UNIVERSITAT DE BARCELONA

Multidimensional assessment and sport performance in elite handball

Evaluación multidimensional y rendimiento deportivo en el balonmano de élite

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Tesis Doctoral

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MULTIDIMENSIONAL ASSESSMENT AND SPORT PERFORMANCE IN ELITE HANDBALL

EVALUACIÓN MULTIDIMENSIONAL Y RENDIMIENTO DEPORTIVO EN EL BALONMANO DE ÉLITE

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*"En esta vida no hay cosas imposibles,
sólo difíciles"*

Roger Font Ribas

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Resumen

La investigación científica en el ámbito del rendimiento deportivo basa parte de sus objetivos en el análisis de aquellos factores que pudieran condicionar, o incluso determinar, el nivel de prestación de un deportista o conjunto de éstos, durante el entrenamiento o la competición (Lago et al., 2011). Actualmente, gracias a las aportaciones del profesor Francisco Seirul·lo (INEFC Barcelona), preparador físico e ideólogo del entrenamiento estructurado (EE) y referente mundial de la mano del FC Barcelona, el estudio y análisis del área del rendimiento deportivo en los deportes de equipo ha evolucionado hacia la especificidad, la individualización, el abordaje global y el aprendizaje diferencial, todo ello respetando las diferentes estructuras que conforman al ser humano deportista (Seirul·lo et al., 2017; Tarragó et al., 2019).

El balonmano es un deporte colectivo de contacto y de alta intensidad cuya producción científica en el área del rendimiento deportivo todavía es escasa si es comparada con otros deportes de equipo. Esto se demuestra cuando, por ejemplo, en Pubmed, se escribe la sintaxis *Handball and Performance* (871 referencias) y en cambio en voleibol (1199 referencias), rugby (2097 referencias), baloncesto (2614 referencias) o fútbol (6951 referencias), los resultados reportados son muy superiores.

Estableciendo una breve cronología sobre la evolución de las aportaciones científicas al estudio del rendimiento deportivo en el balonmano, observamos que ésta se relaciona directamente con la propia evolución de los medios tecnológicos para el registro y análisis de las variables de rendimiento, con especial atención a aquellas referidas a la carga interna y externa, ya sea en laboratorio (Matthys, Fransen, et al., 2013; Krüger et al., 2014), en entrenamiento o en situaciones de competición simulada (Michalsik et al., 2013; Povoas et al., 2014). En relación a la carga interna, hasta la fecha y bajo nuestro conocimiento, todos los estudios se han realizado en condiciones de laboratorio (Chelly et al., 2011; Manchado et al., 2013), de entrenamiento (Michalsik et al., 2014) o con herramientas low cost en base a la percepción subjetiva del esfuerzo (Feriche et al., 2002; Cuadrado-Reyes et al., 2012). En relación a la valoración de la carga externa, ésta ha evolucionado desde los métodos más clásicos y poco inmediatos como la anotación manual (Michalsik et al., 2013) o el video tracking (Cardinale et al., 2017; Povoas et al., 2014) hasta los últimos estudios que utilizan la tecnología IMU (*Inertial Measurement Units*), superando por lo tanto aspectos determinantes como disponer de toda la

información de manera casi inmediata, ecológica, específica y más exacta que las tecnologías anteriores (Barbero et al., 2014; Wik et al., 2017; Luteberget, Trollerud, et al., 2018; Kniubaite et al., 2019; Manchado et al., 2020; Ortega-Becerra et al., 2020). Finalmente, conviene mencionar también a los estudios observacionales que analizan específicamente el componente táctico del juego con el objeto de determinar qué variable o conjunto de éstas pudieran influenciar en el rendimiento del equipo a nivel ofensivo (Lozano et al., 2016; Jiménez-Salas et al., 2020a), defensivo (Prudente et al., 2010; Fasold & Redlich, 2018) o en las diferentes fases del juego (Daza et al., 2017). Bajo este contexto, el objetivo de esta tesis doctoral es analizar, desde una perspectiva multidimensional, el rendimiento deportivo de un conjunto de jugadores de balonmano del FC Barcelona de máximo nivel competitivo en sus respectivas categorías. Desde el paradigma de las estructuras del humano deportista (Seirul·lo et al., 2017) y siguiendo la línea de investigación realizada en el propio club en otros deportes de equipo (Gómez et al., 2019; Tarragó et al., 2019; Pons et al., 2020), se intentará aportar, por primera vez, información basada en la evidencia científica para que pueda ser aplicada por los presentes y futuros entrenadores del balonmano formativo y de élite.

La tesis se ha dividido en cuatro estudios científicos, tres de ellos publicados en la revista *Biology of Sport* (*IF: 4,606; Q1 Sport Sciences*), y el otro en la revista *Sustainability* en el número especial *"Sports Psychology and Performance" (IF: 3,889; Q2 Environmental Sciences).*

El primer estudio tiene por objeto describir las variables de carga externa que soportan los jugadores de balonmano de élite en función de su posición de juego. Como novedad a nivel mundial, se valoró la carga externa mediante tecnología IMU en situación real de competición oficial. De esta manera, se analizaron a 16 jugadores top mundiales (5 extremos, 2 centrales, 6 laterales y 3 pivotes) durante 14 partidos de liga regular en ASOBAL. Las variables analizadas fueron: el tiempo de juego, la carga asumida por el jugador o "player load", determinadas variables derivadas de la aceleración y la distancia recorrida en función de la intensidad de desplazamiento. Las conclusiones del estudio fueron que no se debe entrenar bajo los mismos parámetros de carga externa a todos los jugadores, ya que cada posición condiciona unas determinadas demandas. Gracias a este estudio, los entrenadores poseen ahora, por primera vez, valores de referencia durante la competición de uno de los mejores equipos de balonmano del mundo. Esto debería servirles para optimizar los procesos de adaptación a la carga durante el entrenamiento, individualizándola no sólo en función de las características de cada jugador, sino especialmente en función de su posición de juego.

El segundo estudio se realizó bajo la pandemia del COVID-19, que golpeó a nuestra sociedad de una manera no experimentada hasta entonces, modificando la realidad conocida hasta entonces por toda la humanidad. Esta tesis no fue ajena a dicho impacto. De esta manera, dado que los jugadores del primer equipo de balonmano del FC Barcelona tuvieron que estar confinados en casa de la misma manera que el resto de la sociedad, se les programó un plan de preparación física de 9 semanas a realizar en sus respectivas casas. El objeto del estudio fue comprobar si los efectos de este entrenamiento en casa habían sido efectivos, o no. Así, se valoró antes y después la capacidad aeróbica y la capacidad de salto vertical de 11 jugadores cuyos resultados mostraron que el trabajo individualizado fue óptimo para mantener la capacidad de salto, pero insuficiente para mantener la capacidad aeróbica. A partir de estos resultados se pudieron constatar los principales efectos del desentrenamiento debido a la COVID-19 en un grupo de jugadores profesionales de balonmano de máximo nivel competitivo. Finalmente, a nivel aplicado, gracias a estos resultados y con el soporte de los hallazgos del primer estudio, se pudo programar durante la postemporada, con el objeto de llegar en las mejores condiciones a la pretemporada, un trabajo integral e individualizado para cada jugador, configurado a partir de cada posición de juego y haciendo especial énfasis en recuperar sus aptitudes aeróbicas.

El tercer estudio tuvo por objeto analizar el comportamiento táctico grupal del primer equipo de balonmano del FC Barcelona. Para ello, a través de la metodología observacional (Hernández-Mendo & Anguera, 1999), se creó y validó una herramienta ad hoc mediante la cual se analizaron 14 partidos oficiales en una misma temporada regular de la liga ASOBAL y CHAMPIONS LEAGUE obteniendo un registro de 2581 secuencias. Así, se analizaron las posibles relaciones entre los comportamientos focales de éxito y de fracaso, contrapuestos con otros comportamientos de rendimiento a través de la técnica de coordenadas polares (Anguera, 1997). Los resultados nos mostraron que la clave para conseguir la victoria en los partidos fue conseguir el éxito en la fase defensiva para poder recuperar el balón y tener opciones de ir a la fase del contraataque, siendo ésta la fase donde se podía obtener un gol con mayor claridad. Con esto, los entrenadores deberían incidir, especialmente, en incrementar la eficacia de las fases defensiva y de contrataque, claro está sin obviar el hecho de contemplar de igual modo el entrenamiento de las otras dos restantes (fases de ataque y de defensa de transición).

El cuarto y último estudio, y que cierra esta tesis doctoral, incidió en la valoración de la carga externa e interna durante los microciclos competitivos. Al cuerpo técnico le interesaba conocer si el equipo estaba recibiendo el estímulo adecuado para rendir al máximo nivel los días de competición. 15 jugadores del equipo filial del club (5 extremos, 2 centrales, 4 laterales y 2 pivotes) fueron monitorizados durante 11 partidos y 25 microciclos (semanas). La distancia total recorrida, los metros recorridos a alta intensidad (>18,1 $km \cdot h^{-1}$), el *player load* y la percepción subjetiva del esfuerzo, fueron registrados. Los resultados obtenidos mostraron que durante el microciclo volvían a existir diferencias significativas de carga externa según cada posición de juego. También que dicha carga externa durante los entrenamientos era diferente al ser comparada con la realizada el día de la competición. Una situación que, en relación a la carga interna (percepción subjetiva del esfuerzo manifestada por cada jugador) no repetía el mismo patrón, no habiendo diferencias percibidas por los jugadores entre los días de entrenamiento y el de competición. Estos resultados ayudaron al cuadro técnico, de nuevo, a optimizar la carga de entrenamiento externa individualmente para cada jugador. También para dimensionar, relativizándola, la información sobre el esfuerzo percibido reportada por los jugadores. Éstos, muy probablemente por su elevado nivel condicional y bagaje previo adquirido en cada una de sus posiciones de juego, no eran capaces de discriminar subjetivamente las constatadas diferencias que sí se reflejaban a nivel de carga externa.

Con todo, gracias a la presente tesis basada en el compendio de cuatro publicaciones, se ha podido aportar conocimiento científico aplicado a la mejora y optimización de los procesos de entrenamiento y de competición en el balonmano. Bajo nuestro conocimiento, se aportan por primera vez valores de referencia tanto de carga interna como externa de jugadores de élite mundial, segregados por posiciones de juego en situación tanto de entrenamiento como de competición real. Esto debería servir tanto a la comunidad nacional como internacional del balonmano, para seguir mejorando e impulsando, bajo criterios de evidencia científica, el análisis de la complejidad que supone optimizar íntegramente las diferentes estructuras que conforman al ser humano deportista, en este caso al jugador de balonmano.

Abstract

Scientific research in the field of sports performance bases part of its objectives on the analysis of those factors that could condition, or even determine, the level of performance of an athlete or group of athletes during training or competition (Lago et al., 2011). Nowadays, thanks to the contributions of Francisco Seirul·lo, professor at INEFC Barcelona, physical trainer and ideologist of structured training and world reference at the hands of FC Barcelona, the study and analysis of the area of sports performance in team sports has evolved towards specificity, individualization, global approach and differential learning, all while respecting the different structures that make up the human athlete (Seirul·lo et al., 2017; Tarragó et al., 2019).

Handball is a high-intensity, collective contact sport whose scientific production in the area of sport performance is still much lower compared to other team sports. This is demonstrated when, for example, in Pubmed, the syntax "Handball and Performance" is written (871 references) and in contrast to volleyball (1199 references), rugby (2097 references), basketball (2614 references) or football (6951 references), the reported results are much higher.

Establishing a brief chronology of the evolution of scientific contributions to the study of sporting performance in handball, we observe that this is directly related to the evolution of the technological means for the recording and analysis of performance variables, with special attention to those referring to internal and external load, whether in the laboratory or in the field of sporting performance (Matthys, Fransen, et al., 2013; Krüger et al., 2014), in training or simulated competition situations (Michalsik et al., 2013; Povoas et al., 2014). With regard to internal loading, to date and to our knowledge, all studies have been carried out under laboratory conditions (Chelly et al., 2011; Manchado et al., 2013), training (Michalsik et al., 2014) or with low-cost tools based on subjective perception of effort (Feriche et al., 2002; Cuadrado-Reyes et al., 2012). In relation to the assessment of the external load, this has evolved from the more classical and not very immediate methods such as manual annotation (Michalsik et al., 2013) or video tracking (Povoas et al., 2014; Cardinale et al., 2017) to the latest studies using IMU (Inertial Measurement Units) technology, thus overcoming decisive aspects such as having all the information available in an almost immediate, ecological, specific and more accurate way than previous technologies (Barbero et al., 2014; Wik et al., 2017;

Luteberget, Trollerud, et al., 2018; Kniubaite et al., 2019; Manchado et al., 2020; Ortega-Becerra et al., 2020). Finally, it is worth mentioning observational studies that specifically analyse the tactical component of the game in order to determine which variable or set of variables might influence the team's offensive performance (Lozano et al., 2016; Jiménez-Salas et al., 2020a), defensive (Prudente et al., 2010; Fasold & Redlich, 2018) or in the different phases of the game (Daza et al., 2017).

The aim of this doctoral thesis is to analyse, from a multidimensional perspective, the performance of a group of FC Barcelona handball players at the highest competitive level in their respective categories. From the paradigm of the structures of the human athlete (Seirul·lo et al., 2017) and following the line of research carried out in the club itself in other team sports (Gómez et al., 2019; Tarragó et al., 2019; Pons et al., 2020), will try to provide, for the first time, information based on scientific evidence so that it can be applied by present and future coaches of elite and formative handball.

The thesis has been divided into four scientific studies, three of which have already been published in the journal Biology of Sport (IF: 4,606; Q1 Sport Sciences), and the other in the journal Sustainability in the special issue "Sports Psychology and Performance" (IF: 3,889; Q2 Environmental Sciences).

The first study aims to describe the external load variables of elite handball players depending on their playing position. As a world first, the external load was assessed using IMU technology in a real situation of official competition. In this way, 16 top world players (5 wings, 2 centre backs, 6 backs and 3 pivots) were analysed during 14 regular league matches in ASOBAL. The variables analysed were: playing time, player load, certain variables derived from acceleration and the distance travelled as a function of the intensity of displacement. The conclusions of the study were that not all players should be trained under the same external load parameters, as each position makes certain demands. Thanks to this study, coaches now have, for the first time, reference values during the competition of one of the best handball teams in the world. This should help them to optimise the process of adapting to the load during training, individualising it not only according to the characteristics of each player, but especially according to their playing position.

The second study was performed under the COVID-19 pandemic, which hit our society in a way not experienced until then. This doctoral thesis was not immune to this impact. In this way, given that the players of the first FC Barcelona handball team had to be confined at home in the same way as the rest of society, a 9-week physical conditioning plan was scheduled for them to carry out in their respective homes. The aim of the study was to check whether the effects of this home training had been effective or not. Thus, the aerobic capacity and vertical jumping capacity of 11 players were assessed before and after, and the results showed that the individualised work was optimal for maintaining jumping capacity but was an insufficient stimulus for maintaining aerobic capacity. From these results, the main effects of detraining due to COVID-19 in a group of professional handball players at the highest competitive level could be ascertained. Finally, at the applied level, thanks to these results and with the support of the findings of the first study, it was possible to programme during the post-season, with the aim of arriving in the best conditions for the pre-season, a comprehensive and individualised workout for each player, configured from each playing position and with special emphasis on recovering their aerobic aptitudes.

The third study aimed to analyse the group tactical behaviour of the FC Barcelona first handball team. For this purpose, through observational methodology (Hernández-Mendo & Anguera, 1999), an ad hoc tool was created and validated by means of which 14 official matches were analysed in the same regular season of the ASOBAL league and Champions League, obtaining a record of 2581 sequences. Thus, we analysed the possible relationships between focal behaviours of success and failure, contrasted with other performance behaviours through the polar coordinates technique (Anguera, 1997). The results showed that the key to achieving victory in the matches was to achieve success in the defensive phase in order to recover the ball and have options to go to the counter-attack phase, being this the phase where a goal could be obtained with greater clarity. This indicates that the tasks set by the coaches in training sessions should focus especially on increasing the effectiveness of the defensive and counterattack phases, without, of course, ignoring the fact that the training of the other two phases (attack and transition defence phases) should be considered in the same way.

The fourth and last study, which closes this doctoral thesis, focused on the assessment of the external and internal load during competitive microcycles. The coaching staff was interested in knowing whether the team was receiving the right stimulus to perform at the highest level on the days of competition. 15 players from the club's reserve team (5 wings, 2 centre backs, 4 backs and 2 pivots) were monitored over

11 matches and 25 microcycles (weeks). Total distance run, metres run at high intensity (>18.1 km-h^{-1}), player load and subjective perception of effort were recorded. The results obtained showed that during the microcycles there were again significant differences in external load according to each playing position. Also, that the external load during training was different when compared to the external load on the day of the competition. A situation that, in relation to the internal load (subjective perception of effort expressed by each player) did not repeat the same pattern, with no differences perceived by the players between training and competition days. These results helped the coaching staff, again, to optimise the external training load individually for each player. They also helped to dimension, by relativising it, the information on perceived exertion reported by the players. These players, most probably due to their high conditional level and previous knowledge acquired in each of their playing positions, were not able to subjectively discriminate the differences that were reflected in the external load.

However, thanks to this doctoral thesis based on the compendium of four publications, it has been possible to provide scientific knowledge applied to the improvement and optimization of training and competition processes in handball. To our knowledge, reference values for both internal and external load of world elite players are provided for the first time, segregated by game position in both training and real competition situations. This should serve both the national and international handball community, to continue improving and promoting, under scientific evidence criteria, the analysis of the complexity involved in fully optimizing the different structures that make up the human athlete, in this case the handball player.

Índice de contenidos

Listado de publicaciones

Esta tesis está respaldada por la siguiente producción científica:

Artículos:

Font R, Karcher C, Reche X, Carmona G, Tremps V, Irurtia A. Monitoring external load in elite male handball players depending on playing positions. *Biology of Sport*. 2021;38(3):475–481.

Font R, Irurtia A, Gutierrez JA, Salas S, Vila E, Carmona G. The effects of COVID-19 lockdown on jumping performance and aerobic capacity in elite handball players. *Biology of Sport*. 2021;38(4):753–759.

Font R, Daza G, Iglesias X, Tremps V, Cadens M, Mesas JA, Irurtia A. Analysis of the variables influencing success in elite handball with polar coordinates. *Sustainability*. 2022; 14:15542.

Font R, Karcher C, Loscos-Fàbregas E, Altarriba-Bartés A, Peña J, Vicens-Bordas J, Mesas JA, Irurtia A. The effect of training schedule and playing positions on training loads and game demands in professional handball players. *Biol Sport*. 2023;40(3):857–866.

