eta	Power
Variables	**Season**	**M**	**SD**		**M**	**SD**					
TD (m)	15/16	109,368	4376	d	108,176	3973	bd	1.53	0.20	0.001	0.41
	16/17	109,241	4319	d	107,581	4082	ac				
	17/18	109,321	4189	d	108,205	4238	bd				
	18/19	108,603	4495	abc	107,530	4062	ac				
TD 1st Half (m)	15/16	55,009	2387	d	53,974	2244		3.04	0.03	0.002	0.72
	16/17	54,900	2381	d	53,775	2230	c				
	17/18	54,861	2395	d	54,206	2520	bd				
	18/19	54,526	2374	abc	53,707	2500	c				
TD 2nd Half (m)	15/16	54,358	2660		54,201	2609	bd	1.67	0.17	0.001	0.44
	16/17	54,340	2604		53,806	2618	a				
	17/18	54,460	2546	d	53,999	2578					
	18/19	54,077	2827	c	53,822	2434	a				
HIRD 14–21 km·h^{-1} (m)	15/16	22,304	2050	c	21,743	1987	bc	1.68	0.17	.001	0.44
	16/17	22,267	2112	c	21,383	2022	acd				
	17/18	22,709	2322	ab	22,044	2023	abd				
	18/19	22,472	2217		21,688	1910	bc				
HIRD 1st Half (m)	15/16	11,335	1167	c	10,922	1103	c	1.50	0.21	0.001	0.40
	16/17	11,307	1189	c	10,810	1123	c				
	17/18	11,515	1293	ab	11,174	1154	abd				
	18/19	11,427	1230		10,939	1087	c				
HIRD 2nd Half (m)	15/16	10,969	1135	c	10,821	1160	b	2.85	0.04	0.001	0.69
	16/17	10,960	1140	c	10,573	1142	acd				
	17/18	11,194	1259	ab	10,869	1120	b				
	18/19	11,044	119		10,749	1062	b				

Note: TD = total distance and HIRD = high-intensity running distances; LL1: LaLiga Santander; LL2: LaLiga Smartbank. Posthoc comparisons: a = significant differences compared with 2015/2016 season; b = significant differences compared with 2016/2017 season; c = significant differences compared with 2017/2018 season; d = significant differences compared with 2018/2019 season.

The main difference in the evolution of these professional soccer leagues was the distance covered at very high intensity and sprinting, as shown in Table 3. VHIRD and SpD increased across these four seasons, especially in LL1 ($p < 0.001$ and $p < 0.001$, respectively). During the first half, VHIRD increased significantly in both leagues. Likewise, VHIRD also increased during the second half over the four seasons and in LL1 this increase was significant. In addition, VHIRD was higher in LL1 than in LL2 ($p < 0.001$). For SpD, significant increases were obtained in both leagues ($p < 0.001$). Concretely, in both halves, SpD increased significantly over the four seasons, but it was higher in LL1 than in LL2 ($p < 0.01$).

Finally, Table 4 shows the evolution of SpVHIR and SP across the four seasons and the comparison between the two professional soccer leagues. For SpVHIR, significant increases were found in both leagues ($p < 0.001$). Moreover, SpVHIR was higher in LL1 than in LL2 ($p < 0.001$). On the other hand, SP increased over the four seasons and, in LL2, this increase was significant. SP was also higher in LL1 ($p < 0.001$) than in LL2.

Table 3. MANOVA to compare VHIRD and SpD between seasons and professional soccer leagues.

Variables	Season	LL1 M	LL1 SD	p	LL2 M	LL2 SD	p	F	Sig.	Eta	Power
VHIRD 21–24 km·h^{-1} (m)	2015/2016	3020	375		2817	47	c	7.19	0.00	0.004	0.98
	2016/2017	2988	385	d	2782	47	cd				
	2017/2018	3013	384		2907	49	abd				
	2018/2019	3056	396	b	2836	50	bc				
VHIRD 1st Half (m)	2015/2016	1515	233		1392	358	c	9.65	0.00	0.004	0.99
	2016/2017	1485	230	d	1383	362	c				
	2017/2018	1492	222		1448	392	abd				
	2018/2019	1523	235	b	1406	385	c				
VHIRD 2nd Half (m)	2015/2016	1504	225	d	1424	210	c	2.86	0.04	0.005	0.69
	2016/2017	1503	225		1399	217	c				
	2017/2018	1521	244		1459	232	ab				
	2018/2019	1533	241	a	1429	225					
SpD > 24 km·h^{-1} (m)	2015/2016	2873	468	d	2630	28	c	3.99	0.01	0.003	0.84
	2016/2017	2860	502	cd	2636	29	c				
	2017/2018	2930	486	b	2777	31	abd				
	2018/2019	2959	500	ab	2689	30	c				
SpD 1st Half (m)	2015/2016	1432	286		1299	491	c	5.73	0.00	0.002	0.95
	2016/2017	1413	303	d	1293	466	cd				
	2017/2018	1440	284		1382	477	abd				
	2018/2019	1464	289	b	1335	475	bc				
SpD 2nd Half (m)	2015/2016	1441	285	cd	1331	281	c	1.56	0.20	0.003	0.41
	2016/2017	1447	295	cd	1342	270	c				
	2017/2018	1489	316	ab	1394	285	ab				
	2018/2019	1495	317	ab	1354	267					

Note. VHIRD = very high-intensity running distances, SpD = sprinting distance; LL1: LaLiga Santander; LL2: LaLiga Smartbank. Posthoc comparisons: a = significant differences compared with 2015/2016 season; b = significant differences compared with 2016/2017 season; c = significant differences compared with 2017/2018 season; d = significant differences compared with 2018/2019 season.

Table 4. MANOVA to compare number of sprints at different speed levels between seasons and professional soccer leagues.

Variables	Season	LL1 M	LL1 SD	p	LL2 M	LL2 SD	p	F	Sig.	Eta	Power
No. SpVHIR 21–24 km·h^{-1}	2015/2016	263	29	d	247	224	c	6.85	0.00	0.001	0.98
	2016/2017	262	31	d	245	226	c				
	2017/2018	264	30		255	241	abd				
	2018/2019	268	32	ab	249	228	c				
No. SP > 24 km·h^{-1}	2015/2016	160	22		148	291	c	4.93	0.00	0.001	0.91
	2016/2017	160	23		148	300	c				
	2017/2018	161	22		155	303	abd				
	2018/2019	162	23		150	297	c				

Note. SpVHIR = sprints at very high-intensity running and SP = sprints at more than 24 km·h^{-1}; LL1: LaLiga Santander; LL2: LaLiga Smartbank. Posthoc comparisons: a = significant differences compared with 2015/2016 season; b = significant differences compared with 2016/2017 season; c = significant differences compared with 2017/2018 season; d = significant differences compared with 2018/2019 season.

4. Discussion

This study aimed to analyze and compare the evolution of the match running performance between the top two professional Spanish leagues (LL1 and LL2) across four seasons: 2015/2016–2018/2019. The main findings of the study showed that TD, VHIRD, and SpD were higher in LL1 than in LL2. Concerning the comparison between the first and second halves, we found that high-intensity efforts increased in the second half, especially in LL1. The match running performance evolved during these seasons, showing different changes between the two leagues. Specifically, TD decreased significantly in LL1, whereas VHIRD and SpD increased progressively in both leagues. SpVHIR also increased significantly in both leagues, whereas SP increased significantly only in LL2.