Índice de figuras

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Abreviaturas

B	*Back*
BW	*Body Weight*
CB	*Center Back*
CI	*Confidence Interval*
EE	Entrenamiento Estructurado
EHF	*European Handball Federation*
EHFCL	*European Handball Federation Champions League*
ES	*Effect Size*
GPS	*Global Positioning System*
HD	Humano Deportista
HIA	*High Intensity Acceleration*
HID	*High Intensity Deceleration*
HIIT	*High Intenstiy Interval Training*
HSR	*High Speed Running*
IMUs	*Inertial Measurement Units*
IL	*Internal Load*
LB	*Left Back*
LP	*Line Player*
LPS	*Local Position System*
LW	*Left Wing*
MD	*Match Day*
PIV	*Pivot*
PL	*Player Load*
RB	*Right Back*
RPE	*Rate of Perceived Exertion*
RW	*Right Wing*
SD	*Standard Deviation*
RPE	*Rate of Perceived Exertion*
TAHSUFAIL	*Tactical Analysis Handball Success-Failure*
TD	*Total Distance*
TPL	*Total Player Load*
UWB	*Ultra-Wide Band*
W	*Wings*

1. Introducción

1.1. El balonmano

El balonmano actual es un deporte donde juegan dos equipos formados por 7 jugadores de pista (6 jugadores de campo y un portero) con el objetivo de hacer más goles en la portería contraria que el rival y recibir los mínimos posibles. La duración del partido está formada por dos partes de 30 minutos cada una con un descanso entre 10 o 15 minutos en función de la competición. Una característica importante de las normativas actuales, que nos pueden ayudar a entender el ritmo de juego y su intensidad, es que los cambios entre jugadores son ilimitados y sin tener que parar el tiempo para realizarlos. Esta norma es muy diferente a la mayoría de los deportes. Las reglas han ido evolucionando a lo largo de la historia, haciendo que, hoy, sea un deporte más dinámico y rápido que el de sus orígenes.

Otras de las principales características, es que la relación con el balón siempre tiene que ser con las manos, a excepción del portero. Este último es el único que puede estar tanto dentro del área, sin que sea falta, cómo fuera de ella.

El origen del balonmano no es muy claro ya que, a lo largo de la historia, ha habido muchos juegos que podrían ser antecesores suyos. En la antigua Grecia se jugaba al "*Juego de Urania*" y en la Roma clásica el "*Harpastum*". Posteriormente, en la edad media, un juego denominado el "*Primer Juego del Verano*" tenía un gran parecido al balonmano. Todos estos juegos, fueron evolucionando sobre todo en el centro y norte de Europa. Cada uno tenía sus reglas y sus costumbres. No es hasta a finales del siglo XIX, que el danés Holger Nielsen empezó a unificar y crear unas reglas únicas. La primera vez que se publicaron, fue el 1906 y, hoy en día, se consideran las antecesoras de las reglas actuales del balonmano. Estas reglas siguieron evolucionando, y en el 1917, los alemanes Max Heiser, Karl Schelenz y Erich Konigh crearon una versión más moderna y actualizada. Dos años más tarde, el también alemán Schelenz, las siguió evolucionando. En 1926, se estableció un reglamento internacional de Balonmano y en 1928, 11 países fundaron la Federación Internacional Amateur de Balonmano, organismo que en 1946 se convirtió en la Federación Internacional de Balonmano.

En las Olimpiada de Berlín, 1936, el balonmano se disputaba 11 jugadores contra 11, en el mismo terreno de juego al aire libre que el futbol. Pero debido a su alta práctica en el norte de Europa y a sus condiciones climatológicas, se empezó a practicar dentro de pabellones, modificando sus reglas. Este evolucionó en una reducción de los jugadores, hasta los 7 por equipo actual, y se transformó a un deporte mucho más rápido y dinámico incrementando su práctica y popularidad en el resto del continente. En la actualidad, el balonmano es un deporte Olímpico practicado por hombres y mujeres, aunque con una mayor practica en el continente europeo, es practicado en todos los continentes. A nivel de competiciones de clubs, hay a nivel nacional, a nivel continental y a nivel mundial. A nivel de selecciones nacionales, hay campeonatos de Europa y del Mundo que se disputan cada dos años de forma alterna y forma parte del programa Olímpico cómo ya se ha mencionado.

1.2. El entrenamiento estructurado

En el entrenamiento deportivo, independientemente del nivel del equipo o de los jugadores, han existido diferentes filosofías y teorías que han ido evolucionando a lo largo de la historia. Estas teorías nos han indicado como planificar y organizar los entrenamientos a nivel condicional, de las cualidades físicas básicas, a nivel técnico y a nivel táctico principalmente. Estas teorías han servido de guías a los entrenadores y preparadores físicos, sobre todo, para preparar a los jugadores en sus diferentes facetas para la competición o para su evolución como deportistas.

Tradicionalmente, estas teorías del entrenamiento se han basado en los deportes individuales. Stiff y Verkhoshansky (Stiff & Verkhoshansky, 2000); Matveev (Matveev, 2001), Platonov (Platonov, 2001) han sido algunos de los referentes. Uno de los principales problemas ha sido que estas teorías no estaban adaptadas a los deportes de equipo. El deporte de equipo, a diferencia del deporte individual, está lleno de acciones de incertidumbre, de cambios de ritmo, de movimientos no cíclicos, de caos, de perturbaciones, de toma de decisiones, etc. donde hay que adaptarse continuamente a un móvil, a lo que hace el rival y a los compañeros de equipo. Existe un abanico mucho más amplio de variabilidad tanto a nivel técnico-táctico como a nivel motriz. Basándose en la teoría de los sistemas complejos (Hristovski et al., 2012; Torrents & Balagué, 2018), se han creado otros modelos de entrenamiento mucho más adaptados a estas necesidades de incertidumbre y variación propias de los deportes de equipo.

Uno de estos modelos es el entrenamiento estructurado (EE), basado en las teorías del profesor Seirul·lo (Seirul·lo et al., 2017). A partir de sus ideas surge, en el 1991 en el INEFC de Barcelona, un grupo ideológico formado en sus inicios por Paco Seirul·lo, Xesco Espar, Marcel·lí Massafret y posteriormente por Gerard Moras, Josep Maria Padullés, Julio Tous, Dani Romero y Joan Solé donde desarrollan esta filosofía de trabajo centrada en los deportes de equipo. La teoría del EE se basa en las relaciones que existen entre las diferentes estructuras del humano deportista (HD) y la acción motora en su práctica deportiva adaptada a cada deporte. Se entiende el HD como un sistema biológico dinámico complejo donde todas las partes del sistema y sus diferentes aplicaciones al movimiento se interrelacionan, teniendo clara la premisa que la suma de las partes es mucho mejor para el resultado final (Tarragó et al., 2019). El gran paradigma de esta teoría es evolucionar el entrenamiento racional, analítico, lineal y cuantitativo hacia un entrenamiento más intuitivo, sintético, holístico, no lineal, cualitativo y adaptado a cada deporte (Seirul·lo et al., 2017).

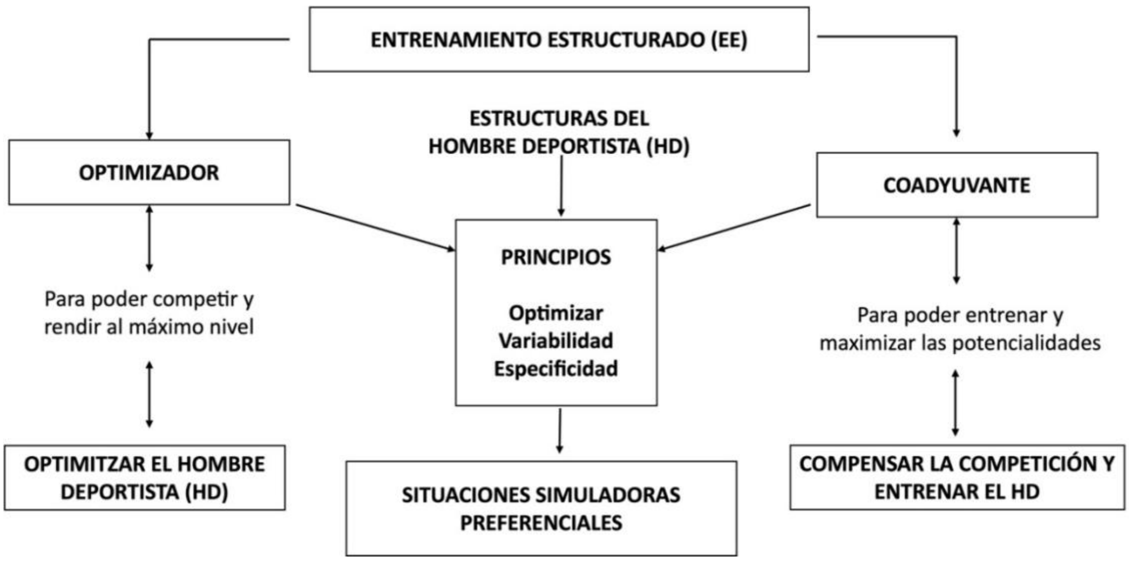

Figura 1. El entrenamiento estructurado. Adaptado de Tarragó et al. (2019).

El EE se organiza en dos grandes áreas: el entrenamiento coadyuvante (Gómez et al., 2019) y el entrenamiento optimizador (Pons et al., 2020). Las diferencias de estas áreas es que el coadyuvante son todos los entrenamientos donde buscamos que el deportista consiga una protección de salud que le permita resistir cada día las propuestas del entrenamiento optimizador (Tarragó et al., 2019). A parte, también son todos los entrenamientos que buscan potenciar todas las estructuras y sistemas que exige la especialidad deportiva y que hacen que el deportista consiga el nivel de rendimiento deseado. Su principal objetivo es preparar al HD para poder entrenar y, a su vez, mejorar las estructuras y sistemas que nos van a ayudar a mejorar el rendimiento del jugador, a partir de elementos que, a priori, no son específicos del juego.

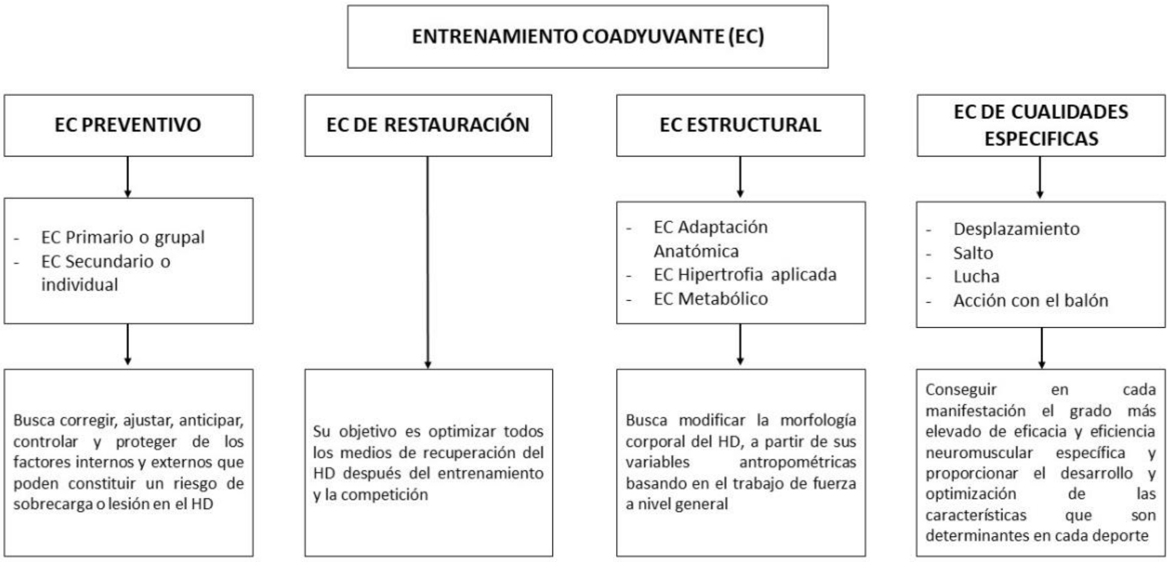

Figura 2. El entrenamiento coadyuvante. Adaptado de Gómez et al. (2019).

Por otro lado, el entrenamiento optimizador es el que prepara al deportista para competir, realizando tareas específicas de cada deporte con sus elementos propios y en el mismo entorno (Tarragó et al., 2019). Este entrenamiento incluye la planificación, el diseño, la ejecución y el control de las tareas para mejorar el rendimiento del HD en las competiciones en las que participe (Pons et al., 2020). El entrenamiento optimizador se basa en generar situaciones simuladoras preferenciales propias de cada deporte que buscan generar acontecimientos que predispongan a un estado de acción y respuesta en un entorno creado que invita a la imitación de los comportamientos que serán simuladores del deporte practicado y que inciden en las diferentes estructuras que configuran al HD (Pons et al., 2020). De esta manera, se basa en un entrenamiento de las cualidades físicas básicas adaptado de diferentes autores (Moras, 1994; Seirul·lo, 1998; Schelling & Torres-Ronda, 2016; Gómez et al., 2019).

Figura 3. El entrenamiento optimizador. Adaptado de Pons et al. (2020).

Dentro del entrenamiento coadyuvante de cualidades específicas y el entrenamiento optimizador, las tareas que se plantean para mejorar las diferentes manifestaciones, tienen un grado de especificidad en función de la semejanza que tienen con el gesto técnico del deporte (Schelling & Torres-Ronda, 2016). Es importante tener claro que estos niveles de aproximación van a ir evolucionando en función del conocimiento que tengamos del deporte y en función de nuestra experiencia profesional y/o académica.

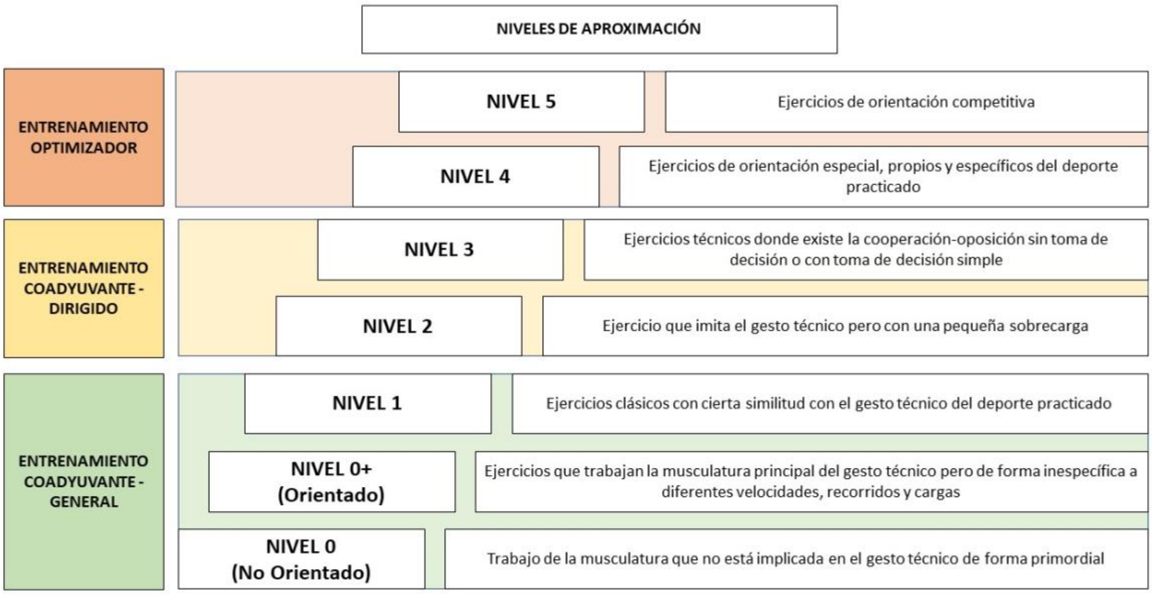

Figura 4. Niveles de aproximación. Adaptado de Gómez et al. (2019).

No hay una teoría que nos acerque más al éxito que otras en el deporte y, dentro de una misma filosofía de trabajo, hay muchos matices y ramificaciones. Pero está claro que el EE es una de las metodologías más aplicadas, hoy en día, en los deportes de equipo ya que nació pensada para ellos. Un ejemplo es el FC Barcelona, un club compuesto por diferentes secciones profesionales con éxitos deportivos a nivel nacional, europeo e internacional (Futbol Masculino, Futbol Femenino, Futbol Sala, Baloncesto, Balonmano y Hoquei Patines). Dentro del club, el Área de Rendimiento ha aplicado esta metodología de trabajo, desarrollando tantos los conceptos teóricos (Gómez et al., 2019; Tarragó et al., 2019; Pons et al., 2020) como su aplicabilidad en los entrenamientos deportivos. Teniendo siempre presente la especificidad, la variabilidad, la optimización, integrando en las tareas propuestas las diferentes estructuras del deportista y planteando una correcta evolución de los ejercicios para finalizar con las situaciones simuladoras preferenciales.

1.3. Las estructuras del deportista

Para poder preparar al HD de la forma más optima posible para resistir la carga de la competición y poder soportar los entrenamientos, hay que trabajarlo en todas sus estructuras. Eso significa que, en todas las tareas planteadas, hay que tener en cuenta todas las partes del HD. Seirul·lo et al., (2017) adaptó las teorías de los sistemas dinámicos al entrenamiento de los deportes de equipo, proponiendo diferentes estructuras de los jugadores que son interdependientes y que actúan durante la práctica deportiva en el contexto propio de los deportes de equipo. Dentro del EE, las diferentes estructuras que forman al jugador son (Tarragó et al., 2019):

- **Estructura bioenergética.** Está relacionada, como su nombre indica, a las vías energéticas. Aporta y renueva la bioenergía haciendo posible el desarrollo de todas las estructuras (Michalsik et al., 2014; Colosio et al., 2020).
- **Estructura cognitiva.** Es responsable del proceso de percepción-acción. Su funcionabilidad se manifiesta en la eficiencia de captar, identificar y tratar la información relevante, relacionada con el entorno del deporte. Se suele relacionar con el concepto de la táctica (Rico-González et al., 2020).
- **Estructura coordinativa.** Está relacionada con la movilidad, lateralidad y disociaciones. Su funcionabilidad se manifiesta con la posibilidad de ejecutar el movimiento deseado de una forma eficiente, sean cuales sean las condiciones del

entorno en las que se tenga que realizar, con la mejor relación con la técnica. Busca eficacia y eficiencia (Vickers, 2007).

- **Estructura condicional.** Tiene relación con las capacidades motrices. Su funcionabilidad se manifiesta por medio de la capacidad de generar tensión intramuscular (fuerza) y las diferentes relaciones con el espacio tiempo de la velocidad y resistencia. Se corresponde a las acciones musculares que nos van a generar el movimiento (Harper et al., 2019).
- **Estructura creativa.** Está relacionada con la capacidad expresiva y las relaciones interpersonales que aparecen en la competición y el entrenamiento. Esta estructura construye las formas de comunicación que son útiles y necesaries en el deporte. Tiene relación con la mayor calidad y experiencia de los jugadores (Kannekens et al., 2009), y el desarrollo creativo de los jugadores en el campo (Orth et al., 2017).
- **Estructura socioafectiva.** Tiene que ver con la relación e identificación con los compañeros y el rol que realiza cada uno. Su funcionabilidad se manifiesta con la calidad y la estabilidad de las relaciones interpersonales fundamentadas en los sentimientos y efectos que se producen durante la práctica deportiva. Es una de las estructuras importantes a trabajar dentro de los deportes de equipo, muy diferente en los deportes individuales (Gorman et al., 2017; Steiner et al., 2017).
- **Estructura emotivo-volitiva.** Está relacionada con los sentimientos propios y los diferentes estados de ánimo. Identifica, regula y encausa todas las emociones y deseos que impulsan a movernos o a no hacerlo. Estructura relacionada con el esfuerzo, la dedicación necesaria para obtener los objetivos deseados. Va asociada a la auto-estructuración (Pérez & Gutierrez-Braojos, 2012) e intentar que el jugador tenga una retroalimentación positiva y nunca negativa que no le permitiría seguir con el proceso de aprendizaje que es el entrenamiento.
- **Estructura mental.** Está relacionada con la autoorganización que el jugador tiene de las estructuras. Combinación y recombinación de facultades cognitivas que posibilita la autoconsciencia y el pensamiento evolutivo de todos los mundos de nuestro existir.

Hay que entender que las diferentes estructuras se relacionan con los diferentes sistemas que nos podemos encontrar durante la práctica deportiva. Por tanto, un correcto trabajo de todas las estructuras nos puede permitir una evolución del HD debido a la optimización equilibrada de todas ellas. Si podemos conseguir esto, los jugadores van a poder crear estructuras de diferentes niveles de sistemas dentro de sistemas. Con el entrenamiento buscamos proponer diferentes situaciones donde se produzca el desequilibrio de alguna estructura para que el jugador sea capaz de su auto estructuración y optimizar, de esta forma, su entrenamiento (Arjol, 2012).

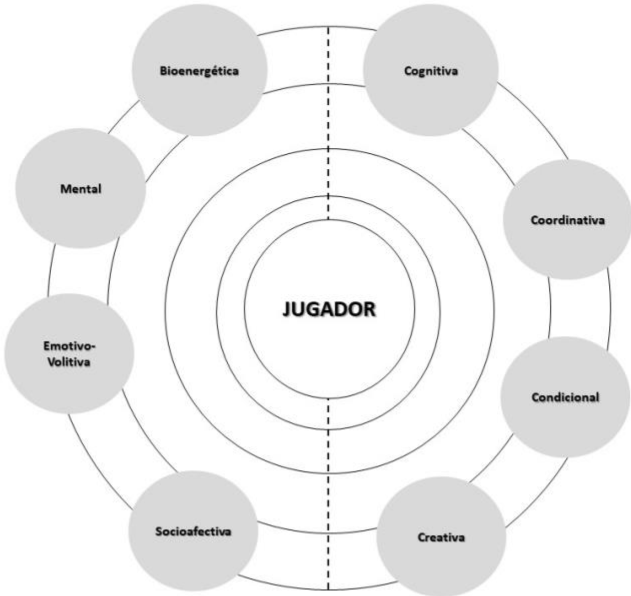

Figura 5. Estructuras del humano deportista (adaptado de Tarragó et al., 2019).

1.4. Control de la carga en los deportes de equipo

Para analizar si los jugadores consiguen adaptarse a las necesidades que nos pide la competición, y para ver si realmente somos capaces de prepararlos en todas sus estructuras, hace falta analizar lo que sucede tanto en el entrenamiento como en la competición. Esta variable la entendemos como carga de entrenamiento y lo que se busca es manipularla para obtener una respuesta deseada al entrenamiento propuesto (Impellizzeri et al., 2019).

Siempre se ha entendido que el 100% de la intensidad de trabajo es la competición, sobre todo des de un prisma de los deportes individuales. A partir de aquí, se busca realizar un ciclo de sobrecarga y compensación para llegar a la competición en el mejor estado de forma posible realizando una fase de tapering (Mujika & Padilla, 2003; Bosquet et al., 2013; Vachon et al., 2021). Este modelo teórico es bastante óptimo para los deportes individuales donde no suele haber competición cada microciclo. Pero en los deportes de equipo, donde suele haber un partido durante la semana, se entiende de una forma global de macrociclo, y a su vez, microciclo a microciclo. Si el equipo es de nivel profesional que disputa competición nacional más competición continental, puede que dispute dos partidos durante la semana. Esto nos da muchas variantes dentro de la planificación de la temporada y, más concretamente, dentro del microciclo. A parte, para realizar la planificación, es importante saber el nivel de los rivales para poder ajustar los mesociclos y microciclos de trabajo en función del nivel de nuestro equipo y nuestros objetivos finales. Podemos encontrarnos con un principio del microciclo donde podemos realizar un trabajo de sobrecarga pues la competición importante es durante el fin de semana o podemos tener la competición importante dentro de la semana teniendo que hacer un trabajo de sobrecarga por detrás de este partido.

La clave es saber que necesidades tienen nuestros jugadores a nivel de carga interna y de carga externa en la competición y si estamos preparándolos de una forma óptima durante los entrenamientos analizando los entrenamientos y los partidos para disponer del mayor número de variables controladas para tener una visión lo más global posible.

1.4.1. Carga interna

Cuando hablamos de carga interna, entendemos el conjunto de exigencias psicológicas y biológicas para poder realizar la actividad física (González Badillo & Gorostiaga, 1995). Con el entrenamiento, buscamos generar adaptaciones al organismo de los jugadores para prepararlos para soportar la carga que nos vamos a encontrar en la competición (Impellizzeri et al., 2019). Hay muchas investigaciones en el deporte que han analizado que sucede a nivel de carga interna durante el entrenamiento y la competición midiendo variables como la frecuencia cardíaca (Berkelmans et al., 2018; McLellan et al., 2011), el nivel de lactato en sangre (Meyer et al., 1999) o el VO2max (Vollaard et al., 2009). Otras investigaciones, se han centrado en controlar de forma subjetiva el estado de fatiga de los jugadores a través del rate of perceived exertion o RPE (Foster et al., 2001, 2021) o a través de diferentes cuestionarios (Heidari et al., 2019).

El control de la frecuencia cardíaca es una herramienta que ha sido ampliamente estudiada y analizada dentro del entrenamiento y las adaptaciones fisiológicas que generamos a nuestros deportistas (Schneider et al., 2018). Se ha utilizado en múltiples investigaciones de forma analítica en diferentes pruebas (Achten & Jeukendrup, 2003; Buchheit, 2014), como pueden ser el test 30-15 (Buchheit, 2010), el yo-yo test (Bangsbo et al., 2012), o el test de carrera progresiva submáxima (Léger et al., 1988) para ver el estado de los jugadores (Aubert et al., 2003; Michael et al., 2017; Schneider et al., 2018), valorando su fatiga y las adaptaciones que estamos generando (Buchheit, 2014; Thorpe et al., 2017), analizando lo que ocurre en los entrenamientos (Alexandre et al., 2012; Berkelmans et al., 2018) o en partidos amistosos (Garcia et al., 2012). En la actualidad, hay muchas tecnologías que nos permiten realizar su control y análisis (Naranjo et al., 2015; Perrotta et al., 2017; Schneider et al., 2018) usándose en competiciones oficiales (McLellan et al., 2011) y obteniendo los resultados casi inmediatos para realizar su análisis. Es un indicador validado, fiable y de fácil uso para ver cómo afecta la carga externa de manera fisiológica a nuestros jugadores. A parte de analizar los datos obtenidos con la frecuencia cardíaca, podemos buscar correlaciones con diferentes variables de carga externa para ver si el entrenamiento que estamos proponiendo genera las adaptaciones que buscamos (Delaney et al., 2018). A su vez, se ha utilizado este indicador para ver el estado de forma de los jugadores en diferentes momentos de la temporada como su estado de forma antes de empezar una pretemporada o ver su evolución a lo largo de esta (Boullosa et al., 2013; Campos-Vazquez et al., 2017).

Otra variable para controlar la carga interna utilizada ampliamente es la acumulación de lactato en sangre (Halson, 2014). El nivel de lactato ha servido para ver que necesidades metabólicas existen en el deporte practicado sobre todo en los cíclicos (Bosquet et al., 2001) pero también se ha validado en los deportes de equipo (Castagna et al., 2010). Se ha analizado que estado de forma tienen los jugadores con esta variable al empezar la pretemporada y al terminarla (Best et al., 2013; Los Arcos et al., 2018), se ha hecho en diferentes tests de laboratorio más analíticos e inespecíficos (Tokmakids et al., 1998; Kaya et al., 2013) o con test específicos para el deporte de equipo, como por ejemplo en futbol (Akubat et al., 2018). Se ha demostrado en deportes de resistencia que a más entrenamiento, se mejora la forma de los deportistas disminuyendo los niveles de lactato (Bosquet et al., 2001) siendo, a su vez, un buen indicador de la intensidad del entrenamiento (Billat, 1996; Halson, 2014). Es importante saber que orientación metabólica tiene nuestro deporte para luego reproducirlo en el entrenamiento analizando la carga interna que podemos encontrar a nivel de lactato en los diferentes ejercicios o tareas que realizamos (Castagna et al., 2013). Lo ideal sería saber que carga interna nos genera cada ejercicio en función de la posición de juego o, a nivel individual, de cada jugador y buscar su relación con lo que sucede en la competición (Rodríguez-Alonso et al., 2003; Matthew & Delextrat, 2009). También se ha validado como un indicador grupal del estado de forma de diferentes equipos del mismo deporte y competición (Ziogas et al., 2011).

Otra herramienta mucho más low cost y cada vez más utilizada para controlar la carga interna de los jugadores es el RPE (Foster et al., 2001). Éste ha sido estudiado para demostrar su fiabilidad y su validez para el control de la carga de entrenamiento tanto en deportes individuales (Wallace et al., 2009; Halson, 2014) como en deportes de equipo (Scott et al., 2014; Crawford et al., 2018). Su objetivo es analizar el estrés psicológico del ejercicio en el jugador (Figura 6), analizando la percepción subjetiva de la fatiga a través de la Escala de Borg (Scott et al., 2014; Foster et al., 2001). A partir de este dato, multiplicado por los minutos de juego en el partido o de entrenamiento, podemos obtener la carga total percibida por los jugadores de forma individual (Gómez-Díaz et al., 2013; Gabbett, 2016). También se puede analizar su relación con parámetros de carga externa; (Bartlett et al., 2017; Delaney et al., 2018) e interna como la frecuencia cardíaca o el nivel de lactato en sangre (Halson, 2014; Foster et al., 2021).

ESCALA DE ESFUERZO DE BORG	
0	Reposo total
1	Esfuerzo muy suave
2	Suave
3	Esfuerzo moderado
4	Un poco duro
5	Duro
6	
7	Muy duro
8	
9	
10	Esfuerzo máximo

Figura 6. Escala de esfuerzo de Borg CR-10.

En la misma línea del RPE, existen los cuestionarios wellness test que también son una herramienta económica, fiable y de muy fácil aplicación para ver las respuestas de los jugadores durante el entrenamiento y el partido (Saw et al., 2016; Heidari et al., 2019). Estos cuestionarios nos indican la percepción subjetiva que tiene el deportista del nivel de estrés y fatiga, importante para ver como toleran la carga de entrenamiento y la competición tanto a nivel fisiológico y psicológico. A día de hoy, son un tipo de prueba muy importante para la valoración del riesgo lesional de los jugadores (McCall et al., 2016). Algunas investigaciones han determinado que sus respuestas son importantes para predecir en el mes anterior a su evaluación (Laux et al., 2015).

Si comparamos este indicador subjetivo con otros, se ha observado que es más sensible a las variaciones diarias de la carga de entrenamiento con otros marcadores como puede ser la frecuencia cardíaca (Thorpe et al., 2016). A parte el nivel de fatiga tiene una elevada correlación con la distancia recorrida a nivel total siendo importante por la relación existente entre carga interna y carga externa (Thorpe et al., 2015, 2017).

1.4.2. Carga externa

Por lo que se refiere a la carga externa, es causada por la actividad y la competición que realizamos (González Badillo & Gorostiaga, 1995). La carga externa suelen ser variables en los deportes de equipo como: la distancia recorrida total, la intensidad de esta distancia, el número de aceleraciones y desaceleraciones, metros recorridos en aceleración y desaceleración, velocidad máxima, número e intensidad de los saltos y aterrizajes. Estas variables son algunos de los ejemplos que se deberían extraer de los diferentes entrenamientos propuestos por los entrenadores o preparadores físicos para generar las adaptaciones deseadas a nivel de carga interna en el organismo de los jugadores (Impellizzeri et al., 2019). Con todo, antes de saber qué carga externa tienen que soportar los jugadores, muchas investigaciones se han centrado para saber que perfil condicional tienen los jugadores en el laboratorio. Con este perfil de cada deporte o jugador, lo que se ha buscado es saber que valores hay que potenciar y trabajar más en los entrenamientos a la vez que valorar diferentes déficits de fuerza o de amplitud de movimiento, por ejemplo, para intentar compensarlos y que no sea un factor lesivo (Lidor & Ziv, 2010; Ramirez-Campillo et al., 2020).

A nivel del control de la carga externa, a lo largo de la historia del entrenamiento, las diferentes tecnologías para el control de esta han ido evolucionado en función del acceso a nuevas herramientas de análisis o de control (Travassos et al., 2013). Una técnica de análisis utilizada para saber la carga externa de diferentes deportes ha sido el video análisis (video tracking). Es una técnica que ha evolucionado des de sus orígenes (Van Gool et al., 1988) hasta la actualidad (Castellano et al., 2014; Stojanović et al., 2018). Para realizar esta técnica, hay que instalar cámaras en el campo de entrenamiento y/o juego o grabarlo con una cámara convencional. Uno de los problemas para este sistema puede ser la instalación de estas cámaras para que la filmación sea automática (Rico-González et al., 2020). Pero es una técnica ampliamente validada y fiable para realizar el análisis del comportamiento de los jugadores en el campo (Barris & Button, 2008; Castellano et al., 2014; Pino-Ortega et al., 2021). A partir del video análisis, podemos conseguir información de la carga externa y el perfil condicional del equipo y de cada jugador vinculadas al estado de forma en función de la posición de juego (McInnes et al., 1995; Di Salvo et al., 2007, 2010), la fatiga (Bradley & Noakes, 2013), el rendimiento a nivel de acciones técnicas (Taylor et al., 2008), el tiempo efectivo de juego (Castellano et al., 2011) o el porcentaje de posesión del balón (Lago, 2009). Estas variables siempre van a estar vinculadas al time-motion y no obtendremos información o no podrán ser cuantificadas con precisión a nivel de cambios de dirección, saltos, aceleraciones, desaceleraciones, impactos… (Castellano et al., 2014).

Como hemos podido ver, todas estas tecnologías tienen un principal problema que es la inmediatez de la información, hecho importante en el deporte de elite y no calculan con precisión todas las variables de carga externa importantes para saber la carga que tienen que soportar los jugadores ya sea en competición o en entrenamiento. Existe una tecnología que ha evolucionado en los últimos años que nos permite tener información en directo de lo que está sucediendo en el entrenamiento o en el partido o de forma muy inmediata y nos da información fiable de muchas variables relacionadas con la carga externa. Este sistema son los *inertial measurements units* (IMUs). Los IMUs están basados en microtecnología (dispositivos inerciales formados por acelerómetro, giroscopio y manómetro) y nos dan datos derivados de un acelerómetro de tres ejes con una frecuencia de muestreo alta (100 Hz) para la descripción y cuantificación de las demandas físicas sea partidos o entrenamientos. En los deportes *outdoor*, su uso ha sido mucho más fácil debido a que se pueden utilizar los sistemas Global Positioning System (GPS) utilizando para el posicionamiento de los jugadores los satélites espaciales (Silva et al., 2016; Rico-González et al., 2020). A nivel de deportes indoor, se ha tenido que diseñar un sistema de antenas dentro de los pabellones, para poder simular los satélites creando un Local Position Systems (LPSs). Estas antenas nos dan toda la información referente al posicionamiento de los jugadores (Alarifi et al., 2016; Rico-González et al., 2020). La transmisión de las ondas en estos dispositivos es de forma inalámbrica y los podemos clasificar en infrarrojos, radio frecuencias (Wi-Fi, Bluetooth y banda ultra ancha o UWB) y sistemas de ultrasonidos (Rico-González et al., 2020).

El sistema UWB ha sido validado y demostrada su fiabilidad para los deportes indoor (Bastida-Castillo et al., 2019; Pino-Ortega et al., 2021). A parte de las antenas, es necesario que los jugadores lleven dispositivos receptores dentro de un peto en el pecho llevando el transmisor en la parte posterior de la espalda (Vázquez-Guerrero et al., 2018). La distancia se calcula a través de diferentes algoritmos de posicionamiento UWB. A partir de esta tecnología, podemos saber la intensidad de los desplazamientos, las aceleraciones, desaceleraciones o velocidad de desplazamiento de los jugadores en entrenamiento, por ejemplo, en baloncesto (Vázquez-Guerrero et al., 2020) o hoquei sobre patines (Fernández et al., 2020). A parte, los sistemas actuales de registro de los datos, a diferencia de otras tecnologías, nos dan información del número y de la intensidad de los saltos, aterrizajes e impactos que el jugador realiza (García et al., 2020) siendo un valor muy importante para tener más información sobre la carga externa y las fuerzas que deberían soportar los jugadores. Otro elemento clave es ver como distribuimos las variables de carga externa durante el microciclo (Martin-Garcia et al., 2018; Illa et al., 2020) y analizar si conseguimos preparar a los jugadores en función de su posición de juego de una forma óptima para soportar la carga del partido (Martín-García et al., 2018; Vázquez-Guerrero et al., 2018). En la actualidad, por ejemplo, en deportes indoor como el baloncesto, existen investigaciones dónde se analiza la distribución de la carga externa en diferentes categorías de equipos de formación (Garcia et al., 2021).

Otra variable utilizada ampliamente en las investigaciones con esta tecnología es el Player Load (PL). El PL nos muestra la acumulación de movimiento en los acelerómetros dándonos un único valor indicativo de la carga externa. Se obtiene a través del cálculo de la raíz cuadrada de la suma de las tasas instantáneas de cambio de aceleración al cuadrado en cada uno de los tres planos dividida por 100 en absoluto (Reche-Soto et al., 2019; Vázquez-Guerrero et al., 2019):

$$PL = \frac{\sqrt{\left(a_{y1} - a_{y-1}\right)^2 + (a_{x1} - a_{x-1})^2 + (a_{z1} - a_{z-1})^2}}{100}$$

Con todo, debe tenerse en cuenta que una de las limitaciones de esta tecnología es que no permite cuantificar acciones musculares isométricas. Estas acciones no se pueden medir con los acelerómetros, pero pueden ser acciones de gran cantidad de fuerza, de mucha exigencia y, en función del deporte y de la posición de juego, lesivas (Cummins et al., 2013; Svilar et al., 2018).

En la actualidad, hay diferentes investigaciones que han correlacionado la carga externa que obtenemos de esta tecnología con la carga interna para intentar controlar la carga total que tiene que soportar el jugador y, a su vez, intentar disminuir el riesgo lesivo (Cummins et al., 2013; McLaren et al., 2018). Se ha demostrado que un incremento de la carga externa se asocia a un mayor número de lesiones en deportes de equipo como el futbol, por ejemplo (Jaspers et al., 2018). En definitiva, tanto entrenadores, preparadores físicos como personal médico, necesitan datos de carga interna y externa para entender las necesidades del entrenamiento y de la competición y ver que le sucede a cada jugador de forma individual (Scanlan et al., 2014). A partir de aquí, podremos analizar si el entrenamiento que planteamos es el apropiado para mejorar el rendimiento del jugador y ayudar a prevenir futuras lesiones.

1.5. Análisis de los comportamientos tácticos en el deporte

Una de las claves en el éxito deportivo es analizar que hacen los jugadores en el campo tácticamente y si como equipo somos capaces de superar al rival. Es importante saber que sucede en cada fase del juego y que sistemas de juego ya sean ofensivos o defensivos son más importantes para conseguir nuestros objetivos. Una de las técnicas utilizadas para conseguir esta visión ha sido el análisis observacional. Una de las ventajas de realizar el análisis con esta técnica es que es ecológica, analiza lo que sucede a nivel deportivo sin modificar el comportamiento natural de los jugadores y equipos (Travassos et al., 2013;

Lozano et al., 2016). Esta metodología ha sido ampliamente utilizada en el ámbito del deporte (Anguera et al., 2011, 2014, 2020; Bakeman & Quera, 2012). A partir de esta técnica, se han descrito diferentes indicadores para valorar el éxito del comportamiento de los equipos en diferentes deportes (Lago & Anguera, 2002; Castellano & Hernández, 2003). En futbol, se ha valorado el éxito en las acciones de córner (Fernández-Hermógenes et al., 2021) o el éxito de los diferentes sistemas defensivos (Castellano & Hernández, 2002) por ejemplo. En baloncesto se ha analizado la influencia del juego interior de los equipos (Morillo-Baro et al., 2021) o para analizar el juego de transición en la liga española (Pastrana-Brincones et al., 2021). A partir de estos análisis, se puede determinar que acciones o sistemas de juego pueden ser más eficientes o menos útiles para conseguir los objetivos que nos proponemos en nuestro juego e introducirlos en las tareas de entrenamiento.