Firstly, concerning the match running performance comparison, we expected that all the physical variables analyzed in the present study would be higher in LL1 than in LL2. The results showed that external load was higher in LL1 than in LL2. In particular, the distances covered at high intensity and the number of high-intensity efforts were significantly higher in LL1. These results showed that the league at the higher competitive level had higher physical demands during matches. Our findings agree with previous studies [7,8,20], which compared the top two Spanish and Norwegian professional soccer leagues, finding that the top-tiered leagues were more physically demanding. Several explanations could be used to interpret our results. One reason could be the physical capacity of the players of these teams, such that the LL1 clubs contributed to improving the match running performance of their players [11]. Another reason could be related to the playing formation used by LL1 teams, as certain playing formations imply higher external loads, and LL1 teams may use these more demanding playing formations [13]. Concerning the differences between halves of the matches, it can be observed that the first half of LL1 is more demanding than the second half.

Secondly, with respect to the evolution of match running performance during these four seasons, we expected an increase in total distance, the distances covered at high intensity, and the number of very high-intensity running efforts. On the contrary, the changes showed significant decreases in TD in both professional soccer leagues. A possible cause of this may be the playing style used by teams of LaLiga [21] because, in recent years, there has been a gradual increase in teams that prioritized ball possession, confirming that in ball control plays with few transitions players covered less total running distances, although greater distances were covered at high intensity [22]. In addition, the introduction of Video Assistant Referee (VAR) has led to a decrease in effective game time, which has contributed to the decrease in TD [23,24].

In agreement with our hypothesis, where we expected an increase in the distances covered at high intensity and the number of very high-intensity running efforts, the results showed that significant increases in distances covered and efforts performed at high intensity were obtained during the four seasons. In this sense, the significant increases in HIRD and VHIRD are indicators of the evolution and changes occurring in soccer, where players are now trained to perform more high-intensity actions. This has probably been caused by the current training perspective, which increases the presence of high-intensity stimuli according to the competition demands and it decreases the rate of injuries, as achieving optimal player performance while minimizing the risk of injury is the main objective [12,25,26]. These types of efforts are keys to achieving high performances in soccer [27,28] and they are important in decisive situations in professional football. They are the most dominant actions when scoring goals [29]. In this sense, in the 2018/2019 season, VAR was added, which promoted longer recovery times, where high-intensity efforts predominate [24]. Another possible reason could be the tactical evolution of football. Today's models and playstyles tend to advance defensive pressure lines, resulting in larger spaces and more actions performed at high intensity to take advantage of these spaces.

When examining the match running performance separated by halves, TD decreased in LL1 across the second half, contrary to the results shown in LL2, where TD increased. In addition, in LL1, the decrease in TD in the second half was less than in the first halves of the matches. These results could be explained by the high equality between the teams in LL1 and LL2, where the matches are usually decided in the second half. The decrease in TD in LL1 is further supported by the fact that LL1 teams performed a large number of high-intensity efforts compared to LL2 during the first half, which could cause a decrease in TD during the second half [30].

Finally, concerning the comparison of the evolution between the two professional soccer leagues, we found that in LL1 there is a trend toward a progressive increase in VHIRD and SpD, especially in the second half, whereas in LL2, the trend is not clear. On the other hand, VHIRD and SpD increased during the second halves in both professional soccer leagues, contrary to the results reported in previous studies [31]. A possible reason for these results is the higher TD and high-intensity efforts performed by the substitutes during the second halves [32]. Although we stated that the equality between teams was higher in LL2, another possible explanation is the increase in the effect of match status during the second halves. In both leagues, time pressure is higher in the second half. For example, it is not the same to be losing 1–0 at half-time as at 80 min. The effects of time pressure and match status probably increase high-intensity actions [17,33].

4.1. Limitations and Future Perspectives

Taking into account the characteristics of the present study and the novelty of this topic, we considered some limitations with a view to future research. In the 2018/2019 season, VAR was added, which has promoted longer recovery times. In future investigations, we should analyze the differences in the external load before and after the implementation of VAR. In addition, we did not analyze other physical variables such as accelerations and decelerations, which are part of the external load of soccer matches [34]. Thus, these types of physical variables must be analyzed to obtain more information about the match running performance of the competition. Finally, another possible study would be about the different evolution of each team across these seasons (e.g., according to classification or playing style).

4.2. Practical Applications

Based on the results obtained, some practical applications can be extracted. Firstly, the paradigm of match running performance has changed across the seasons. Thus, it is also necessary for physical training in soccer to evolve in keeping with current match physical demands to optimize the training process. In this sense, knowledge about the match running performance allows coaches to design soccer training with the correct stimuli to optimize players' performances. In this regard, this type of stimuli constitutes a methodology for injury prevention and could reduce the injury rate of soccer players. In addition, the evolution of high-intensity efforts is very important in designing specific training tasks that reproduce competition demands. Finally, it was found that the Spanish LL1 is more demanding than LL2, and this information is very important to practitioners who are training in each professional soccer league, since it allows them to discern the different external loads in both the first and second divisions.

5. Conclusions

The present research describes and compares the differences in match running performances between the top two Spanish professional soccer leagues across four seasons. Firstly, the results showed higher external loads in LL1 than in LL2. Concretely, the distances covered at high intensity are higher in LL1 than in LL2. Secondly, the decrease in total distance and the increase in distance covered and efforts performed at high intensity are the main changes in the external load of soccer in both leagues. Finally, VHIRD and SpD increased during the second halves in both professional soccer leagues. In summary, we must take into account the evolution of the match running performance in training and the teams' playing styles to ensure that players are trained to perform more high-intensity efforts during the matches.

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Estudio IV: Training in Team Sports: Optimizing Training at FCB

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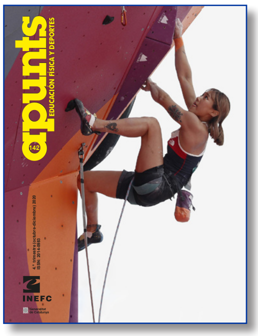

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Training in Team Sports: Optimising Training at FCB

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New Olimpic Sports for Tokyo 2020. Climbing. Photo: Climbing. Asian Games 2018. Women's combined final. Competes Kim Ja-in from South Korea. Climbing leader. JSC Sport Climbing. Palembang, Indonesia. REUTERS / Edgar Su.

Abstract
In the pursuit of sporting success, the main objectives in top-level sport include winning and improving results. The sport sciences constantly strive to apply new training methodologies and systems to enhance and maintain the performance of sportsmen and women. Team sports involve competitions held over long periods of time and also subject the athlete to high competitive stress. They therefore call for methods tailored to their specific features. The methodology called structured training is organised into two areas of action: coadjuvant and optimiser. This article expounds the foundations and the main facets of optimiser training. This publication is part of a set of three articles that explain the basics of the structured training method.

Keyword: performance, physical abilities, structured training, coadjuvant training, methodology.

Introduction

Over the years, the improvement of sports performance in training has prompted the emergence of a number of methodological currents whose common denominator is sporting success. The advent of new theories brought a new training paradigm called structured training (ST), which pursues the all-round development of the sportsman or woman (Tarragó et al., 2019; Seirul·lo, cited by Ribera, 2009). This methodological trend has been innovative in team sports and is particularly relevant for football. Based on the principle that sport-specific training produces better performance adjustments, one of the objectives is to design training tasks which replicate the context and conditions of competition in order to achieve the best possible optimisation of the human athlete's (HA) different structures (Pinder et al., 2011; Tarragó et al., 2019). Figure 1 shows the structures that comprise ST.

In recent decades, FC Barcelona has developed a training methodology for team sports anchored in what is called structured training (ST) (Seirul·lo, 1987; Tarragó et al., 2019), in turn rooted in an interest in the HA: "women and men who are involved in a game/sport who share with others a common interest in winning and in besting opponents to obtain compensation for the effort and dedication required by this objective" (Tarragó et al., 2019).

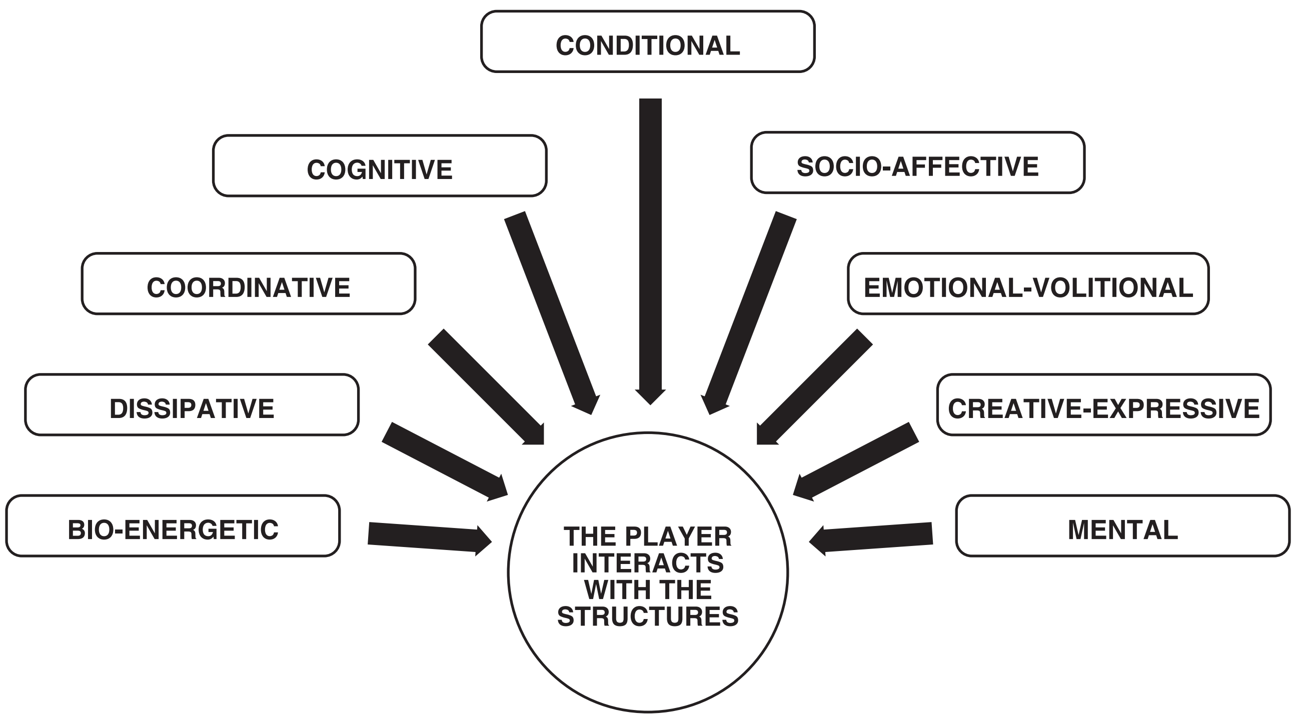
ST is organised on the basis of two paradigms or areas of action, known as optimiser training (OT) and coadjuvant training (CT) (Gómez, et al., 2019), two types of complementary training derived from the theory of complex non-linear dynamic systems (Hristovski et al., 2011; Balagué et al., 2014). From this new standpoint, training constitutes a single process of optimisation of the athlete, i.e. the individual is at the centre and it is therefore he or she who has the capacity to optimise their potential resources (Sánchez & Uriondo, 2012), which entails imbuing practices with a non-linear concept based on self-organisation and variability (Guerrero & Damunt, 2019).

The purpose of this article is to describe the key principles and aspects of OT as one of the two areas of action, together with coadjuvant training (Gómez et al., 2019) for HAs (Tarragó et al., 2019a) developed for team sports at FC Barcelona (FCB).

Optimiser training

Optimiser training (OT) is "training that includes the planning, design, execution and control of the tasks of the sport in question and whose objective is the HA's performance in all the competitions in which they participate throughout their sporting life" (Romero & Tous, 2010, foreword by

Figure 1
Structures that conform the human athlete (HA) in structured training.



Seirul·lo, paragraph 1); "We could say that this training essentially prepares HAs to compete and therefore requires training tasks to be performed in an environment and with elements that are specific to the game" (Tarragó et al., 2019, pp. 105-106), and it is performed primarily on the training ground or court.

Through practice, OT seeks to stimulate and develop the HA's capacities through their structures consistently with their level of development and physical-cognitive maturation, while also taking positional specificity, chronological timing and the features which define the athlete into consideration. OT respects self-structuring and proposes various training tasks and stimuli in an appropriate way, thus consolidating the evolution of the HA and their optimal readiness for competition.

Preferential simulation situations

By using preferential simulation situations (PSSs), OT makes it possible to generate practical proposals that interact with and approach the sport being played. PSSs are about generating events and sets of situations conducive to a state of action and response in a created environment which encourages the imitation of behaviours that simulate the game/sport and preferentially impact the HA's different constituent structures. This preference is achieved through the purpose of the task, which in turn is guided by means of rules, spaces and the number of participating players, which are variable and are tailored to suit the objective. These situations will be defined and extracted by the coaching staff and each player through the analysis and interpretation of the real game (Tarragó et al., 2019).

Given that the objective and foundations of ST are to measure the HA (Arjol, 2012), its practical approach delivers a high level of interaction in the competition of the sport in question. In this context, OT involves an exchange, cooperation and synergy between all the systems that constitute the HA's structures, thereby fostering a different functional capacity which none of these structures separately possesses. This self-organisation corresponds to complex systems' capacity to spontaneously form organisational patterns in the absence of information which imposes order. OT is therefore arranged in micro-structural units by the PSSs (Seirul·lo, cited by Ribera, 2009) and constitutes a specific and differential training practice for team sports.

Using these PSSs, the design of practice situations which are as close as possible to the reality of the game and its internal logic will be examined. This involves generating tasks in which the players have to resolve different situations continually, generating both voluntary and involuntary responses facilitated by extensive practice.