1.6. Análisis del balonmano

En el balonmano, igual que en otros deportes, se ha intentado explicar el deporte des de diferentes perspectivas. Una de las claves para el éxito deportivo, sea este el que sea en función del equipo y del club, es analizar al máximo el deporte en cuestión. Este análisis debería permitir a los entrenadores, preparadores físicos y cuerpo médico, plantear entrenamientos adaptados a que los jugadores puedan soportar la carga de entrenamiento y competición, que los entrenamientos preparen de forma óptima a los jugadores para soportar esta carga competitiva y, a su vez, ayuden a los jugadores a prevenir lesiones propias del balonmano. También deberíamos saber que sucede a nivel de carga interna en función de la carga externa a la que estamos sometiendo en cada sesión, sea entrenamiento o partido, a nuestros jugadores.

1.6.1. Análisis de la carga interna en el balonmano

Hay diferentes investigaciones que se han centrado en saber el perfil fisiológico de los jugadores de balonmano. Estos perfiles se han determinado normalmente en el laboratorio, con pruebas máximas inespecíficas del deporte. Es la forma más fácil de obtener estos perfiles si se dispone del material y la infraestructura adecuada que suele ser costosa. Se ha buscado la frecuencia cardíaca máxima (Manchado et al., 2013; Wagner et al., 2016; Michalsik & Wagner, 2021), el VO2 máx. (Wagner et al., 2016, 2019) y el nivel de lactato en test incrementales (Chelly et al., 2011). Con todo, y bajo un contexto de análisis pormenorizado de estas variables, sería necesario investigar en base a las características individuales y a la posición de juego de cada jugador de balonmano. Desde el punto de vista del EE, este perfil individual nos debería permitir diseñar rutinas de trabajo adaptadas a las necesidades de cada jugador o adaptar los descansos en el partido debido a la naturaleza propia del balonmano que permite los cambios de jugadores sin parar el tiempo y de forma ilimitada. Adicionalmente, la obtención de estos datos de carga interna debería realizarse con pruebas específicas adaptadas al balonmano con movimientos propios del deporte y que se pudieran reproducir en entrenamiento. Hay algunas investigaciones que han intentado reproducir movimientos específicos para encontrar estas diferentes variables (Wagner et al., 2016; Michalsik & Wagner, 2021). Los resultados obtenidos en estas pruebas deberían ser mucha más ecológicos que los obtenidos con las pruebas incrementales de laboratorio y, bajo mi experiencia, con una mayor implicación por parte del jugador que ve mayor relación con el entrenamiento.

Un aspecto relevante a señalar es que los valores de análisis asociados a cada jugador deberían monitorizarse también durante la competición. Existen diferentes investigaciones que han analizado parámetros de carga interna como la frecuencia cardiaca en partidos con jugadores jóvenes (Gupta & Goswami, 2017; Ortega-Becerra et al., 2020), simulando un partido de balonmano (Barbero et al., 2014), en mujeres (Manchado et al., 2013) o en diferentes partidos oficiales (Povoas et al., 2014). Otras se han centrado en valorar el nivel de lactato en sangre (Povoas, 2009; Michalsik, 2011;) o el VO2máx (Povoas, 2009). Con todo, debido a su complejidad, es difícil hallar investigaciones basadas en competiciones oficiales con equipos de elite.

A nivel de carga interna y más allá de variables de tipo fisiológico, también se ha analizado el estado físico reportado subjetivamente por el jugador de balonmano posteriormente a una situación de entrenamiento o partido. Para realizar este control, hay diferentes investigaciones que han usado el RPE, vista su validez y fiabilidad (Feriche et al., 2002). En este sentido, se han hallado asociaciones con la frecuencia cardiaca (Cuadrado-Reyes et al., 2012), en pruebas específicas para valorar la fatiga en el lanzamiento (Nuño et al., 2016), en situaciones de fatiga acumulada mediante ejercicios realizados en espacios reducidos (Mhenni et al., 2017) y en situación de competición real en partidos oficiales (Kniubaite et al., 2019). Teniendo en cuenta la necesaria curva de aprendizaje de cada jugador, la valoración de la RPE se demuestra como una herramienta que podemos usar siempre, en diferentes momentos del entrenamiento, juguemos en casa o fuera o si queremos controlar como se encuentran nuestros jugadores durante las semanas que están con sus equipos nacionales y queremos controlar su carga y nivel de estrés. Sólo teniendo esta respuesta subjetiva de los jugadores, multiplicando por los minutos de entrenamiento o partido, podemos controlar la carga total y ver como ésta evoluciona microciclo tras microciclo (Foster et al., 2021). A su vez, nos puede ayudar para prevenir un exceso de carga de trabajo y prevenir lesiones debido a la sobrecarga (Hulin et al., 2016).

1.6.2. Análisis de la carga externa en el balonmano

Igual que sucede con el control de la carga interna, hay diferentes investigaciones más propias de laboratorio que se han centrado en saber el perfil condicional de los jugadores de balonmano. Este perfil nos debería servir para saber que necesidades físicas necesitan nuestros jugadores y adaptar los entrenamientos. Se ha estudiado valores de fuerza con ejercicios generales como squat o press de banca en jugadores y jugadoras en formación (Ingebrigtsen et al., 2013) o diferentes pruebas de velocidad y desplazamientos más o menos específicos (Matthys, Fransen, et al., 2013; Matthys, Vaeyens, et al., 2013), adaptado a las posiciones de juego (Krüger et al., 2014) o analizando las diferencias entre chicos y chicas jóvenes (Camacho-Cardenosa et al., 2018). También se ha observado que valores tienen los jugadores a nivel de potencia de salto con diferentes pruebas como el squat jump, el countermovement jump o el drop jump (Ingebrigtsen et al., 2013; Massuça & Fragoso, 2013; Matthys, Vaeyens, et al., 2013). Una opción interesante con los valores obtenidos en los test de salto es analizar que sucede antes y después de un entrenamiento o partido para valorar la fatiga de los jugadores y cuando estos pueden volver a entrenar o a jugar el partido con unos valores aceptables que demuestren su recuperación (Oliveira et al., 2014). Esta variable es importante debido a la naturaleza del balonmano, tanto para mejorar el rendimiento como para predecir déficits y prevenir posibles lesiones en la extremidad inferior (Olsen et al., 2006; Langevoort et al., 2007; Mónaco et al., 2019). Dentro de estas pruebas condicionales, se han analizado a los jugadores con pruebas donde se ha valorado los desplazamientos específicos propios de un partido de balonmano

(Matthys, Vaeyens, et al., 2013; Massuca et al., 2015; Wagner et al., 2016; Schwesig et al., 2017; Michalsik & Wagner, 2021). El tener analizado y claro estas variables más condicionales, son claves ya que pueden influenciar en la carga de entrenamiento (Impellizzeri et al., 2019), en obtener un perfil por posición o en prevenir lesiones y valorar déficits. Una vez obtenidos todos estos resultados, hay que incorporarlos en el entrenamiento, en las diferentes tareas, pero, sobre todo, lo importante es saber que exigencias nos está demandando la competición y como las trabajamos durante los entrenamientos, en las diferentes tareas y si preparamos óptimamente a nuestros jugadores, de forma individual para soportar estas cargas.

Las diferentes técnicas de análisis de la carga externa en balonmano han ido evolucionando igual que en los demás deportes. Una técnica muy utilizada en el ámbito de la investigación es el video tracking. Esta técnica nos pueda dar mucha información una vez realizado el partido, pero no es inmediata y estamos en un momento en que los diferentes cuerpos técnicos suelen pedir inmediatez. Si que es verdad que en otros deportes han creado softwares de análisis que en poco tiempo tienes la información de la carga externa de los jugadores en el partido, pero, bajo nuestra búsqueda y experiencia profesional, no hemos encontrado ninguna investigación que se haya centrado en ello. A través de esta técnica se ha descrito que los laterales son las que realizan mayores desplazamientos en un partido (Michalsik et al., 2013; Povoas et al., 2014), los metros recorridos relativos a los minutos jugados siendo un buen indicador de la intensidad (Luig et al., 2008; Povoas, 2009), que los extremos, en ciertas investigaciones, son los que realizan más metros a alta intensidad (Povoas et al., 2014), como se distribuyen los metros recorridos en función de la intensidad de la carrera (Sibila et al., 2004; Luig et al., 2008; Povoas et al., 2012), que velocidad máxima pueden alcanzar los jugadores en partido (Cardinale et al., 2017) o el tiempo de juego en partido de cada posición (Cardinale et al., 2017). Con todo, estas variables obtenidas dependerán, en gran medida, del modelo de juego del equipo observado.

Un aspecto relevante que destacar cuando se analiza la carga externa en el balonmano, a parte de la no inmediatez del reporte de datos, es que los movimientos explosivos, las aceleraciones y desaceleraciones, la intensidad de los saltos y de los aterrizajes e impactos, todavía no han sido adecuadamente registrados. En este sentido, existen estudios de más de dos décadas, realizados mediante video grabación, que indican que el balonmano es un deporte de alta intensidad más por sus impactos que por el ritmo de sus desplazamientos (Rannou et al., 2001). Dado el avance de la tecnología y del propio deporte, es probable que ahora conviniera actualizar esta información mediante la realización de los correspondientes estudios. Ciertamente, tanto el perfil condicional como el ritmo de juego en el balonmano actual se han incrementado exponencialmente, con un número de posesiones mayor y consecuentemente también un mayor número de goles. También se han introducido nuevas reglas como la del 7x6, que aumentan las exigencias del juego. Con todo, hoy es posible monitorizar esta realidad del balonmano actual mediante los dispositivos IMU. Éstos no sólo han sido validados para deportes indoor, sino que lo han estado de forma específica también para el balonmano (Bastida-Castillo et al., 2018; Luteberget, Holme, et al., 2018).

Los dispositivos IMUs, aunque corresponden con una tecnología que ha sido ampliamente usada y con muchas publicaciones en otros deportes outdoor (futbol y rugby, por ejemplo) o indoor (baloncesto), en balonmano, el número de publicaciones e investigaciones con ella no es muy amplio. Si que hoy en día hay diferentes clubs de élite que usan estos dispositivos, pero de momento, la mayoría usa estos datos para modificar y valorar su preparación y no para publicar e investigar y compartir el conocimiento que obtienen.

Con el uso en nuestro día a día de estos dispositivos, podríamos registrar acciones de alta intensidad, movimientos más explosivos, saltos, impactos, aterrizajes y el número de veces que ocurren y clasificarlos en función de su intensidad. A la vez que obtendríamos datos como distancia, velocidad máxima, minutos de participación de los jugadores, aceleraciones y desaceleraciones y todo tanto a nivel de equipo, como a nivel de cada posición como a nivel individual por jugador. Pero bajo mi punto de vista, la clave seria que pudiéramos obtener los datos de carga externa que nos da la competición siempre que se nos permita y ver como adaptamos los entrenamientos y si preparamos a los jugadores de una forma correcta en función de las necesidades de cada uno de ellos. Al final, conseguir lo que nos planteamos con el EE de la individualización del trabajo. En la actualidad, des de la preparación física debemos exigirnos realizar entrenamientos individualizados para cada jugador en función de sus necesidades de carga externa, de sus adaptaciones fisiológicas, de su historial lesivo o de sus preferencias y no realizar todo el equipo el mismo entrenamiento.

A nivel de investigaciones, debido al elevado coste de colocar antenas para similar la posición de los jugadores, algunas de ellas han realizado diferentes partidos simulados al aire libre, usando los satélites para generar esta posición (Ortega-Becerra et al., 2020). Es un primer avance al uso de estos sistemas.

También existen investigaciones donde se han realizado partidos simulados dentro de un pabellón para obtener estas variables descritas anteriormente (Barbero et al., 2014). Pero la mayoría de los datos que hemos encontrados en nuestra búsqueda relacionados con estos dispositivos son todos en competición. Hay una investigación que registra la distancia recorrida por jugadores masculinos de elite en función de la intensidad del desplazamiento por posiciones y en la fase ofensiva o defensiva (Manchado et al., 2020) y todos los demás son competiciones femeninas. Se han estudiado las acciones de alta intensidad y la variable de PL en partidos internacionales de selecciones de mujeres en función de la posición de juego (Luteberget & Spencer, 2017; Wik et al., 2017) o el PL, este indicador general sobre la carga externa en partidos de liga nacional (Kniubaite et al., 2019). Sólo hemos encontrado una investigación que se haya centrado en analizar que ocurre en diferentes tareas de juego en entrenamiento (Luteberget, Trollerud, et al., 2018).

Analizando todos los datos existentes, haría falta realizar una descripción de los datos de carga externa en competición en una temporada en hombres ya que son datos inexistentes con esta tecnología y ver como distribuimos los contenidos dentro del microciclo para analizar si preparamos a los jugadores de la mejor forma posible para soportar la carga competitiva de cada jugador.

1.6.3. Análisis del comportamiento táctico en balonmano

El día a día de los equipos, independientemente del nivel que tengan, es analizar a los rivales con los que van a jugar el fin de semana y analizar como juega su propio equipo y ver si siguen el modelo de juego que, el cuerpo técnico y el entrenador en concreto, han decidido realizar. Este análisis sirve para ver cómo se puede conseguir anular el equipo rival en su fase ofensiva y encontrar debilidades en su modelo defensivo para conseguir acabar en gol.

A parte del uso de este análisis para mejorar los resultados deportivos, también se han realizado múltiples investigaciones a través de la metodología observacional para analizar que ocurre en las diferentes fases del juego e intentar ser más eficientes en nuestro juego y en los entrenamientos modificando el tiempo que destinamos a cada fase.

Se han analizado los sistemas ofensivos utilizados por selecciones (Lozano & Camerino, 2012), la eficacia de estos sistemas contra diferentes sistemas defensivos (Rogulj et al., 2011; Jiménez-Salas et al., 2020a;) o que sucede en momentos críticos del partido en ataque (Lozano et al., 2016). También se ha analizado que sucede en la fase del contraataque en función de si son jugadores seniors o jugadores en formación (Jiménez-Salas et al., 2020b) o que sucede en la última acción de finalización (Meletakos et al., 2011). A nivel defensivo, se ha buscado la relación con el portero y el resultado (Pascual et al., 2010) o la relación atacante/defensor (Prudente et al., 2010) o la eficacia del hecho de realizar más o menos golpes francos para interrumpir el ritmo del ataque para que tengan que construir de nuevo su fase ofensiva (Fasold & Redlich, 2018).

Al final, lo que se busca con estos análisis es buscar que indicadores nos van a acercar al éxito o al fracaso (Daza et al., 2017). Está claro que cada equipo tiene un modelo de juego muy concreto en las diferentes fases del juego, pero sería muy interesante que analizáramos que queremos conseguir en cada fase y que indicadores nos van a hacer fracasar o triunfar para poder trabajarlos en los entrenamientos e inculcarlos a nuestros jugadores. No hay que olvidar que el balonmano es un deporte de equipo y todos los jugadores tienen que cumplir ciertas normas de relación en la pista para conseguir el objetivo propuesto.

Creo que es interesante realizar este análisis a nivel de clubes ya que la mayoría de las investigaciones se han basado en partidos de selecciones nacionales y hay poca información sobre modelos de juego de equipos ganadores y que basen su entrenamiento en la metodología del EE. A parte, no todas las fases están investigadas por igual ya que no hay casi publicaciones que se centren en el balance defensivo para intentar contrarrestar la opción de finalización más fácil que es el contraataque.

1.7. El rendimiento deportivo

En conclusión, después de analizar todas estas diferentes facetes que forman un jugador y que hay que tener que controlar, entiendo que no sólo debemos tener un tipo de valoración o analizar un tipo de variables. Cuantas más variables podamos controlar, sobre todo en el balonmano de élite, más cerca podremos estar de conseguir nuestros objetivos.

Hay que conocer qué tipo de variables de carga interna tienen nuestros jugadores con diferentes pruebas analíticas y pruebas específicas para el balonmano. Hay que dominar que carga externa tienen que soportar nuestros jugadores durante la competición para poder reproducirlas en el día a día de nuestros entrenamientos y hay que saber que acciones son las más eficaces en las diferentes fases del juego para conseguir el éxito en el partido. Pero todas estas variables no hay que verlas des de una visión general y ya no des de una visión de cada posición de juego, sino que hay que analizarlas des de una individualización de cada jugador, adaptando nuestro trabajo, el entrenamiento, en función de lo que necesite cada HD.

2. Objetivos

2.1. Objetivo general

El objetivo general de esta tesis doctoral es analizar, des de una perspectiva multidimensional, el rendimiento deportivo de los jugadores de balonmano. Para ello se ha credo una línea de trabajo donde se aporten datos objetivos sobre esta valoración del rendimiento con diferentes tecnologías y herramientas, tanto de carga interna como externa y su análisis.

2.2. Objetivos específicos

Estudio 1

Analizar las demandas físicas de carga externa de cada posición de juego del balonmano en la élite que nos exige la competición mediante el análisis de los partidos en una temporada completa.

Estudio 2

Valorar la eficacia de un programa de entrenamiento en casa para mantener la capacidad aeróbica y la fuerza explosiva de las extremidades inferiores en jugadores de balonmano de élite durante el confinamiento por la COVID-19.

Estudio 3

Identificar que variables del modelo de juego que intervienen en un partido influyen en el éxito o el fracaso en las diferentes fases del juego en un equipo de élite de balonmano durante todos los partidos en una temporada regular

Estudio 4

Los objetivos en este estudio fueron varios:

1. Describir las diferencias de carga de entrenamiento, tanto interna como externa, entre las diferentes posiciones de juego en jugadores de balonmano.
2. Analizar las demandas de competición a nivel de carga interna y externa entre las diferentes posiciones de juego en jugadores de balonmano y ver las diferencias existentes entre los diferentes días del microciclo y la competición para valorar si los preparamos de forma óptima para soportar la carga competitiva.

3. Métodos

3.1. Estructura de la tesis

Esta tesis consta de cuatro investigaciones donde en cada una de ellas se ha intentado describir y obtener información sobre unas variables que nos permitieran valorar el rendimiento en jugadores de balonmano. Primero de todo hacía falta saber que necesidades nos demanda la competición en un equipo de élite en función de la posición de juego de los jugadores. En nuestra búsqueda, no hemos encontrado ningún estudio donde nos dijera estas necesidades y creemos que era vital empezar por esta cuestión para, a partir de este primer estudio, ver cómo debemos entrenar partiendo de la base que la competición es la máxima especificidad en cualquier deporte de equipo.

Debido a la pandemia de la COVID-19, generamos otra investigación donde valoramos el estado de forma de los jugadores después de realizar un trabajo de fuerza y resistencia adaptado en sus domicilios. La importancia de esta valoración post confinamiento fue que pudimos saber en qué estado de forma se encontraban a nivel de tests analíticos que los jugadores tenían muy familiarizados para poder diseñar un trabajo condicional individualizado para cada uno de ellos para empezar la pretemporada siguiente sin un incremento exponencial de lesiones

En el estudio 3 buscamos analizar el comportamiento de los jugadores y del equipo a nivel más táctico en las diferentes fases del juego para determinar que variables nos acercaban al éxito competitivo y poder reproducirlas o destinar más tiempo de trabajo en los entrenamientos del equipo.