The term "simulation situation" refers to the reproduction of experiences and interactions of game events. The term "preferential situation" suggests the emphasis on or intention to optimise some of the HA's structures. This preference yields a practical situation conceived to accomplish the objective of the session through highly-varied interactions with systems of other synergetic structures.

HAs' characteristics and abilities will inform their training process whilst permitting the development of the structures being challenged by the PSSs. OT involves interactivity, cooperation and partnership between all the systems that make up the HAs' structures. The PSSs will therefore be optimising for the HA and must be presented through global tasks executed preferably in groups and not for the purpose of learning/interpreting the exercise but rather the "game" (Seirul·lo, 2015). In this way, the athlete will be encouraged to focus on the dynamics of the "game" rather than on the rules involved in the task or the instructions of the coaching staff, thereby avoiding not only "playing according to the rules" but also "playing in the content", thus fostering "playing in the context" (Guerrero & Damunt, 2019).

Each PSS calls for the involvement of the HA's different systems or structures which the coach will have to identify. Each player has to bring into play the systems that best respond to the situation created based on their own lifelong self-organisation process. Each HA will deal with this by optimising in a distinct way. OT is about not restricting the exchange of practice with the HA by making it easier to identify basic specific sources of information, such as the determination of the conditional characteristics of the dominant leg, preferential co-ordination patterns in shooting, preferred communication channels, etc., but rather encourages pursuing the attainment of a higher hierarchical level of cognition, relating this intervention to the player's hypercomplexity, for example by addressing the socio-affective dimension, helping them to identify preferential relationships when sharing a mutual intervention/assistance space with a particular teammate.

In recent years, the growing interest in studying the complexity of living organisms and their self-organisation has led to non-linear approaches to learning. It would appear that repeating tasks under the same conditions of practice does not produce the necessary "fluctuations" in the systems involved in order to change their state. Instead, models based on the approach of "constantly changing tasks" through a "variation" in the execution conditions would yield the disruptions required to lead to a change of functionality in the systems involved (Schöllhorn, et al., 2012; Balagué et al., 2014). With introjection and feedback, all the structures that make up the HA can be optimised, provided that this is done in "repetitions and variations" (Schöllhorn et al., 2015). Consequently, variability and specificity in the stimuli must be prioritised so that the HA can manage them, taking the HA as both a means and an end (Tarragó et al., 2019).

Several authors have classified PSSs by determining a task organisation based on different levels of approaching, specificity and/or concreteness (Moras, 1994; Schelling & Torres-Ronda, 2016; Seirul·lo, 2009). Seirul·lo (1998) classifies strength exercises according to their orientation and level of approach to competition, categorising them as general, targeted, special and competitive. This relationship with specificity in OT is established through the nature of the PSSs, distinguishing them by their general orientation: the nature and organisation of the PSS are similar to those of competition, albeit with a low specific cognitive load; targeted orientation: the nature and organisation of the PSS are similar to competition. This includes specific coordinated actions with non-specific decision-making with a special orientation: the nature and organisation of the PSS are similar to competition with specific decision-making; and competitive orientation: the nature and organisation of the PSS are the same as competition with totally specific decision-making (Solé, 2006).

Conjectures in the preparation of PSSs in OT

PSSs conform the training sessions of the training cycle, which in turn represents the functional unit of ST organisation. This functional unit is called the structured micro-cycle (SM) and manages the cycle between matches. Each micro-cycle interacts with the previous and the following micro-cycle to form sequences of three micro-cycles. Dynamics are established between them in the form of functional relationships between the PSSs of each training day that make up the SM. These relationships are brought about by valid "conjectures" in the configuration of the ST (Seirul·lo, 2015). They are the concepts and assertions supported by signs, observations, symptoms and opinions extracted from the practice of the OT, once it has been accepted and understood that its validity is shaped by the knowledge contributed by the complexity sciences (Arjol, 2012).

The conjectures that determine the preparation of the PSSs are:

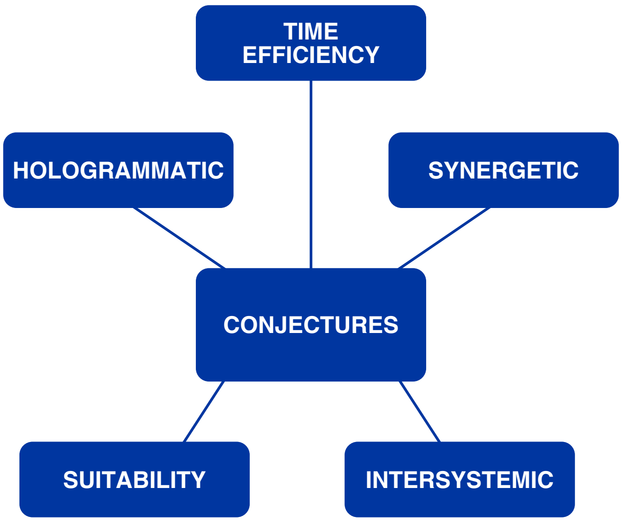
Time efficiency conjecture: defined as the time it takes for a PSS to induce the intended optimising effect on the HA, known as the "shift effect". As the time available in the training sessions is limited, each action is designed to foster efficiency and quality in effort management.

Synergistic conjecture: this refers to the effect achieved by the combination of actions. These synergetic effects are produced between the components of successive PSSs performed in the same session (synchronously) and also across successive sessions (diachronically) within the SM. When a change is sought in the HA, one also talks about the intersystemic effect, to with a system open to the outside world through projection and introjection mechanisms. It is precisely this form of relationship that is called intersystemic when any optimising effect of a system expands its change to other systems of the high structures involved simultaneously.

Suitability conjecture: this refers to the aptitude, good predisposition or capacity that someone has for a specific, adequate and appropriate purpose. The PSSs should be presented in a suitable way to achieve the improvement of the HA in terms of the game's demands. When generating the PSSs it is crucial to identify what is specific and unique to the speciality in which the training is performed in order to understand it in all its entirety and complexity.

Hologrammatic conjecture: this configures the PSSs in OT. It is defined as perceptive capacity (from mind to consciousness) with the ability to capture and gather information that is present, is produced or may be produced during the game. In OT there need to be PSSs where the HA captures and recognises all the situations addressed to acquire them in order to be able to cope with the complexity of the game as efficiently as possible. Figure 2 shows the situations that shape the production of PSSs.

Figure 2
Conjectures that bring about a change in the HA.



Preferential simulation situations

Situation

The PSSs are located in a context that sets up action and response in a game/sport environment comprised of all the elements involved: the athlete, their teammates, opponents, the moment when the action is created, etc. (Balagué et al., 2014). The tasks are global, in groups, and various time sequences are proposed which are integrated into the complex context of the game (Pol, 2014).

Another key aspect is the specificity of the PSSs used in training. The concept of "specificity" refers to the kind of elements that are specific to a given sports speciality as well as to a specific situational sensitivity on the part of the player as the "own micro-environment" of this game/sport during competition (Tarragó et al., 2019). Drawing on the ST proposal, competition is the event in which all the structures of the HA are most intensively activated, hence the PSSs with the greatest number of stimulated structures within an environment similar to the actual game will have greater specificity.

In recent years there has been growing interest in the complexity of nature and change, which are based on a non-linear understanding of causality, whereby small causes can generate major effects and vice versa (Moras et al., 2018; Tarrago et al., 2019). The PSSs addressed under these criteria not only maintain their essential nature for learning but also become more attractive in practice due to the constant challenge they pose to the HA.

Variability as the basis of OT is the ability to change training conditions to trigger new response learnings so that through these variations the athlete has to adapt their performance and establish new parameters for speed, path, strength, etc. (Schmidt, et al., 2018). This learning is therefore another characteristic element based on the constant resolution of new and varied situations without losing its appearance or preferential objective (Hristovski, et al., 2011). The repetition of specific disturbances typical of the game and of "our game" should be facilitated and can be modified by reducing the degrees of freedom and by means of conditioning and/or constraints (facilitating contexts rather than simplifying them), albeit by means of variable execution. As a complex dynamic system, the player will constantly find themselves in changing contexts to which they will have to adapt continuously. This means the motor behaviour or action to be optimised will not be inflexible and nor will it attempt to follow a pre-established model (Guerrero & Damunt, 2019) while reducing the inherently harmful rate of repetitive practices and increasing the associated creativity. "Adaptability as a product of variability is closely tied to creativity" (Orth et al., 2017).

Simulator

The "simulator" concept refers to the need to use the practical proposal to reproduce the elements typical of the game and which reproduce competition and its specific demands (Balagué et al., 2014). The qualitative orientation of the proposed exercises should be borne in mind in order to convey information that can be identified as having significant value and efficiency for the self-optimisation of the HA (Pol, 2014). The impact on top-level team sports players is usually high.

The use of simulator situations makes it possible to generate exercises of varying specificity or approaching level to the demand (Schelling & Torres-Ronda, 2016), which is related to the planning and control of the PSSs; an adaptation of the load throughout the season helps to plan and generate sequences based on the coach's needs.

Preferential

The "preferential" concept refers to managing the elements of the PSSs in order to distinguish a structure that conforms the HA in the context of OT. This priority leads to a practical situation intended to achieve the objective of the session, i.e. to afford preference/priority to one or more specific structures. This does not mean that this preferential structure rules out any relationship with the others, since the great variety of the game allows interrelationships (Pol, 2014).

It is essential to view the PSSs as a differentiated source of requirements so that even if the same task is proposed for a group of players it does not involve the same level of demands on each one of them; levels of demands have to be adjusted to suit the HA's configuration/shape, bearing in mind specific modifications tailored to individual needs to enable better self-optimisation of each player.

Specific qualities of OT

The distinctive behaviour of each type of sport is determined by the inherent characteristics of the sport/game in question (Seirul·lo, 1998). When considering specific qualities (SQ), a complex relationship is established between the HA's systems which is carried out with movement, through the application of muscle strength. "Strength" means the basic physical quality from which the other qualities are expressed since it is the generator of movement.

OT of the SQs is based on a methodological proposal adapted from Moras (1994), Seirul·lo (1998), Schelling and Torres-Ronda (2016) and Gómez et al. (2019), proposing a breakdown of the game into work areas, contents and alternative training of these contents in accordance with their orientation and the approaching levels that can be attained by promoting each player's technical execution levels (Gómez et al., 2019).

The "work areas" are determined by the four specific expressions of strength required in football and team sports in general: displacement, jump, fight and ball action strength, as depicted in Figure 3 (Gómez et al., 2019; modified from Schelling & Torres-Ronda, 2016).

The PSS proposal in OT includes all the HA's structures, conditioned by the interpretation of the game and the rules of the sports speciality that determine the dominant motor skills and the interactions between teammates, opponents and the environment (Seirul·lo, 1998); all these aspects are strongly influenced by the methodological proposal and the game model implemented by the coaching staff.

The integration of technology into the dynamics of professional teams has made it possible to accurately ascertain conditional characteristics by studying the external and internal load experienced by athletes throughout training and competition (Castellano et al., 2011). Examples include geolocation systems known by the EPTS (Electronic Performance and Tracking Systems) initialism and the semi-automatic, multiple-camera System Technology (VID) tracking systems used in games in La Liga, the Champions League and other competitions. These technological systems make it possible to monitor the actions of the game and to track load based on different conditional variables, thereby simplifying the planning of training units and PSS design. The most recent evolutionary studies of competitive analysis show a significant increase in external load due to high-intensity actions (metres covered at high intensity, number of accelerations, etc.). The relevant information gathered allows objective and efficient action to be taken through OT in response to the needs of the sportsperson vis-à-vis competition. The use of this technology allows the description of the SQs and their behaviour in OT. In line with the suggestion made by Gómez et al., (2019), the expression of strength in all SQs as part of OT and the degree of presence in the performance of sports in shared spaces are presented below (Figures 4,5,6 and 7).

Systems that make up optimiser training of specific qualities. The transition from football to other team sports

Displacement

OT for displacement strength SQ is comprised of all actions on and off the ball, of variable duration and intensity, in which displacement takes place. It includes all types of running (forward, sideways or backwards), changes of direction, turns, feints, accelerations, decelerations, braking, etc., in which the basic principles of the movements focus on precision and on the efficient application of a certain strength in an optimal space and time (Gómez et al., 2019). One of the distinctive aspects with respect to CT and which impacts the SQs is the need to adapt to a changing environment generated by the interactions between teammates, opponents and a ball that alters these relationships continuously.

The implementation of GPS technology makes it possible to identify the speed and amount of displacement of players in regular training and competition. This "intensity" has been classified in several speed ranges in order to evaluate the locomotor conditional demand. By way of example, in a number of football studies (Pons et al., 2019), displacement speed has been categorised in ranges from 0 to 6, 6 to 12, 12 to 18, 18 to 21, 21 to 24 and above 24 kph. Another measurable aspect is the athlete's actions when accelerating or decelerating, which are also expressed in different ranges (Akenhead, et al. 2013). These variables are very important in team sports and are directly related to the HA's neuromuscular structure (Loturco, et al., 2018).

To develop the displacement SQ, a number of game conditions must be considered, affording preference to each one of the situations involved in the sports speciality. The actions which determine the displacement SQ, depicted in Figure 4, are: changes of rhythm (accelerations and decelerations); displacement speed, changes of direction and changes in amplitude and frequency of supports, all of them adapting to the interaction with the environment, opponents and teammates, giving priority to the HA's conditional efficiency.

Figure 3
Specific qualities in OT.

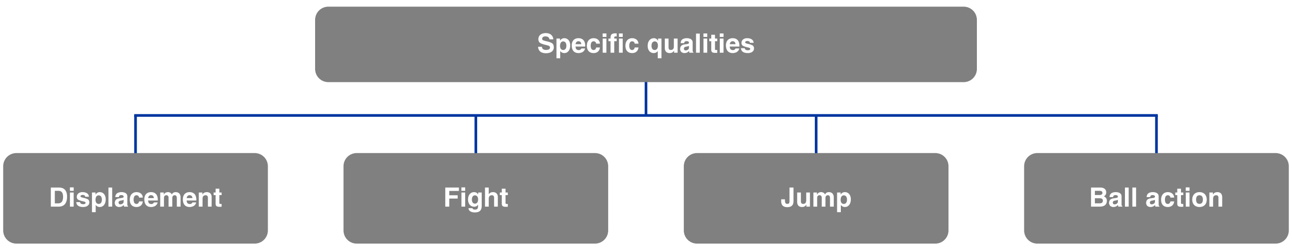


Figure 4
Actions involved in the displacement SQ.