Una vez sabíamos las demandas de la competición del primer estudio, analizamos en el estudio 4 las demandas de un equipo filial y como se distribuían estas demandas de carga interna y carga externa en función de la posición de juego, durante el microciclo. Saber cómo entrenamos durante la semana es clave, bajo nuestro punto de vista, para ver si preparamos a los jugadores de forma óptima para soportar la carga de la competición.

Tabla 1. Configuración esquemática de la tesis

	ESTUDIO 1	ESTUDIO 2	ESTUDIO 3	ESTUDIO 4
Objetivo general	Conocer las demandas por posición de juego en competición de élite	Valorar la eficacia de un programa de entrenamiento en casa para mantener la capacidad aeróbica y la fuerza explosiva de las extremidades inferiores.	Identificar que variables del modelo de juego que intervienen en un partido influyen en el éxito o el fracaso en las diferentes fases del juego	Conocer las demandas por posición de juego en competición de élite y comparativa con el entrenamiento
Diseño	Transversal y observacional	Diseño retrospectivo	Metodología Observacional	Diseño transversal y observacional
Muestra	16 jugadores de élite de balonmano	11 jugadores de élite de balonmano	14 partidos de élite de balonmano	15 jugadores profesionales de balonmano
Variables	Tiempo de juego (min)	Frecuencia cardiaca (bpm)	Conducta focal ÉXITO	Distancia recorrida total y en función velocidad (m)
	Distancia recorrida total y en función velocidad (m)	Lactato sanguíneo (mmol/L)	Conducta focal FRACASO	High-Speed Running ($m{\cdot}s^{-1}$)
	Velocidad máxima ($m{\cdot}min^{-1}$)	Altura salto vertical (cm)	Fases del juego	Player Load (au)
	Velocidad promedio ($m{\cdot}min^{-1}$)		Número jugadores	RPE (au)
	High-Speed Running ($m{\cdot}s^{-1}$)		Marcador	
	Número de aceleraciones y desaceleraciones (n)		Secuencias	
	Aceleraciones y desaceleraciones Alta Intensidad ($m{\cdot}s^{-2}$)		Sistemas ofensivos y defensivos propios y del rival	
	Aceleraciones y desaceleraciones Alta Intensidad relativo al tiempo ($m{\cdot}s^{-2}{\cdot}min^{-1}$)		Zona de finalización	
	Player Load (au) y Player Load relativo al tiempo ($TPL{\cdot}min^{-1}$)		Resultados intermedios	
			Resultados finales	
			Acciones disciplinaries propias y del rival	
Material	WIMU PRO™ system con acelerómetro, giroscopio y magnetómetro a 100 Hz y barómetro a 120 kPa	Cinta Garmin® HR vinculado a WIMU PRO™	Instrumento observación TAHSUFAIL	WIMU PRO™ system con acelerómetro, giroscopio y magnetómetro a 100 Hz y barómetro a 120 kPa
		Analizador de lactate y tiras reactivas (Lactate Scout)	Software LINCE PLUS	
		Plataforma de contactos Chronojump Boscosystem	Software HOISAN	

3.2. Participantes

Una de las claves de esta tesis es la calidad de los participantes. En el estudio 1, estudio 2 y estudio 4 estamos hablando de un equipo de la máxima categoría a nivel mundial de balonmano. Durante las 11 temporadas que este doctorando ha formado parte del cuerpo técnico como entrenador de porteros primero y preparador físico y readaptador después, el equipo ha conseguido 58 títulos nacionales e internacionales. La mayoría de los jugadores que han formado parte de los diferentes estudios son o han sido internacionales por sus selecciones nacionales, reforzando la calidad de la muestra. A parte, la importancia de disponer de estos sujetos es el hecho de poder mostrar datos reales en la élite y poder compartir los resultados, hecho que no es nada habitual en muchos deportes e investigaciones.

3.2.1. Estudio 1

En este primer estudio se analizaron los datos de 16 jugadores profesionales de elite de balonmano masculino del primer equipo del FC Barcelona de balonmano. Los jugadores estaban divididos por su posición de juego en cinco extremos (26.6±6.3 años; 183.1±4.4 cm; 83.2±4.1 kg), dos centrales (32.0±7.1 años; 192.8±1.0 cm; 93.8±4.9 kg), seis laterales (26.3±4.8 años; 195.3±2.8 cm; 97.8±5.1 kg) y tres pivotes (28.3±4.0 años; 198.0±8.4 cm; 101.5±4.9 kg). Se optó por dividir la primera línea en central y laterales ya que en muchas investigaciones lo analizan como una única posición, pero, bajo nuestra opinión, sus necesidades condicionales y en el juego nos parecían diferentes.

Los datos se obtuvieron del seguimiento de los jugadores durante los partidos disputados como local durante la temporada 2017-2018. Todos los jugadores fueron informados durante la firma de sus contratos de una cláusula en la que aceptaban su participación en proyectos de investigación, por lo que no fue necesaria la aprobación de un comité de ética (Winter & Maughan, 2009). Aun así, todos los jugadores fueron informados sobre los propósitos del estudio, los riesgos conocidos y los posibles peligros asociados, ajustándose a la Declaración de Helsinki de la Asociación Médica Mundial (actualizada en 2013).

3.2.2. Estudio 2

El estudio se realizó con 11 jugadores de balonmano profesional del más alto nivel del primer equipo del FC Barcelona. Todos los jugadores que participaron en el estudio eran jugadores internacionales con sus respectivas selecciones nacionales durante la temporada en la que participaron en el estudio. Los jugadores que participaron en el estudio eran tres extremos (26.3 ± 3.7 años; 185.3 ± 4.7 cm; 83.2 ± 6.5 kg), cuatro laterales (29.5 ± 7.0 años; 193.3 ± 5.1 cm; 98.3 ± 7.4 kg), tres pivotes (27.9 ± 6.4 años; 195.0 ± 3.0 cm; 105.3 ± 9.2 kg) y un portero (27.9 ± 0 años; 190.0 ± 0 cm; 84.0 ± 0 kg). Los datos se obtuvieron de diferentes pruebas de valoración del estado de forma de los jugadores que se realizaban habitualmente durante la temporada, estando los jugadores familiarizados con ellos. Las pruebas del estudio se realizaron el 29 enero del 2020 y el 18 de mayo del mismo año. Todos los jugadores fueron informados durante la firma de sus contratos de una cláusula en la que aceptaban su participación en proyectos de investigación, por lo que no fue necesaria la aprobación de un comité de ética (Winter & Maughan, 2009). Aun así, todos los jugadores fueron informados sobre los propósitos del estudio, los riesgos conocidos y los posibles peligros asociados, ajustándose a la Declaración de Helsinki de la Asociación Médica Mundial (actualizada en 2013).

3.2.3. Estudio 3

Se analizaron catorce partidos del primer equipo del FC Barcelona de balonmano, siete de la máxima categoría española, la Liga Asobal, y siete de la máxima categoría del balonmano europeo, la Liga de Campeones de la European Handball Federation (EHFLCL) de la temporada 2019-2020. En los 14 partidos se analizó el juego de un total de 23 jugadores del FC Barcelona. Los videos que se usaron eran de acceso público ya que fueron retransmitidos en directo o se podían obtener a través del canal de la EHF. Al ser videos de libre acceso, según el Informe Belmont[1], no fue necesario la obtención de un consentimiento informado por parte de los jugadores (Pastrana-Brincones et al., 2021). Se eligieron los partidos de casa porque eran más fáciles de obtener y de mejor calidad que los de fuera ya que se obtuvieron directamente del equipo de producción de televisión. El Informe Belmont describe los principios éticos básicos y las directrices relativas a las cuestiones éticas en la investigación con seres humanos. Además, este estudio no requirió una revisión por parte de un comité de ética de investigación, ni un consentimiento informado por escrito por las siguientes razones (a) implico la observación de individuos en lugares públicos (pabellón deportivo); (b) los individuos o grupos observados no tuvieron una expectativa razonable de privacidad; (c) no implico la intervención del investigador ni la interacción directa con los individuos.

[1](https://student.societyforscience. org/human-participants)

3.2.4. Estudio 4

Este estudio se hizo con el segundo equipo del FC Barcelona de balonmano, con jugadores profesionales en etapa de formación todavía. Algunos de estos jugadores del estudio entrenaban habitualmente con el primer equipo llegando a disputar algún partido oficial de liga o competición europea con ellos. Algunos de ellos eran jugadores internacionales con sus equipos de nacionales con su respectiva categoría en función de su edad. Los jugadores del estudio fueron agrupados por su posición de juego. Estos eran, tres extremos izquierdos (edad: 23.0±0.0 años, peso: 78.5±3.5 kg, altura: 176.0±0.0 cm), dos extremos derechos (edad: 23.5±0.7 años, peso: 73.0±2.8 kg, altura: 179.0±1.4 cm), tres centrales (edad: 24.0±1.0 años, peso: 90.3±9.3 kg, altura: 190.3±7.5 cm), tres laterales izquierdos (edad: 23.7±0.6 años, peso: 93.0±6.6 kg, altura: 192.3±3.5 cm), dos laterales derechos (edad: 23.0±0.0 años, peso: 89.5±16.3 kg, altura: 194.5±9.2 cm), y dos pivotes (edad: 29.5±4.9 años, peso: 100.5±7.8 kg, altura: 192.5±3.5 cm).

Los datos de la investigación fueron obtenidos debido al proceso de seguimiento diario de los jugadores durante los entrenamientos y los partidos durante toda la temporada 2018-2019. Todos los jugadores fueron informados durante la firma de sus contratos de una cláusula en la que aceptaban su participación en proyectos de investigación, por lo que no fue necesaria la aprobación de un comité de ética (Winter & Maughan, 2009). Aun así, todos los jugadores fueron informados sobre los propósitos del estudio, los riesgos conocidos y los posibles peligros asociados, ajustándose a la Declaración de Helsinki de la Asociación Médica Mundial (actualizada en 2013).

3.3. Material

3.3.1. Estudio 1

El estudio se realizó con el sistema WIMU PRO™ (RealTrack Systems S.L., Almería, España). Cada dispositivo, cuyas dimensiones eran 81x45x16 mm (alto/ancho/profundidad) y con un peso de 70 g, se colocó en la espalda de cada jugador con petos ajustables (Rasán®, Valencia, España). Todos los jugadores estaban acostumbrados a este tipo de dispositivo y a su forma de sujeción, ya que habían entrenado con este sistema durante toda la temporada.

El sistema funciona mediante triangulaciones entre cuatro antenas con tecnología patentada de banda ultra ancha (frecuencia de muestreo de 18 Hz) colocadas a 5 m de cada una de las esquinas de la cancha y a una altura de 6 metros. Estas unidades incluyen varios sensores que registran a diferentes frecuencias de muestreo. La frecuencia de muestreo utilizada para los tres ejes, el acelerómetro, el giroscopio y el magnetómetro fue de 100 Hz y de 120 kPa para el barómetro (Bastida-Castillo et al., 2018; Bastida-Castillo et al., 2019).

3.3.2. Estudio 2

En este estudio utilizamos diferentes materiales en función de la prueba de valoración.

- Prueba de carrera submáxima incremental:

Durante la prueba, se registró la frecuencia cardíaca (FC) utilizando una cinta Garmin® HR. El monitor de FC se conectó al sistema WIMU PRO™ (Realtrack Systems, S.L., Almería, España) y los datos se analizaron posteriormente utilizando los valores medios de FC para cada etapa de la prueba de carrera submáxima en lanzadera.

Un minuto después de la finalización de la prueba, se pinchó a los jugadores en el lóbulo de la oreja para analizar los niveles de lactato en sangre (Rodríguez-Alonso et al., 2003; Matthew & Delextrat, 2009; Gupta & Goswami, 2017). El análisis se realizó con un analizador de lactato Lactate Scout + y tiras reactivas Lactate Scout (Nova Biomedical, Waltham, MA, USA).

- Prueba de salto vertical, *countermovement jump* (CMJ):

Para esta prueba se utilizó una plataforma de contacto (Chronojump Boscosystem, Barcelona, España) para evaluar la altura del CMJ. El hardware estaba conectado a un ordenador que mostraba la altura de salto vertical (cm) mediante un software gratuito (2.0.2., Chronojump Boscosystem Software, Barcelona, España). Este tipo de tecnología ha demostrado su fiabilidad y validez en otro tipo de investigaciones con pruebas de salto vertical (Pueo et al., 2020). Los jugadores realizaron dos CMJ bilaterales y dos CMJ unilaterales con cada pierna. Se registró el mejor resultado de cada prueba (altura, cm) y se utilizó para el análisis posterior.

3.3.3. Estudio 3

Para llevar a cabo la investigación, se construyó un instrumento de observación ad hoc para analizar todas las variables que pueden darse en todas las fases de un partido de balonmano. Todas las categorías cumplían el requisito de exhaustividad y exclusividad mutua (Anguera & Hernández, 2013; Jiménez-Salas et al., 2020b). La herramienta creada fue llamada TACTICAL ANALYSIS HANDBALL SUCCES-FAILURE (TAHSUFAIL) y fue evaluada por un grupo de 13 expertos, todos ellos licenciados en ciencias del deporte y con una mínima experiencia como entrenadores de balonmano en equipos de primera de división en diferentes países de dos años. El análisis del coeficiente V de Aiken (Aiken, 1985) entre las valoraciones de los expertos de las diferentes categorías determinó un valor de 0.99 para la pertenencia y de 0.97 para la claridad, obteniendo un total de 0.98 y demostrando la validez de la herramienta. La observación de los partidos fue realizada por cuatros observadores, licenciados en ciencias del deporte, preparadores físicos en equipos de élite y con 10 años de experiencia en el balonmano. La fiabilidad del instrumento se validó tras un período de entrenamiento entre los observadores. Se realizaron las pruebas de concordancia intra-observador e inter-observador para validar el análisis de los partidos. La tabla 2 muestra los diferentes estadísticos que se utilizaron para la validación del instrumento inter-observador: Kappa de Cohen (Krippendorff, 2018); Kappa de Fleiss (Fleiss et al., 2013) y Coeficiente Iota (Conger, 1980). Todos los resultados obtenidos validaron a los observadores.

Tabla 2. Resultados de validación del instrumento intra- e inter-observador

Coefficient for entire session	Intra- observer agreement	Inter-observer agreement
Cohen's Kappa	0.98	0.97
Fleiss' Alpha	0.98	0.97
Iota Coefficient	0.98	0.97

Una vez creada y validada la herramienta, se analizaron todos los partidos con el software libre LINCE PLUS (versión 1.3.2. release) (Soto-Fernández et al., 2021). Este software ha sido utilizado en diversas investigaciones en el ámbito del deporte con metodología observacional (Lozano et al., 2016). Todos los criterios e instrumentos de observación fueron introducidos en el software. Al finalizar el análisis de todos los partidos observados, se obtuvo un total de 2581 secuencias. Para cada coincidencia, se exportó un registro codificado de todos los datos en formato Excel.

3.3.4. Estudio 4

Igual que en el estudio 1, el registro de los datos se realizó con el sistema WIMU PRO™ (RealTrack Systems S.L., Almería, España). Cada dispositivo, cuyas dimensiones eran 81x45x16 mm (alto/ancho/profundidad) y con un peso de 70 g, se colocó en la espalda de cada jugador con petos ajustables (Rasán®, Valencia, España). Todos los jugadores estaban acostumbrados a este tipo de dispositivo y a su forma de sujeción, ya que habían entrenado con este sistema durante toda la temporada.

El sistema funciona mediante triangulaciones entre cuatro antenas con tecnología patentada de banda ultra ancha (frecuencia de muestreo de 18 Hz) colocadas a 5 m de cada una de las esquinas de la cancha y a una altura de 6 metros. Estas unidades incluyen varios sensores que registran a diferentes frecuencias de muestreo. La frecuencia de muestreo utilizada para los tres ejes, el acelerómetro, el giroscopio y el magnetómetro fue de 100 Hz y de 120 kPa para el barómetro (Bastida-Castillo et al., 2018; Bastida-Castillo et al., 2019).

3.4. Análisis de los datos

3.4.1. Estudio 1

El registro de datos de posicionamiento de este estudio fue monitorizado en tiempo real y posteriormente analizado mediante el software SPRO™ versión 937 (SPRO™, RealTrack Systems, 2018). El análisis estadístico se realizó con el software R Studio (v1.1.463 Studio, Boston, Massachusetts).

3.4.2. Estudio 2

El registro de datos de frecuencia cardíaca fue monitorizado en tiempo real y posteriormente analizado mediante el software SPRO™ versión 966-967 (SPRO™, RealTrack Systems, 2018). El registro de datos de saltos fue analizado con el software gratuito (2.0.2., Chronojump Boscosystem Software, Barcelona, España). Todo el análisis estadístico se realizó con el programa SPSS version 23.0 (SPSS Statistics, IBM Corp., Armonk, NY, USA).

3.4.3. Estudio 3

Una vez obtenidos los datos de los partidos del estudio 4, se utilizó el programa Hoisan (Hernández-Mendo et al., 2014) para la codificación y posterior análisis con coordenadas polares y la representación (Rodríguez-Medina et al., 2019). A parte, se realizó un análisis de generalizabilidad (Cronbach et al., 1972) a través del software SAGT, versión 1.0 (Hernández-Mendo et al., 2016) (ver tabla 3). Siguiendo a Miranda et al., (2019), se llevaron a cabo dos planes de medición para analizar los datos obtenidos: a) La generalizabilidad de los resultados obtenidos (número de secuencias que componen la muestra) y b) la validez del instrumento de observación: a) El coeficiente de generalizabilidad (relativo y absoluto 0.998) correspondiente al plan de medida [Categorías]/[Secuencias] establece que con el número de secuencias analizadas se obtiene una alta fiabilidad de precisión de generalización. b) Respecto al plan de medición [Secuencias]/[Categorías], el coeficiente de generalizabilidad (relativo y absoluto 0.000) apoya dentro del marco teórico de la Teoría de la Generalizabilidad, la validez del instrumento de observación diseñado (Blanco-Villaseñor & Escolano Pérez, 2017).

Tabla 3. Resultados del diseño de la generalizabilidad [Categorías] [Secuencias].

Sources of variation	Sum of squares	Degree of freedom	Mean square	% Variance	Standard error
[SECUENCIAS]	12.838	1667	0.008	0	0
[CATEGORIAS]	3842.188	68	56.503	27.616	0.006
[SECUENCIAS][CATEGORIAS]	10048.711	113.356	0.089	72.384	0

3.4.4. Estudio 4

El registro de datos de posicionamiento fue monitorizado en tiempo real y posteriormente analizado mediante el software SPRO^{TM} versión 946-949 (SPRO™, RealTrack Systems, 2018). El registro de todas las sesiones de entrenamiento y de partidos dio lugar a 1033 registros para la carga externa y 1.008 archivos para la carga interna. Los análisis estadísticos se realizaron con R Studio (v1.3 Studio, Boston, Massachusetts) y el paquete Esvis (v0.3.1).

3.5. Análisis Estadístico

3.5.1. Estudio 1

Las estadísticas descriptivas se presentaron como medias y desviaciones estándar (SD). Las diferencias entre las posiciones de juego se analizaron mediante los estadísticos del tamaño del efecto (Effect Size, ES) de Cohen y el intervalo de confianza (CI) de ±90%. El criterio para determinar el tamaño del ES fue <0.2 | 0.2 a 0.59 | 0.6 a 1.19 | 1.2 a 1.99 | ≥2.0, considerando estos valores como trivial, pequeño, moderado, grande y muy grande, respectivamente (Hopkins et al., 2009). El porcentaje de probabilidad de diferencia entre los grupos se calculó y se consideró como casi seguro que no (<0,5%), muy improbable (<0.5%), improbable (<25%), posiblemente (25-75%), probable (>75%), muy probable (>95%) o muy probable (>99,5%). Un porcentaje de probabilidad de diferencia <75% se consideró una magnitud sustancial. Se utilizó un umbral de probabilidad del 5% para las magnitudes sustanciales, lo que significa que una probabilidad de >5% tanto en sentido positivo como negativo se consideró poco clara. También se calcularon las diferencias significativas. La prueba de Kolmogorov-Smirnov confirmó una distribución no normal de todas las variables analizadas. Se realizó la prueba de Kruskal-Wallis para comparar las cuatro posiciones de juego, seguida de la prueba de rangos con signo de Wilcoxon con ajuste de Holm para determinar las diferencias entre las posiciones por parejas. En las pruebas estadísticas que lo requerían, el nivel de significación fue de p<0,05.

3.5.2. Estudio 2

Se comprobó la normalidad de los datos mediante la prueba de Shapiro-Wilk. Se utilizó una prueba t de *Student* de muestras pareadas para evaluar las diferencias en las variables de interés (masa corporal, frecuencia cardíaca media, concentración de lactato en sangre capilar, altura CMJ) de los períodos Pre y Post. Se utilizó la d de Cohen para calcular el tamaño del efecto (ES). Los umbrales para las estadísticas de ES fueron triviales (ES<0.20); pequeños (0.20<ES<0.59); moderados (0.60<ES<1.19); grandes (1.20<ES<1.99); y muy grandes (ES>2.0) (Hopkins et al., 2009). Todos los datos se presentaron como media ± desviación estándar (SD) y el nivel de significación se fijó en p < 0,05.

3.5.3. Estudio 3

Para encontrar las variables más significativas en las diferentes fases del juego, se utilizó la técnica de coordenadas polares para reducir el gran volumen de datos obtenidos (Castellano & Hernández, 2003). Esta técnica se basa en un análisis secuencial de los desfases prospectivos y retrospectivos de los datos obtenidos (Sackett, 1980; Anguera, 1997) y nos permite observar las relaciones existentes entre las conductas que conforman el sistema taxonómico que hemos creado (Castellano & Hernández, 2003). A partir de este análisis obtuvimos el estadístico de contraste, Zsum ($Zsum = \Sigma z/ \sqrt{n}$, donde n es el número de retardos) (Cochran, 1954) con rangos de retardo de □5 a +5. Una vez obtenidos estos resultados, realizamos una representación gráfica de las relaciones encontrada entre las categorías focales, en nuestro caso éxito o fracaso, y las condicionadas a nivel de vectores (Hernández-Mendo & Anguera, 1999). La longitud del vector es la distancia entre el origen de coordenadas Zsum (0.0) y el punto de intersección (valor Zsum de la conducta focal en el eje X y valor Zsum de la conducta condicionada en el eje Y). Las relaciones se consideran significativas ($p < 0,05$) cuando las longitudes son superiores a 1.96 (Tarragó et al., 2017). Este valor lo obtenemos con la raíz cuadrado de la suma del cuadrado de la Zsum de X (prospectiva) y el cuadrado de Zum de Y (retrospectiva). Además, el ángulo del vector (φ = Arco seno de Y/Radio) determina la naturaleza de la relación (Castellano & Hernández, 2003). Las relaciones que encontramos en cada cuadrante están representadas en la figura 7 (Castellano & Hernández, 2003).

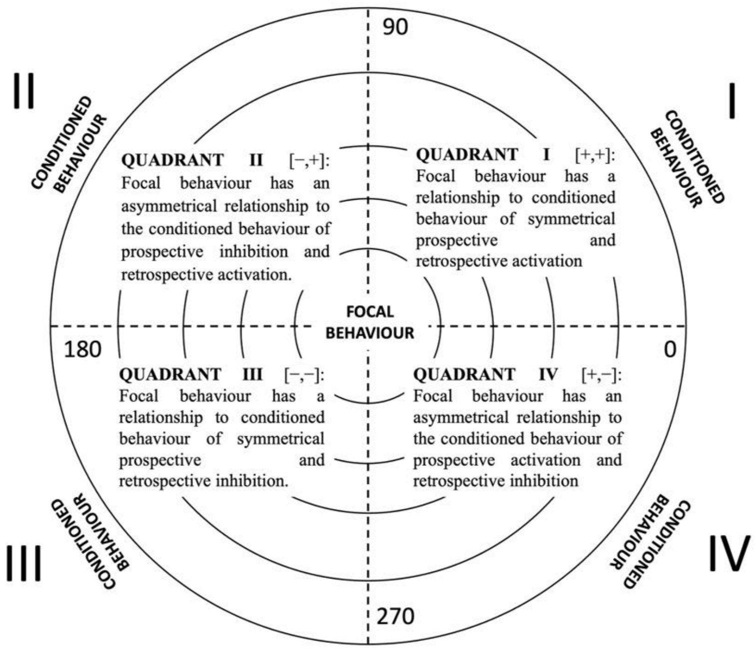

Figura 7. Características de cada cuadrante de las coordenadas polares.

3.5.4. Estudio 4

Los datos en este estudio 3 fueron presentados como medias y desviaciones estándar (SD). Todos los datos se transformaron primero en logaritmos para evitar el sesgo derivado del error de no uniformidad. Para comparar la carga externa e interna, entre y dentro de las diferentes posiciones de juego durante los partidos y las sesiones de entrenamiento, se calcularon las diferencias estandarizadas de la media (tamaño del efecto de Cohen). Para ver el tamaño del efecto (ES) se calificaron los resultados utilizando la escala de Hopkins: 0.2 (pequeño), 0.6 (moderado), 1.2 (grande), 2.0 (muy grande) (Hopkins et al., 2009). También se calculó el intervalo de confianza del 90% para cada tamaño del efecto (ES). Teniendo en cuenta el elevado número de comparaciones, no se analizaron los resultados cuando el límite inferior del ES era inferior a 0.6. También se calcularon los porcentajes de las demandas de partido para cada variable siguiendo esta fórmula:

$$\frac{Session\ demand - Mean\ playing\ position\ game\ demand}{Mean\ playing\ position\ game\ demand} \times 100$$

4. Estudios de investigación originales

4.1. Estudio 1: *Monitoring external load in elite male handball players depending on playing positions*

* Font R., Karcher C., Reche X., Carmona G., Tremps V., Irurtia A. (2021). Monitoring external load in elite male handball players depending on playing positions. Biol Sport, 38(3):475–481.

Abstract

Monitoring workload is critical for elite training and competition, as well as preventing potential sports injuries. The assessment of external load in team sports has been provided with new technologies that help coaches to individualize training and optimize their team's playing system. In this study we have characterized the physical demands of an elite handball team during an entire sports season. Novel data is reported for each playing position of this highly strenuous body-contact team sport. Sixteen world top players (5 Wings, 2 Center Backs, 6 Backs, 3 Line Players) were equipped with a local positioning system (WIMU PRO™) during fourteen official Spanish first league matches. Playing time, total distance covered at different running speeds, and acceleration variables, were monitored. During a handball match, Wings perform the largest distance covered at high-speed running (>5.0 $m \cdot s^{-1}$): 410.3±193.2 m, and by sprint (>6.7 $m \cdot s^{-1}$): 98.0±75.4 m. Center Backs conforms the following playing position that supports the highest speed intensities during the matches (high-speed running: 243.2±130.2 m; sprint: 62.0±54.2 m). Center Backs also registers the largest number of high-intensity decelerations (n=142.7±59.5) compared to Wings (n=112.9±56.0), Backs (n=105.2±49.2) and Line Players: 99.6±28.9). This study provides helpful information for professional coaches and their technical staff to optimize training load and individualize the physical demands of their elite male handball players depending on each playing position.

Keywords: training load, accelerometer, match analysis, handball, IMU, workload

Introduction

Global positioning systems are widely used in outdoor team sports such as rugby or football (Schuster et al., 2018; Rago et al., 2019). This system also carries an embedded inertial measurement unit (IMUs) (e.g. accelerometer, magnetometer) recorder with a good level of validity (Bastida-Castillo et al., 2018), a wide range of metrics (e.g., distance and number of sprints), although GPS cannot be used indoors (the GPS signal is blocked). Recently, many companies have developed ultra-wide band systems to collect real-time data in indoor sports (Bastida-Castillo et al., 2019). This new technology has led to a better understanding of the players' responses to training and competition (Luteberget, Trollerud, et al., 2018; Kniubaite et al., 2019; Vázquez-Guerrero et al., 2019).

Although there are still limitations that should not be overlooked (Bastida-Castillo et al., 2018), technical staff can now adjust player workloads more precisely according to game demands (Barbero et al., 2014). These aspects are essential in handball, since playing positions largely influence game demands (Karcher & Buchheit, 2014). As a result, coaches can design training content adapted to playing position and playing style, which should lead to a better performance (Luteberget, Trollerud, et al., 2018) and fewer injuries (Mónaco et al., 2019).

At present, despite greater access to technology, there are still few scientific contributions related to game demands in handball. Additionally, most of this research has been conducted with video tracking (Luig et al., 2008; Cardinale et al., 2017) or hand notational analysis (Michalsik et al., 2013). These technologies have been shown to be less adapted to recording explosive actions typical of handball than IMUs systems (Barbero et al., 2014; Ortega-Becerra et al., 2020). In this indoor context, despite the proven accuracy (Bastida-Castillo et al., 2018) and reliability (Luteberget, Holme, et al., 2018) of IMUs, more studies are needed applied to official competitions in elite male handball players. Previous studies have provided specific information, but only based on game-simulated situations in elite women (Wik et al., 2017; Luteberget, Trollerud, et al., 2018) training sessions in adolescent male players (Ortega-Becerra et al., 2020), or during 30-minutes outdoor (Barbero et al., 2014).

The evolution of the Total Player Load (TPL) was also analysed, reporting, for the first time ever, the external load indicator for each player in relation to actual playing time, i.e., providing information on the intensity level achieved per unit of time. These studies did not report any information about player displacement (e.g. distance covered at different speeds) which are of paramount information to coaches (Wik et al., 2017; Luteberget, Trollerud, et al., 2018). It is worth noting that game demands are gender-dependent in elite handball (Michalsik & Aagaard, 2015), which makes these results useless for male elite players. To our knowledge, the physical demands in an elite men's handball team have never been described during a sports season.

Thus, the aim of this study was to characterise position-specific physical demands in elite handball players by measuring external load during a competitive season to provide a benchmark for coaches and the related training staff to optimise player preparation.

Material and methods

Experimental approach to the problem

We conducted a cross-sectional, observational study to determine the differences between each playing position: Wings (W), Center Backs (CB), Backs (B) and Line Players (LP). Results corresponding to the average of 14 competitive official home matches disputed in 2017-18 ASOBAL league (Spanish national premier league). We collected 188 records from the 16 players selected from the 14 games (61 from W, 18 from CB, 68 from B and 41 from LP).

Subjects

We analysed 16 professional elite male players from the same team throughout the season. The team was comprised of five W (26.6±6.3 years; 183.1±4.4 cm; 83.2±4.1 kg), two CB (32.0±7.1 years; 192.8±1.0 cm; 93.8±4.9 kg), six B (26.3±4.8 years; 195.3±2.8 cm; 97.8±5.1 kg) and three LP (28.3±4.0 years; 198.0±8.4 cm; 101.5±4.9 kg). The data came from daily monitoring of all the players in the team throughout the season both in training and in competition. Consequently, the approval of an ethics committee was not required (Winter & Maughan, 2009).

Competitive match monitoring

The study was carried out using the WIMU PRO™ system (RealTrack Systems S.L., Almería, Spain). Each device, whose dimensions were 81x45x16 mm (height/width/depth) and weighed 70 g, was fitted to the back of each player with adjustable bibs (Rasán®, Valencia, Spain). All the players were used to this type of device and the way it is fastened, as they had trained with this system all season (Bastida-Castillo et al., 2019; Bastida-Castillo et al., 2018).

Playing time was only recorded when the players were on court. The time spent between player rotation, timeouts (a maximum of three per match), periods when the game was interrupted and the disciplinary sanctions typical of handball where the players must leave the court for two minutes were omitted.

As 14 games were monitored, all the players included in the study participated in the game for an average of approximately 60 minutes per game. The team's game model used mainly a 6/0 defence (six players aligned near the 6-metre zone) and was conducive to a remarkably high game pace with many counterattacks.

Data processing

The positioning data record was monitored in real time and subsequently analysed using the SPRO™ software version 937 (SPRO™, RealTrack Systems, 2018). The system operates by means of triangulations between four antennas with patented ultra-wideband technology (18 Hz sampling frequency) placed 5 m away from each one of the corners of the court and at a height of 6 metres. These units include several sensors that record at different sampling frequencies. The sampling frequency used for 3-axis, accelerometer, gyroscope, and magnetometer was 100 Hz and 120 kPa for the barometer (Bastida-Castillo et al., 2018; Bastida-Castillo et al., 2019).

A previous validation study has found a total bias in the mean velocity measurement between 1.18 and 1.32 km/h while the bias in distance was between 2.32 and 4.32 m (Bastida-Castillo et al., 2018) In addition, good inter-unit and intra-unit reliability was reported (intraclass correlation coefficients > 0.93) (Bastida-Castillo et al., 2018).

The effective playing time (PT, in min), distance covered (TD, in m), maximum speed achieved ($m \cdot s^{-1}$), average speed ($m \cdot s^{-1}$) and high-speed running (HSR, distance covered in metres above 5.0 m·s-1) (Michalsik et al., 2015; Ortega-Becerra et al., 2020) were extracted from the raw data reported by the system using SPRO™ software. We retrieved the distance covered at different speeds: walking (0.0-1.7 $m \cdot s^{-1}$), jogging (1.8-3.3 $m \cdot s^{-1}$), slow running (3.4-5.0 $m \cdot s^{-1}$), running (5.1-5.8 $m \cdot s^{-1}$), high-intensity running (5.9-6.7 $m \cdot s^{-1}$) and sprint (>6.7 $m \cdot s^{-1}$). The total number of accelerations, decelerations, high-intensity accelerations (HIA), high-intensity decelerations (HID) (in $m \cdot s^{-2}$) and

HIA/HID per min ($m \cdot s^{-2} \cdot min^{-1}$) were recorded. HIA and HID were defined as events above 2 g (Barbero et al., 2014; Vázquez-Guerrero et al., 2019). We calculated the TPL (Total PlayerLoad). The TPL is a vector magnitude expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each one of the three planes divided by 100 in absolute (Vázquez-Guerrero et al., 2019) or relative time - $TPL \cdot min^{-1}$ - (Luteberget & Spencer, 2017; Wik et al., 2017).

Statistical analysis

Descriptive statistics are presented as means and standard deviations (SD). Differences between playing positions were analysed using Cohen's effect size (ES) statistics and ±90% CI. The criterion for determining the size of the ES was: <0.2 | 0.2 to 0.59 | 0.6 to 1.19 | 1.2 to 1.99 | ≥2.0, considering these values as trivial, small, moderate, large and very large, respectively (Hopkins et al., 2009). The percentage likelihood of difference between groups was calculated and regarded as almost certainly not (<0.5%), very unlikely (<0.5%), unlikely (<25%), possibly (25-75%), likely (>75%), very likely (>95%) or most likely (>99.5%). A percentage likelihood of difference <75% was regarded as a substantial magnitude. Threshold chances of 5% for substantial magnitudes were used, meaning that a likelihood of >5% in both a positive and negative direction was considered unclear. We also calculated significant differences. The Kolmogorov-Smirnov test confirmed a non-normal distribution of all the variables analysed. The Kruskal-Wallis test was performed to compare the four playing positions, followed by the Wilcoxon signed-rank test with Holm adjustment to determine the differences between positions in pairs. In the statistical tests that required it, the significance level was $p<0.05$. The statistical analysis was performed using the R Studio Software (v1.1.463 Studio, Boston, Massachusetts). The measurement error of all the metrics we used are not available, thus we could not include them in our statistical analysis.

Results

The playing time did not present any significant difference between playing positions (p=0.06), although CB (65.6±12.6 min) played moderately more than LP (56.3±12 min, ES=0.75) and slightly more than B (59±12.5 min, ES=0.5) and W (60.8± 6.9 min, ES=0.27). The total distances travelled were significantly different between playing positions (p<0.0001). CB (4040±1007 m) and W (3903±1224 m) covered moderately more distance (ES=1.06, p<0.001 and ES=0.77, p<0.0001, respectively) than B

(3571±864 m) and LP (3149±630 m) during a game. The distance travelled per minute was significantly different between playing positions ($p<0.0001$). W (64.5±10.4 $m\cdot min^{-1}$), CB (62.3±11.6 $m\cdot min^{-1}$) and B (61.8±7.8 $m\cdot min^{-1}$) travelled moderately faster on average than LP (56.5±6.6 $m\cdot min^{-1}$, ES=0.91, 0.62 and 0.74 respectively).

TPL was significantly different between playing positions ($p<0.05$). CB (71.2±12.6 AU) bore moderately more TPL than LP (59.5±12 AU, ES=0.7), slightly more than B (62.3±17.7 AU, ES=0.5), although W had a similar load (68.1±23.1 AU, ES=0.15). The total number of accelerations and decelerations performed during a game were equivalent for W, CB and B (acceleration: 1167.5±337, 1166.9±203.9, 1125.9±271.6, respectively, ES=0.01 to 0.15; deceleration: 1164.4±336.2, 1161.4±203.9, 1120.7±271.1, respectively, ES=0.01 to 0.18). LP differ only slightly from CB in this aspect (acceleration: 1102.5±264.1, ES=0.22: deceleration: 1106.15±263.4, ES=0.21). The analysis of the total number of accelerations and decelerations did not present any significant (p=0.82 and (p=0.79, respectively) or substantial differences. Table 4 presents the external load variable and Figure 8 the distance travelled at different speeds.

Discussion

To our knowledge, this is the first time that an elite men's handball team had been monitored by IMUs during 14 official matches from a top-level national regular league. The main findings are that CB and W differ substantially from B and LP. The external load differences between CB and B are as high as can be justified a dedicated analysis.

Total distance, playing time and TPL

CB played more and travelled the greatest distance, followed by W, and LP had the least external physical load. Despite some controversies in the calculation and meanings of TPL, this metric is one of the most used variables to control external load during competition and training in team sports (Luteberget, Holme, et al., 2018; Kniubaite et al., 2019; Vázquez-Guerrero et al., 2019). CB bore the highest TPL, followed by W, B and LP. To our knowledge, no study has been conducted with this metric. One might think that time spent in the field (i.e., more opportunities to produce external load) should affect the TPL expressed by unit of time (minutes). Surprisingly, this metric was practically identical for all playing positions (≈ 1.1±0.2 $AU\cdot min^{-1}$).

Table 4. Effect size and statistically differences between playing positions (IMU).