Fight

The fight strength SQ is comprised of all actions on and off the ball, of variable duration and intensity, in which at least two players contest a position or path using part or all of their body to win out, such as ball protection, charging, tackling, losing a marker or fighting to gain a position (Gómez et al., 2019).

Figure 5 shows different actions (before, during and after) to enable the management of the different PSSs, providing variability in fight strength actions. The situations that occur in each sport speciality call for a different application of strength (Seirul·lo, 1998). OT seeks to generate specific stimuli adapted to the sport and each HA based on individual characteristics and taking the positional role into account.

Figure 5
Actions involved in the fight SQ.

Jump

OT for the jump strength SQ is comprised of all actions on and off the ball, of variable duration and intensity, in which there is a jump; this initial thrust can be one- or two-footed, stationary or moving, where the body goes into the air and with a greater incidence in vertical displacement (Gómez et al., 2019).

As an SQ included within the complexity of the game, jumping should be considered as a training component of OT although it is also addressed in CT. Each sport has its own specific jumping characteristics, and consequently game situations in which there are actions in the air (heading and clearances), drives and receptions should be categorised with the diversity of situations appropriate to each sport while taking into account the individual characteristics of the HA.

Figure 6 shows different actions (before, during and after) and their variability in jump strength actions.

Figure 6
Actions involved in the jump SQ.

On-the-ball action

OT for the on-the-ball action strength SQ is comprised of all actions on and off the ball, of variable duration and intensity, in which there is contact with the ball, such as control, dribbling, passing, shooting, clearances, headers, etc. (Gómez et al., 2019).

The action the HA performs on the object varies according to the specificity of each sport when game actions are performed. In terms of on-the-ball actions, passing, kicking and shooting actions, conditioned by the interaction with teammates, opponents and the relationship space, must be taken into consideration.

Figure 7 shows different actions (before, during and after) and their variability in on-the-ball strength actions.

Finally, Table 1 is a summary of the specific qualities and approaching levels.

Future studies and ongoing research should enable further progress in using training methodologies and systems tailored to team sports. The implementation of new technologies for tracking both external and internal loads will make it easier to shape micro-cycles and session and task design based on objective data and criteria. Similarly, research into the relationship between complex systems and sports should be continued in order to buttress strategies which boost their applicability to team sports training and be able to cater to the individual characteristics of HAs.

Figure 7
Actions involved in the on-the-ball ball Action SQ.

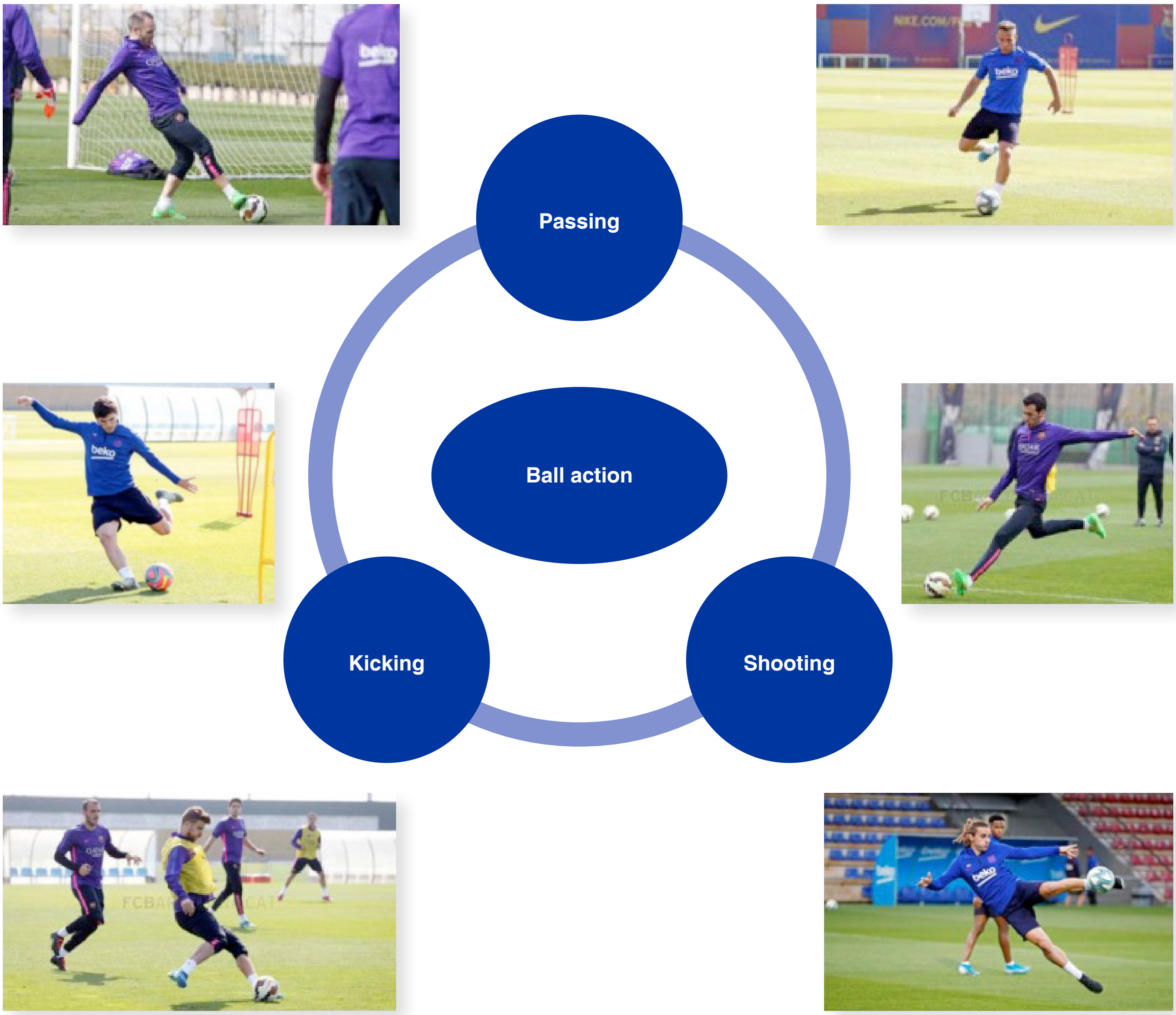


Table 1
Summary table of the Specific Qualities and their approaching levels or nature.

Approaching levels	General	Targeted	Special	Competitive
Displacement				
Changes of rhythm Accelerations / Decelerations Changes in amplitude and frequency of supports Control of running for passing and shooting actions	Linear displacements at different speeds with changes of direction. Displacements between 5-12 m focusing on accelerations and decelerations. Resisted displacements. Displacements over small obstacles. Stride amplitude displacement changes of support amplitude and frequency.	Same actions as general work but introducing a ball, before, during and after. Pass and overlap. Passing sequence. Circuit with combined displacement actions.	Situations played Position game (3v3 + 2) Area 14x12, (4v4 + 3) Area 16x18 (4v4 + 2), Area 18x20 Situation game (5v5 + 3) Area 20x24, (6v6 + 3) Area 22x26 (7v7 + 3) Area 29x25 (8v8 + 3) Area 30x26 Structured SSGs (3v3) (3v3 + 1), (4v4) (4v4 + 1) (5v5) (5v5 + 1), (6v6) (6v6 + 1) LSGs Area ½ pitch, box to box Friendly match	Actual play 11v11 official match situation
Fight				
Throw off balance Grab Push	General proposal for large muscle groups. Self-loading proposal / Medicine ball. Proposal of tasks with partners. Grabbing, throwing off balance and pushing.	Proposal on and off ball in small areas. Proposal for fight game actions with circuits.	Position game Situation game Structured SSGs Competitive units LSGs Friendly match	Actual play 11v11 official match situation
Jump				
Actions in the air (Clearing/heading) Drives (Clearing/heading) Receptions	General proposal for large muscle groups. Proposal with belts, resistance bands. Successive jumps over hurdles with different amplitudes and heights.	Proposal of tasks on and off ball. Proposal of centre and heading tasks in both offensive and defensive actions.	Competitive units LSGs Friendly match	Actual play 11v11 official match situation
On-the-ball action				
Passing Shooting Kicking	General proposal for large muscle groups. Passing tasks with displacements. Accuracy passing tasks.	Rondo. Passing sequence. Circuit with combined passing actions with teammates and opposition with displacements Proposal of tasks with shooting	Position game Situation game Structured SSGs Competitive units LSGs Friendly match	Actual play 11v11 official match situation

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4. DISCUSIÓN GLOBAL DE LOS RESULTADOS

El objetivo principal de esta tesis ha sido cuantificar, analizar, conocer, comparar y objetivar la evolución de la carga externa de 1ª y 2ª división del fútbol profesional en la Liga Española durante 4 temporadas 2015-2016, 2016-2017, 2017-2018 y 2018-2019. Se realizó un estudio en profundidad de las 4 temporadas, utilizando datos aportados por la tecnología del sistema de seguimiento de vídeo VTS de Mediacoach. Se ha realizado un estudio que, hasta la fecha, es inédito en el fútbol español. Este análisis longitudinal retrospectivo de la carga externa nos permite tener una visión más actual de las necesidades reales del fútbol de élite. El conocimiento ajustado a la realidad nos facilita tomar decisiones más científicas al tiempo que generamos los contenidos y tareas en las sesiones de entrenamiento con el fin de optimizar el rendimiento del jugador de fútbol.

La suposición basada en nuestra experiencia laboral en el futbol profesional respecto a un aumento de las distancias recorridas a alta intensidad y también del número de esfuerzos de carrera de muy alta intensidad, se ha contrastado con los resultados de nuestro estudio que muestran aumentos significativos de las distancias recorridas y los esfuerzos realizados a alta intensidad durante las cuatro temporadas en las dos ligas del futbol profesional español. Otro hallazgo elocuente es que los resultados reportan que la carga externa fue mayor en la LL1 que en la LL2. En particular, las distancias cubiertas de alta intensidad y el número de esfuerzos de alta intensidad son significativamente mayores en LL1. Estos resultados indican que la liga de superior categoría tiene mayores exigencias físicas durante los partidos. Estos descubrimientos son indicadores de la evolución y los cambios que se están produciendo en el fútbol español. Dichos resultados coinciden con los estudios de la Premier League realizados por Barnes et al., (2014) en los cuales se observa un incremento de las distancias recorridas en alta intensidad y el número de esfuerzos realizados en alta intensidad.

Al mismo tiempo creemos que existen varias razones que han repercutido en este incremento de las demandas condicionales de alta intensidad en los últimos años. Una de las razones podría ser la mejora de la preparación física de los jugadores en los clubes, otra argumentación podría ser la tendencia actual del entrenamiento, que aumenta la presencia de estímulos de alta intensidad de acuerdo con las demandas de la competición como se puede ver en el estudio longitudinal de (Ekstrand et al., 2021), donde se refiere a este aumento. Otra posible razón podría ser la evolución táctica del fútbol, los modelos y estilos de juego actuales que tienden a avanzar en las líneas de presión defensiva, lo que provoca espacios más grandes y más acciones llevadas a cabo a alta intensidad para aprovechar estos espacios. En relación a las exigencias de carga externa de los modelos y estilos de juego Tierney et al., (2016) estudiaron diferentes formaciones de juego concluyendo que el sistema 1-3-5-2 parece ser el más exigente en distancia total recorrida y en distancias en alta y muy alta intensidad.

Destacamos los resultados obtenidos en esta tesis y consideramos que hay que tenerlos en cuenta para la optimización del rendimiento del jugador, para prevenir lesiones y para identificar fatiga en relación al estudio realizado por Hader et al., (2019), donde se observa grandes correlaciones entre la distancia recorrida en alta intensidad y la fatiga.

Con el fin de aportar información sobre la correlación existente de los datos obtenidos de carga externa mediante los dos sistemas tecnológicos, GPS Wimu Pro y VTS Mediacoach, hemos realizado esta investigación con la utilización de variables locomotoras y mecánicas según Fernández et al., (2016). Los resultados muestran que se puede intercambiar la información entre ambos sistemas. Lo que facilita los procesos de análisis a los cuerpos técnicos de los equipos del futbol profesional. Este estudio de correlación y comparación de los dos sistemas GPS y VTS están presentes en los estudios I y II.

En referencia al estudio I (Pons et al., 2019) se obtuvieron datos similares del sistema VTS Mediacoach y GPS Wimu Pro sobre la distancia total recorrida, la distancia por minuto recorrida, la velocidad media y máxima y la distancia recorrida en diversos sectores de velocidad. Estos hallazgos coinciden con los reportados por otros autores en diferentes estudios centrados en el análisis de la correlación de ambos sistemas (Buchheit et al., 2014; Felipe et al., 2019; Taberner et al., 2019). El coeficiente de variación entre dispositivos fue cercano a cero (<5%) en la distancia total, distancia por minuto, velocidad media, velocidad máxima, distancia caminando de 0-6km/h y distancia trotando. Entre el 9% y 15% para la distancia corriendo entre 12-18km/h, distancia entre 14-21km/h HIRD, distancia en carrera entre 21-24km/h VHIRD, esprines a intensidades bajas 21-24km/h SpVHIR y esprines a alta intensidad, más de 24km/h SP. Estos resultados muestran la posibilidad de correlacionar y comparar los valores de la carga externa de jugadores de entrenamiento y competición.

La literatura reciente en este campo concluyó que las diferencias entre las tecnologías no eran tan significativas en distancias y velocidades, pero todas las tecnologías tenían en común que la magnitud del error aumentaba a medida que aumentaba la velocidad. En nuestro caso, las diferencias entre los dos sistemas eran menores que en estudios anteriores, posiblemente debido a los avances tecnológicos en los dos procedimientos de recopilación de información. En los últimos años, se ha hecho un gran esfuerzo para mejorar las dos tecnologías utilizadas en este estudio.