Variables	Wings (W)	ES	Rating	Center Backs (CB)	ES	Rating	Backs (B)	ES	Rating	Line players (LP)
TPL·min (AU·min -1)	1.1 ± 0.2	CB: 0.11 B: 0.31 LP: 0.24	trivial small small	1.1 ± 0.2	B: 0.20 LP: 0.13	trivial trivial	1.1 ± 0.2	LP: 0.08	trivial	1.1 ± 0.2
MaxV (m·s-1)	6.4 ± 0.6 [b]	CB: 0.12 B: 0.62 ** LP: 0.25	trivial moderate small	6.3 ± 0.6	B: 0.52 * LP: 0.14	small trivial	5.9 ± 0.8	LP: 0.36 *	small	6.2 ± 0.8
HSR (m)	410.3 ± 193.2 [ab]	CB: 1.10 *** B: 1.65 *** LP: 1.66 ***	moderate large large	243.2 ± 130.2 [c]	B: 0.66 * LP: 0.65 *	moderate moderate	161.7 ± 110.1	LP: 0.05	trivial	172.4 ± 96.0
HSR · min-1 (m)	6.6 ± 2.3	CB: 1.64 *** B: -2.05 *** LP: -1.80 ***	large very large large	3.7 ± 1.7	B: -0.50 * LP: -0.28	small small	2.6 ± 1.6	LP: 0.20	trivial	3,2 ± 1.8
HSR (n)	39.6 ± 18.2	CB: 0.30 B: 0.04 *** LP: 1.02 ***	small moderate moderate	34.9 ± 18.1	B: 0.64 * LP: 0.69 *	moderate moderate	23.4 ± 15.8	LP: 0.04 *	trivial	24.3 ± 11.2
HIA (m·s-2) (n)	134.8 ± 60.7	CB: 0.23 B: 0.24 LP: 0.46 *	small small small	148.7 ± 59.2	B: 0.49 * LP: 0.76 *	small moderate	121.2 ± 53.9	LP: 0.21 *	small	112.0 ± 33.6
HID (m·s-2) (n)	112.9 ± 56	CB: 0.51 * B: 0.15 LP: 0.30	small trivial small	142.7 ± 59.5	B: 0.69 * LP: 0.91 **	moderate moderate	105.2 ± 49.2	LP: 0.14	trivial	99.6 ± 28.9
HIA·min (m·s-2·min-1)	2.2 ± 0.8	CB: 0.06 B: 0.24 LP: 0.46	trivial trivial small	2.3 ± 0.8	B: 0.26 LP: 0.32	small small	2.1 ± 0.8	LP: -0.03	trivial	2.0 ± 0.6
HID·min (m·s-2·min-1)	1.8 ± 0.8	CB: 0.41 * B: 0.08 LP: 0.05*	small trivial trivial	2.2 ± 0.8	B: 0.50 * LP: 0.52 *	small small	1.8 ± 0.7	LP: 0.05 *	trivial	1.8 ± 0.5

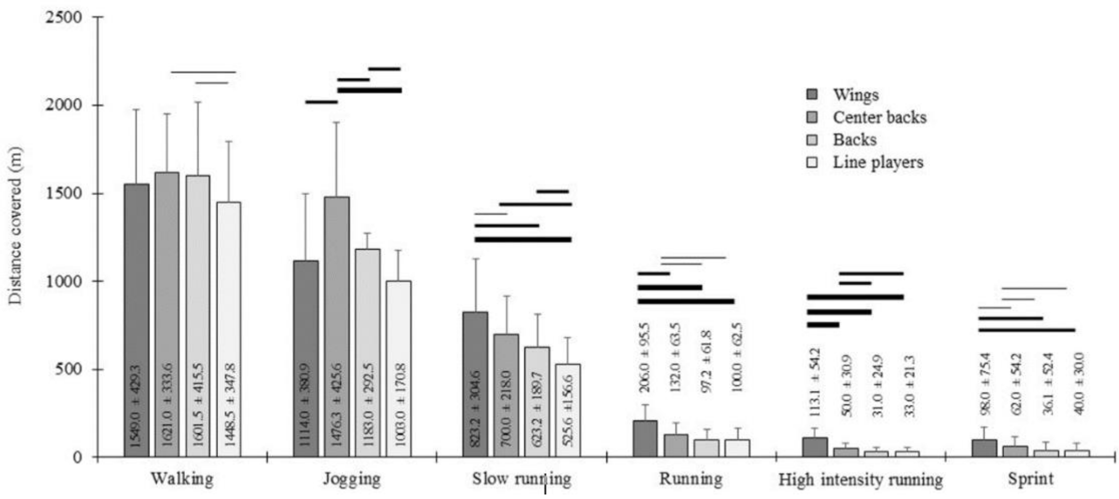

Figure 8. Distance covered at different speeds according to each playing position.

Note: Speed criteria: Walking (0-1.7 $m \cdot s^{-1}$), Jogging (1.8-3.3 $m \cdot s^{-1}$), Slow running (3.4-5.0 $m \cdot s^{-1}$), Running (5.1-5.8 $m \cdot s^{-1}$), High-intensity running (5.9-6.7 $m \cdot s^{-1}$), Sprint (>6.7 $m \cdot s^{-1}$). Statistical differences: large ($p<0.0001$): ▬ , moderate ($p<0.01$): ▬ , small ($p<0.05$): — .Only effect sizes with a substantial probability of difference (> 75%) are shown.

This is a reminder of the complexity of the TPL formula, mainly based on acceleration, and therefore not simply dependent on effective playing time or distance covered (Luteberget & Spencer, 2017; Luteberget, Holme, et al., 2018; Luteberget, Trollerud, et al., 2018). Furthermore, it is difficult to compare the results of this paper with those from other handball studies, on account of different age (Mancha-Triguero et al., 2018), population type: level (Luteberget, Trollerud, et al., 2018) and gender (Luteberget, Holme, et al., 2018; Kniubaite et al., 2019) and game type: non-competitive games (Barbero et al., 2014) and competitive games (Luteberget & Spencer, 2017; Wik et al., 2017; Kniubaite et al., 2019). These results question the usefulness of this variable in assessing external load in handball. Most of the works in the literature have merged CB and B (Luig et al., 2008; Michalsik et al., 2015). To our knowledge, only (Cardinale et al., 2017) and (Barbero et al., 2014) have studied CB separately, albeit with a different tracking technology or in non-ecological conditions. Our results confirm that the external loads borne by the CB are the highest and therefore call for a specific approach. The results obtained by the other players are consistent with previous studies conducted by video-recording (Karcher & Buchheit, 2014; Michalsik et al., 2015).

Running pace, distance and running speed

Many authors have measured the distance travelled per minute in their work, although the different methodologies used to measure playing time (taking or not taking player rotations into account, team time out and actual playing time) have rendered this number virtually impossible to compare (Barbero et al., 2014; Karcher & Buchheit, 2014). Distance covered at different speeds is noteworthy since it is directly related to the game model. The technical staff can therefore use this indicator to design training content, particularly at metabolic level. All players, regardless of position, covered between 70% and 78% of the total distance at a running pace of less than 3.3 $m \cdot s^{-1}$ (walking and/or jogging) and between 17% to 21% at between 3.3 and 5 $m \cdot s^{-1}$. W covered a significantly greater distance above 5 $m \cdot s^{-1}$ compared to the other players. These results are consistent with those of previous studies (Michalsik et al., 2013; Povoas et al., 2014), although it should be borne in mind that hand notational technologies were used.

Sprint and high-speed running

Playing elite handball calls for a substantial volume of high-speed running (Barbero et al., 2014). As stated before, IMU could have validity and reliability concerns when measuring high-speed running (Bogild et al., 2020), therefore our results and conclusions could not be definitive. However, these variables are extremely important for training and the prevention of injury. Previous studies (Barbero et al., 2014) conducted with GPS during 30-minute outdoor training games reported higher sprinting speeds for W (6.9±0.3 $m \cdot s^{-1}$ vs. 6.4±0.6 $m \cdot s^{-1}$), similar results for CB (6.1±0.3 vs. 6.3±0.6 $m \cdot s^{-1}$) and B (6.1±0.3 vs. 5.9±0.8 $m \cdot s^{-1}$). LP reached a higher sprinting speed in our study (6.2±0.8 vs. 5.5±0.4 $m \cdot s^{-1}$), which is even higher than B. Many factors could explain these differences, such as the team's game model, the individual characteristics of each player, fatigue (our data were collected during whole games) and a higher number of games (i.e., 14). On comparing the value of maximal sprinting speed expressed during games to sprint testing (e.g., 30-m straight-line sprinting) some substantial differences emerge. In our study, the mean maximal sprinting performed by W was about 17% (1.8 vs. 2.1 $m \cdot s^{-1}$) lower than that which was obtained by players from the same level in a 30-m sprint (Bogild et al., 2020). This difference highlights the fact that it is highly likely that handball players do not frequently reach their maximal velocity during games. Coaches should consider this aspect. On the other hand, W presented the greatest high-speed load, as they covered the higher HSR distance each minute and performed the highest number of HSR. CB completed the highest number of HSR but with a low HSR value covered each minute (3.7±1.7 $HSR \cdot min^{-1}$). This paradox could be related to the technical and tactical demands of this playing position. CB are a in a central position in which they perform many short high intensity runs towards goal.

It is also useful to know how many metres players travel in HSR during a match. These values are especially important for coaches to manage HSR volume during a training session or a microcycle. Previous research conducted by means of video analysis yielded similar results to our study, in which W covered the greatest distance at speeds above 5 $m \cdot s^{-1}$ (Michalsik et al., 2015; Cardinale et al., 2017). It is worth noting that the distance covered above 5.8 $m \cdot s^{-1}$ fluctuates greatly. The CV ranged from 46% for the high-intensity runs to 145% (for running, high-intensity running and sprinting). These variations reflect the unpredictable character of game demands in team sports (Vázquez-Guerrero et al., 2019) and/or the limits of the device in high-speed running measurement. Before drawing any definitive conclusion regarding high speed running and sprinting, we need to be more confident about the validity and the reliability of the device.

Acceleration and deceleration

Players' ability to accelerate and decelerate is particularly important in meeting tactical and technical demands in handball. This is evident in the numerous changes of direction that take place during a match (Karcher & Buchheit, 2014). Our results indicate that all players perform a similar number of accelerations and decelerations. CB performed the highest number of HIA (148.7±59.2 $n \cdot s^{-2}$) and HID (142.7±59.5 $n \cdot s^{-2}$). This should also be related to the technical and tactical demands of the playing position and the HSR per minute. When these values were standardised by playing time ($m \cdot s^{-1} \cdot min^{-1}$), the results were similar (Table 4). These results coincide with those obtained in previous studies conducted by means of video recording (Manchado et al., 2013), albeit not with others (Karcher & Buchheit, 2014). However, the comparison of both studies is once again difficult, either because they involved women or because they were based on GPS monitoring during outdoor training games, respectively. Decelerations lead to a significant eccentric demand on players, which could induce many negative effects (e.g., muscle damage) and injuries (Harper et al., 2019). The technical staff should monitor this aspect. Even if the threshold is lower in our study (2 vs. 2.5 g), handball induces one of the highest decelerations loads for players in team sports (Harper et al., 2019).

Methodological considerations

In most studies, CB were included with the lateral backs (i.e., right and left) in the Backs category (Michalsik et al., 2013). This aspect is important, because this clustering potentially conceals some especially important information for the technical staff. Probably, physical demands on the court decreases for CB and increases for LB, so that it is difficult for the coach to adjust it. To our knowledge, only two studies have made a distinction between these players (Barbero et al., 2014; Cardinale et al., 2017). Another important consideration is that neither video-based nor IMU analysis could measure the external load in handball extensively. The actions performed on the training field did not always produce a movement or an acceleration. For example, to block their opponent, LP use a high level of isometric strength and need to maneuverer vigorously with their arms to gain an advantageous position. IMUs could register some movement (e.g., acceleration) in these situations but their intensities are far from the level of isometric force required in this type of action. These activities produce a high cardiac output (Povoas et al., 2014) but are not clearly observable with IMUs or video tracking. While this study provides an analysis of the external load of male elite handball teams, it is limited to certain global metrics and does not provide a further insight into handball-specific movements such as sideways and backward displacements and jumps, hence greater work is required to necessary to get elucidate these aspects further.

Limitations

A team can use different defensive systems (different spatial and functional organisation, e.g., 6/0, 5/1) depending on the coach's choice. These options rely on many factors (e.g., the opponents, coach philosophy and team characteristics). Each team chooses its own defensive system but also must contend with the opponent's. These tactical options are likely to have many consequences in terms of physical demands, although we are not aware of any study that confirms this hypothesis. The data presented in this investigation are based only on home games (with a predominantly 6/0 defensive system and an offensive game based on counterattack and speed) which can also affect game demands (Diana et al., 2017). Since we monitored the same team over 14 games, it should be noted that many variables could have influenced outcomes, such as the level of the opponents (Gómez Carmona et al., 2019) and game plan (Abdelkrim et al., 2010). Another issue is that player rotation is unlimited in handball, and most teams use offensive and defensive specialists with systematic changes. These constant rotations pose numerous difficulties in analysing game demands.

Practical applications

Our results could provide external load reference values for other handball male elite teams. CB and W present a similar level of external load. This is important in designing appropriate training content, particularly for high-speed running. These findings have certain direct implications for injury prevention. Technical staff should apply the same amount of speed training for CB and W. LP and B bear the smallest external load in our study, but it should be remembered that IMUs could not accurately measure LP performance. As a result, the needs of these two playing positions should be different. It is important to adapt training load and training content to each playing position and coaches should establish at least three different groups: 1) CB and W, 2) B, 3) LP.

Conclusions

The analysis of all the variables monitored with an IMU system suggests that both CB and W positions have the highest external load, while by contrast B and especially LP have the lowest load. W and CB perform a substantially greater number of sprints and high-speed running than the other players. Some methodological and technological issues limit the analysis of handball-specific movements (e.g., jumps and sideways and backward movements) and research that overcomes these difficulties is called for. Coaches and practitioners will also need to understand how contextual factors (e.g., level of the opponent, game location, score and game plan) affect physical game demands. This knowledge could lead to better training load manage and the design of specific training content.

4.2. Estudio 2: *The effects of Covid-19 lockdown on jumping performance and aerobic capacity in elite handball players*

* Font R., Irurtia A., Gutierrez J.A., Salas S., Vila E., Carmona G. (2021). The effects of COVID-19 lockdown on jumping performance and aerobic capacity in elite handball players. Biol Sport, 38(4):753–759.

Abstract

Aims: The aim of this research was to analyse the capacity of a home-based training programme to preserve aerobic capacity and lower limb explosive strength in top-level handball players during the COVID-19 lockdown. **Methods**: Eleven top-level male handball players from the same team participated in the study. A submaximal shuttle run test and a counter-movement jump test were used to measure the players' aerobic fitness and lower limb explosive strength, respectively. A 9-week home-based training was performed during lockdown. Pre-test measurements were assessed before the pandemic on 29 January 2020 and ended on 18 May 2020. **Results:** Moderate significant mean heart rate increases were found in the late stages of the submaximal shuttle run test after the lockdown (stage 5, 8.6%, $p = 0.015$; ES = 0.873; stage 6, 7.7%, $p = 0.020$; ES = 0.886; stage 7, 6.4%, $p = 0.019$; ES= 0.827). Moderate significant blood lactate increases were observed immediately after the submaximal shuttle run test following the lockdown (30.1%, $p = 0.016$; ES = 0.670). In contrast, no changes were found in jump performance. **Conclusions:** A structured home-based training programme during the COVID-19 lockdown preserved lower limb explosive strength but was an insufficient stimulus to maintain aerobic capacity in top-level handball players.

Keywords: Elite team sports, detraining, heart rate, lactate, pandemic, jumping

Introduction

The first cases of Coronavirus (COVID-19 or SARS-CoV-2) were detected in Wuhan, China, at the end of 2019 (Singhal, 2020). Subsequently, due to the effects of the virus and its easy spread, different countries opted to quarantine and isolate their citizens, confining them to their homes. In Spain, a state of alarm was declared on 15 March, which affected the entire population (Mon-lópez, García-aliaga, et al., 2020). At the sporting level, all territorial, national and international competitions were suspended. In handball, the last matches were played on 7 and 8 March 2020 and all players had to stay at home at least until 4 May 2020 (Mon-lópez, De La Rubia, et al., 2020). The different competitions did not resume again until August 2020 and only for elite teams (national and European competitions). The importance in handball of certain levels of strength, speed and aerobic endurance to withstand training and competition is well known (Gorostiaga et al., 1999; Buchheit et al., 2009; Nikolaidis & Ingebrigtsen, 2013; Karcher & Buchheit, 2014). It is also true that high intensity work is increasingly important due to the increase in the number of possessions in the game and the pace of play (Karcher & Buchheit, 2014). During this entire period of home confinement, the players had to work in their respective homes to avoid partially or totally losing previously acquired morphological and physiological adaptations through detraining/a decrease in training (Eirale et al., 2020; Impellizzeri et al., 2020; Mujika & Padilla, 2000a, 2000b; Peña et al., 2021). The difficulties of finding optimal spaces to train or having adequate training material and the uncertainty as to when competitions would resume generated frustration and demotivation in many athletes during this period (Guilherme et al., 2020). Individualized work routines were planned to reduce this training handicap as much as possible, and to counter lack of motivation, poor nutrition and resting issues that may affect the athletes' ability to maintain proper habits and routines (Andreato et al., 2020; Fikenzer et al., 2021; Jukic et al., 2020; Peña et al., 2021). In many cases material was provided to the players and group sessions were held by videoconference (Sarto et al., 2020; Peña et al., 2021). Most of the current research on detraining is characterized by much shorter periods of time than that of this pandemic (Mujika & Padilla, 2000a, 2000b). However, there is a lack of information regarding the capacity of home training programmes to preserve general fitness levels (lower limb explosive strength and aerobic capacity) in top handball players during the COVID-19 lockdown.

To the best of our knowledge, only one previous study (Fikenzer et al., 2021) has investigated the effects of a given training programme in the aerobic capacity of elite handball players. This kind of studies might provide valuable insights about the real impact of home training programmes to prevent detrimental effects on the general fitness of elite handball players. Accordingly, the aim of this research was to analyse the effectiveness of a home training programme to preserve aerobic capacity and lower limb explosive strength in top-level handball players during the COVID-19 lockdown.

Methods

Design

A retrospective design was used to compare the change in submaximal shuttle run test and jump test performance. A 9-week home-based training was performed during lockdown. Pre-test measurements were assessed before the pandemic on 29 January 2020 and ended on 18 May 2020. The tests were conducted on the same day, first performing the submaximal shuttle run test in two groups of five and six players, respectively, and then the counter-movement jump (CMJ) test. The submaximal shuttle run and the CMJ tests were used to measure the players' aerobic fitness and lower limb explosive strength (both bilateral and unilateral), respectively.

Subjects

The study was conducted on 11 top-level male professional handball players from the same team throughout the same season. These were all international players with their respective national teams during the season in which they participated in this study. The players were three wings (26.3 ± 3.7 years; 185.3 ± 4.7 cm; 83.2 ± 6.5 kg), four backs (29.5 ± 7.0 years; 193.3 ± 5.1 cm; 98.3 ± 7.4 kg), three line players (27.9 ± 6.4 years; 195.0 ± 3.0 cm; 105.3 ± 9.2 kg) and one goalkeeper (27.9 ± 0 years; 190.0 ± 0 cm; 84.0 ± 0 kg). The data was obtained from the periodic monitoring of the players during training sessions. All players signed a contractual clause accepting their participation in research projects, therefore approval by an ethics committee was not required (Winter & Maughan, 2009). However, all players were informed about the purpose of the study, the known risks and possible associated hazards. The research was in accordance with the Declaration of Helsinki, and professional players gave informed consent prior to participation through their contracts.