El estudio II realizado en esta tesis, focalizó la atención en el análisis de la correlación entre los dos sistemas que actualmente se utilizan en el fútbol profesional para el control de carga externa tanto en entrenamiento como en competición GPS Wimu Pro y VTS Mediacoach, con variables como aceleraciones y desaceleraciones ubicadas dentro del grupo de variables mecánicas según Fernández et al., (2016) y con la inclusión dentro de este estudio de dos variables novedosas como son: distancia recorrida en aceleración y la distancia recorrida en desaceleración. Este segundo estudio se originó cuando por parte del sistema de VTS Mediacoch en la temporada 2017-18 se empieza a reportar información del número de aceleraciones y desaceleraciones. Esto originó la idea de realizar el estudio de correlación y comparación de los sistemas, puesto que el sistema GPS ya reportaba los datos de ACC y DEC. Se debe tener presente que este es el primer estudio en el futbol español que compara las aceleraciones y desaceleraciones de un sistema VTS con las de un sistema GPS a través de datos de seguimiento reales en competiciones oficiales. La mayoría de los estudios anteriores se han realizado en entornos no ecológicos que simplemente simulan condiciones de competición.

Con respecto a los hallazgos encontrados se muestra una buena coincidencia comparando ambos sistemas en el número de ACC y DEC en los diferentes rangos de intensidades, aunque debemos tener presente algunos matices. Wimu Pro proporciona valores más altos que Mediacoach en situaciones de baja intensidad ($<2m/s^2$). Por el contrario, Mediacoach registró valores ligeramente superiores a los de Wimu Pro en ACC y DEC de alta intensidad ($>3m/s^2$). Esta diferencia también ha sido reportada por otros autores y podría deberse a que los sistemas difieren al considerar cuándo comienza la aceleración; mientras que Mediacoach sólo registra movimientos (y por lo tanto aceleraciones) cuando ha habido un desplazamiento mínimo de un metro. Wimu Pro registra una aceleración cuando hay una diferencia específica en la derivada de velocidad. Por esta razón, Wimu Pro podría sobreestimar los valores de aceleración en rangos medios y bajos. Por otro lado, las puntuaciones CV y SWC eran adecuadas para intensidades bajas, pero presentaban problemas con altas intensidades, lo que requiere precaución al interpretar e intercambiar la información de ACC/DEC ($>3m/s^2$) entre ambos sistemas. Dicho problema podría resolverse modificando el procedimiento para tener en cuenta el comienzo de una aceleración.

Otro aspecto analizado en este estudio II son las distancias cubiertas en diferentes rangos de aceleración y desaceleración. Wimu Pro registró una distancia ligeramente mayor en aceleraciones de 0 a $1m/s^2$ y en desaceleraciones superiores a $3m/s^2$. Mientras que Mediacoach sobreestimo ligeramente la distancia para otras aceleraciones y desaceleraciones. Para todas las distancias recorridas en aceleración y desaceleración hubo concordancia entre las medias para Mediacoach y Wimu Pro mostradas, excepto en desaceleraciones de (0 a $1m/s^2$), que mostraron una pequeña diferencia.

Un punto de vista importante de este estudio es que los datos de distancias recorridas durante aceleraciones y desaceleraciones son datos novedosos ya que, históricamente, se han analizado distancias desde un prisma de variables locomotoras. La contribución de estas variables se debe incorporar, según nuestro criterio, al control de la carga externa por parte de toda la comunidad científica del fútbol.

Además, respecto al punto anterior me gustaría matizar que, aunque esta investigación demuestra una similitud de los resultados entre los dos instrumentos, se debe seguir investigando especialmente con intensidades de alta aceleración. En cuanto a la perspectiva ecológica que analiza las coincidencias de este estudio, consideramos que la posible transferencia de estos resultados es útil para que investigadores y profesionales puedan avanzar en términos de conocimiento y aplicación.

Al referirnos al Estudio IV de esta tesis, aportamos una herramienta de cálculo más precisa de la carga externa que permitirá una mejor aplicación y gestión del EO como componente del EE

(Tarragó et al., 2019) conjuntamente con el Entrenamiento Coadyuvante (Gómez et al., 2019). Dicha metodología del EO se ha usado en los últimos años en el primer equipo del FCB teniendo presente los datos reportados de carga externa por los dos sistemas. El aporte preciso de datos de carga externa facilita la gestión diaria de los jugadores con el objetivo de optimizar la duración de su rendimiento y anticiparse a la aparición de lesiones.

5. CONCLUSIONES

En este punto mostramos las conclusiones obtenidas de los cuatro estudios realizados que conforman esta tesis. Son las siguientes:

1. Se identifica una disminución de la distancia total recorrida, especialmente en la LL1 junto con un aumento de las distancias y los esfuerzos realizados en alta intensidad en ambas ligas.

2. Comparativamente los resultados mostraron cargas externas más altas en la LL1 que en LL2. En concreto las distancias cubiertas en alta intensidad son más altas en LL1 que en LL2.

3. Los tipos de esfuerzos que incrementaron a lo largo de las 4 temporadas en ambas ligas fueron la distancia entre 14-21Km/h HIRD, distancia a muy alta intensidad entre 21-24km/h VHIRD y la distancia en esprín por encima de 24km/h SpD. Este incremento fue más destacable en LL1.

4. Los datos de VHIRD y SpD aumentaron durante las primeras y segundas partes en las dos ligas de fútbol profesional. Este incremento en cada una de las partes es más significativo en la LL1, a lo largo de las 4 temporadas.

5. Respecto a los esprines entre 21-24km/h SpVHIR, y esprines por encima de 24km/h SP se encontraron incrementos significativos en ambas ligas en las 4 temporadas. Estos incrementos fueron mayores en LL1 que en LL2.

6. Para el control de la carga externa mediante las variables locomotoras se puede utilizar ambos sistemas: GPS de Wimu Pro y VTS de Mediacoach. De manera conjunta y se puede intercambiar la información.

7. Se puede intercambiar la información de las variables mecánicas con ambos sistemas, en referencia al número de ACC, DEC y metros en distancias recorridas en ACC y DEC, para el control de carga externa, aunque con cautela en los diferentes rangos de velocidad en altas intensidades.

8. Se han establecido las bases para generar ecuaciones predictivas que permitan intercambiar datos con otros dispositivos de análisis de carga externa, con los beneficios que esto puede conllevar para los profesionales e investigadores.

9. Los datos de los estudios I y II proporcionan una elevada relevancia ecológica para analizar situaciones de competición real, relacionadas con las demandas físicas mediante los sistemas tecnológicos, VTS de Mediacoach y GPS de Wimu Pro.

10. La metodología del EO se puede apoyar en la información de los sistemas tecnológicos analizados en esta tesis para la planificación de las sesiones de entrenamiento y el diseño de las Situaciones Simuladoras Preferenciales (SSP) / ejercicios y describir las cualidades especificas CE y su comportamiento en el EO.

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