Submaximal shuttle run test

To assess the aerobic capacity of the players, the multistage 20 metre shuttle run test (Léger et al., 1988) was performed up to stage number 8. The test consisted of running continuously between two lines placed 20 m apart at running speeds increased by appropriate intervals at a pre-recorded beep. Mean velocity started at 8.5 $km \cdot h^{-1}$ for the first minute (stage 1), increasing by 0.5 $km \cdot h^{-1}$ every minute up to 12 $km \cdot h^{-1}$ (stage 8). During the test, heart rate (HR) was registered using a Garmin® HR strap. The HR monitor was linked to the WIMU PRO™ system (Realtrack Systems, S.L., Almeria, Spain) and data was analysed thereafter using mean HR values for each submaximal shuttle run test stage. One minute after the end of the test, players were pricked in the earlobe to analyse blood lactate levels (Rodríguez-Alonso et al., 2003; Matthew & Delextrat, 2009; Gupta & Goswami, 2017). The analysis was performed with a Lactate Scout + lactate analyser and Lactate Scout test strips (Nova Biomedical, Waltham, MA, USA).

Jump

The CMJ test was used to assess vertical jump performance as an indicator of lower limb explosive strength (Carmona et al., 2015). Players performed a fast flexion movement of the knee joint followed by a maximum-effort vertical jump, maintaining the hands-on-hips position until the final phase of the jump. A contact platform (Chronojump Boscosystem, Barcelona, Spain) was used to assess CMJ height. The hardware was connected to a computer which displayed the vertical jump height (cm) using free software (2.0.2., Chronojump Boscosystem Software, Barcelona, Spain). This type of technology has proven its reliability and validity in other types of research with vertical jump tests (Pueo et al., 2020). Players performed two bilateral CMJs and two unilateral CMJs with each leg. The best result of each test (height, cm) was recorded and used for further analysis.

Home training programme during COVID-19 lockdown

Each week during confinement, players received a structured training programme to follow at home. Basically, the home-based training programme consisted in five training days, from Monday to Friday, with a break over the weekend. During the first eight weeks, three strength training sessions were performed per week (on Mondays, Wednesdays, and Fridays) and two endurance-oriented sessions (on Tuesdays and Thursdays). During the last week (week 9), two strength training sessions and five endurance sessions (three outdoor running sessions and two stationary bike sessions at home) were performed. There was around a 40% reduction in workload volume between what the players actually did at home during the COVID-19 lockdown compared to what they would have performed under normal training and competition. During confinement, players performed an average of 27 strength training sessions, including both individual sessions and online group sessions. All sessions conducted at home followed the medical recommendations derived from the COVID-19 pandemic (Bisciotti et al., 2020; Eirale et al., 2020). All sessions were preceded by a general warm up consisting in ~10 min of low intensity cycling (stationary bike), mobility and lumbo-pelvic stability exercises. In the first four weeks, strength training was endurance-oriented and over the last four weeks strength training was hypertrophy- oriented (Gómez et al., 2019). Individual hypertrophy-oriented training programmes were organized in super-sets in which a combination of low specificity level exercises (i.e., bilateral squat-based exercises) preceded slightly more specific exercises (more dynamic correspondence with handball-specific movements, i.e., vertical jump exercises) (Gómez et al., 2019). Regarding endurance training, players performed an average of 19 sessions. The first four weeks, players performed individual strength-based HIIT circuits, and from the fifth week onwards they were prescribed general aerobic fitness training sessions based on continuous and progressive exercises. Both subjective RPE (Foster et al., 2001, 2021) and the OMNI Perceived Exertion Scale (OMNI-Res Scale) for Resistance Exercise (Robertson et al., 2003) were used to prescribe intensity during training sessions. See figure 9 for a complete overview of the basic characteristics of the home-based training programme.

Statistics

Data were tested for approximation to a normal distribution using the Shapiro–Wilk test. A paired Student's t-test was used to evaluate differences in variables of interest (body mass, mean heart rate, capillary blood lactate concentration, CMJ height) from Pre and Post periods. Cohen's d was used to calculate the effect size (ES). Thresholds for ES statistics were trivial (ES<0.20); small (0.20<ES<0.59); moderate (0.60<ES<1.19); large (1.20<ES<1.99); and very large (ES>2.0) (Hopkins et al., 2009). All data were reported as mean ± standard deviation and the level of significance was set at $p < 0.05$. All statistical analyses were conducted using SPSS version 23.0 (SPSS Statistics, IBM Corp., Armonk, NY, USA).

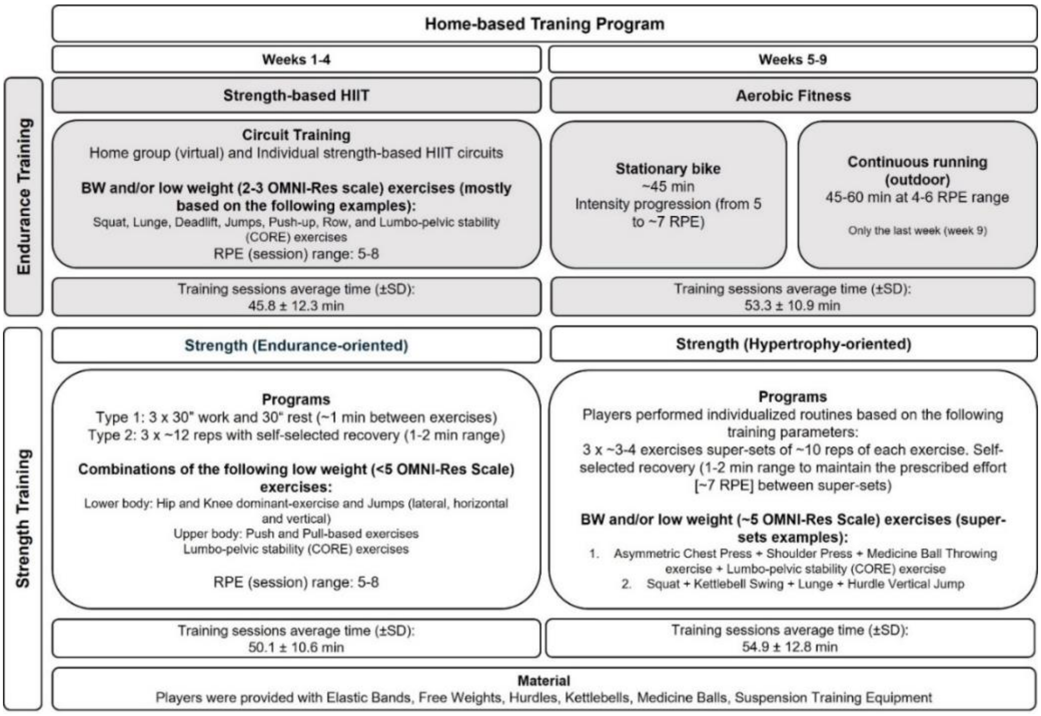

Figure 9. Home training programme overview. BW, body weight; HIIT, high-intensity interval training; OMNI-Res Scale, Perceived Exertion Scale for Resistance Exercise; RPE, rating of perceived exertion.

Results

No significant differences (ES = -0.036, trivial) were found in body mass following the home training programme (pre-lockdown: 99.0 ± 12.4 kg and post-lockdown: 98.6± 12.7 kg).

Submaximal shuttle run test

Moderate, non-significant mean HR increases were observed in the early stages of the submaximal shuttle run test (aerobic capacity) (from stage 1, 108 ± 15 and 117 ± 11 bpm; stage 2, 127 ± 11 and 141 ± 21 bpm; stage 3, 133 ± 12 and 147 ± 20 bpm; stage 4, 140 ± 12 and 153 ± 19 bpm of HR mean values from before and after the home training programme, respectively) and moderate, significant changes were observed in later stages (from stage 5, 145 ± 13 and 158 ± 15 bpm [p = 0.015]; stage 6, 152 ± 12 and 164 ± 14 bpm [p= 0.020]; stage 7, 157 ± 11 and 167 ± 13 bpm [p = 0.019] of HR mean values from before and after the home training programme, respectively) (see Figure 10). Finally, only small, non-significant, increases were found in the last stage (stage 8, 163 ± 10 and 168 ± 13 bpm of HR mean values from before and after the home training programme, respectively). It must be stated that results from this test were derived from 9 players due to HR band registration problems with 2 of the players from the sample.

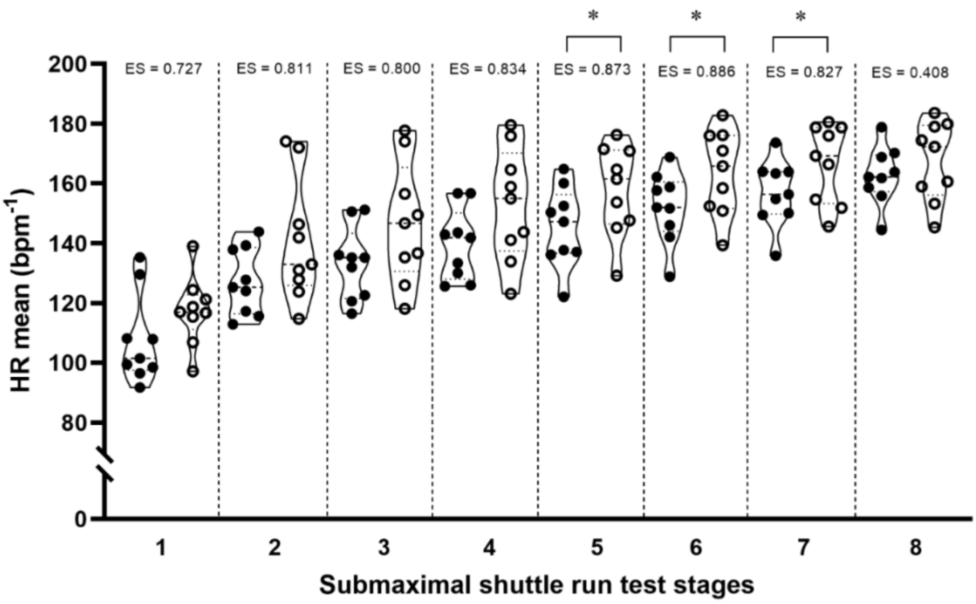

Figure 10. Mean heart rate values from each multistage 20 metre shuttle run test. Black circles, pre-lockdown; White circles, post-lockdown. ES, Cohen's d effect size. *Significantly different at $p < 0.05$.

Regarding lactate, moderate, significant increases (4.1±1.4 and 5.3±2.2 [$p=0.016$] mmol/L mean values from before and after the home training programme, respectively) were found (see Figure 11).

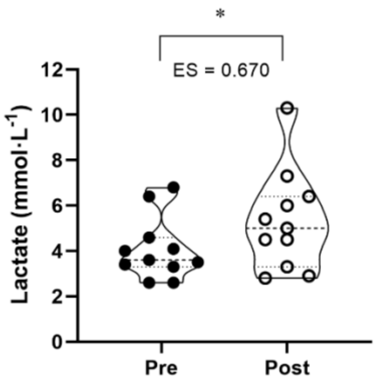

Figure 11. Capillary blood lactate concentration. Black circles, pre-lockdown (Pre); White circles, post-lockdown (Post). ES, Cohen's d effect size. *Significantly different at $p < 0.05$.

Jump test

No changes were found in jump performance (41.8 ± 8.3 and 41.0 ± 7.0 cm of bilateral CMJ, 20.9 ± 7.3 and 22.3 ± 4.7 cm of unilateral CMJ [right], and 21.7 ± 4.4 and 22.4 ±

3.2 cm of unilateral CMJ [left] height from before and after the home training programme, respectively) (see Figure 12).

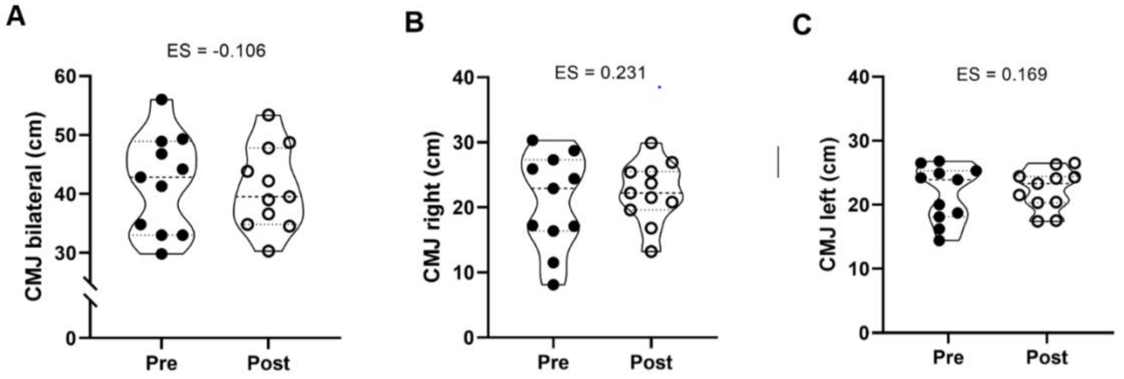

Figure 12. Counter movement jump (CMJ) height. Black circles, pre-lockdown (Pre); White circles, post-lockdown (Post). ES, Cohen's d effect size.

Discussion

The aim of this research was to analyse the ability of a home training programme to preserve aerobic capacity and lower limb explosive strength in top-level handball players during the COVID-19 lockdown. The home training programmes followed by the players maintained lower limb explosive strength, measured as CMJ performance (jump height), but appeared to be insufficient to maintain aerobic capacity.

Aerobic Capacity

Moderate, significant HR increases were observed in the last stages of the submaximal shuttle run test after the COVID-19 lockdown (see Figure 10). This might be indicative of a loss of aerobic capacity (Schneider et al., 2018; Dauty et al., 202). It has been well established that detraining, due to training suppression or inadequate training, induces maximum HR increases (between 5% and 10%) (Mujika & Padilla, 2000a). Although this was not exactly the case during the lockdown scenario, the home training programmes probably failed in providing a sufficient stimulus to maintain aerobic capacity in elite handball players. This was also previously described by (Fikenzer et al., 2021) who found that endurance capacity, measured by the maximum mean velocity achieved in a multistage 20 metre shuttle run test, was diminished in most elite handball players from a given team due to the unspecific and inadequate stimuli provided by a home-based training program during the COVID-19 lockdown. Dauty et al. (2021), found similar results with the yo-yo test in young football players. The dependence on volume of endurance training responses (Fitts et al., 1975) would explain the incapacity of home training programmes to maintain aerobic capacity in highly-trained top handball players. In fact, the home training volumes were approximately 40% lower than those achieved during the regular season right before the lockdown. Moreover, our players only received running-specific stimuli during the last two weeks of the lockdown (see Figure 9), reinforcing the notion that the lack of training specificity also contributed, to some extent, to the loss of aerobic capacity (Dauty et al., 2021; Fikenzer et al., 2021). The moderate, significant increases in lactate after COVID-19 lockdown were also indicative of a decrease in the players' aerobic capacity (see Figure 11) (Mujika & Padilla, 2000a; Nakisa & Ghasemzadeh, 2021). Specifically, lactate increases are indicative of a reduction in the oxidative capacity of the muscle (Mujika & Padilla, 2000a) and present a high correlation with endurance capacity in trained populations (Yoshida et al., 1987). Altogether with HR values, these results confirmed that home-based endurance training was insufficient to maintain aerobic fitness in top-level handball players. However, it must be considered that since only moderate (ES) changes in aerobic fitness indicators (HR and Lactate) were found after the lockdown, it seems reasonable to expect a rapid recovery of pre (before lockdown) values when players returned to on-court sport-contextualized training regimes.

Lower limb explosive strength

Regarding CMJ performance as an indicator of lower limb explosive strength (Carmona et al., 2015), no changes were found between the two test periods (see Figure 12), showing that the training stimuli provided by the strength home-based training programme (Figure 9) was adequate to preserve jump capacity. Despite certain signs of detraining in neuromuscular-related qualities and peak power output, similar results have been previously reported in the literature about home training programmes' capacity to preserve jump performance (height) in professional football players (Cohen et al., 2020; Rampinini et al., 2021) and futsal players (Spyrou et al., 2021). Specifically, Rampinini et al. (2021) analysed fifty professional football players and found that 2-3 bodyweight or small weight strength training sessions per week at home during COVID-19 lockdown preserved CMJ height despite a moderate (ES) loss in peak power output. Those authors (Rampinini et al., 2021) also found similar results following the transition period, where similar bodyweight training strategies were implemented. In this regard, it has also been observed in national level handball players that a 7 weeks interruption of the external weight-based strength training, were players only performed sport-specific training and bodyweight exercises, was enough to maintain jump performance (height) (Marques & Gonzalez-Badillo, 2006). Therefore, and although a certain degree of loss in jump-related neuromuscular qualities might be expected, home-based lower limb strength training programmes, despite the differences in training contents and strategies (including equipment), seem to be capable of maintaining jump performance measured as CMJ height.

Limitations

An important limitation of this study was the impossibility of assessing the whole team after the lockdown because many players were in their respective home countries. Despite this limitation, 11 top-level handball players were analysed, all whom were international players with their respective national teams. Finally, since the findings of this study come from 11 high-level handball players from a single team, caution is advised when generalising from these results, as different home training strategies in different team sport athletes might induce different adaptations.

Practical applications

A structured home-based training programme based on body weight and low weight exercises provides sufficient stimulus to maintain jump performance (jumping height), an indicator of lower limb explosive strength, in top-level handball players. In contrast, the home-based training programme described did not succeed in preserving aerobic fitness in the cohort under study. An earlier implementation of aerobic fitness training strategies might have helped in the preservation of players endurance capacity. However, since the loss in aerobic fitness indicators was moderate (ES), a rapid recovery of pre (before lockdown) values may be expected when players return to on-court sport-contextualized training regimes. Overall, the results of this study support existing general recommendations on the training approach during COVID-19 lockout periods (Yousfi et al., 2020).

Conclusions

In conclusion, a structured home-based training programme during COVID-19 lockdown preserved lower limb explosive strength but was an insufficient stimulus to maintain endurance capacity in top-level handball players.

4.3. Estudio 3: *Analysis of the variables influencing success in elite handball with polar coordinates*

* Font R., Daza G., Irurtia A., Tremps V., Cadens M., Mesas JA., Iglesias X. (2022). Analysis of the variables influencing success in elite handball with polar coordinates. *Sustainability,* 14(23):15542.

Abstract

In today's elite handball, coaching staff seek to know as much as possible about all the details of their sport to gain an advantage by adapting their model of play or by looking for the opponent's weak points. Therefore, the aim of this study was to analyse which variables can influence success in each phase of the match with polar coordinates. Observational methodology was used to analyse success or failure within the nature of handball by means of an ad hoc observation instrument designed and validated for this research. A total of 14 elite men's handball matches from the 2019–2020 season were analysed. The relationships between success and failure of all behaviours were performed with polar coordinates. The results show that one of the keys to achieving victory in matches is centred on a high level of success in the defensive phase that allows the team to recover the ball and to be able to go on the counterattack to obtain a clear option for a goal. This research allows us to see how we can achieve success in the different phases of the game and improve team performance with these indicators. These results suggest that it is necessary for teams to train at a high pace of play, linking the different phases of the game in order to recover the ball in the defensive phase and attack in the shortest possible time against an unstructured defence to achieve success in the match and the final victory.

Keywords: Team Sports; Observational Methodology; Competition; Performance indicators; Key Behaviour

Introduction

There is a lot of research that has shown that knowing what the players need to endure on a conditional level in handball is key to improving performance (Luteberget & Spencer, 2017; Luteberget, Trollerud, et al., 2018; Font et al., 2021) and, in turn, preventing injuries (Mónaco et al., 2019).

In handball, these needs have also been described either through the video tracking (Cardinale et al., 2017), hand notational analysis (Manchado et al., 2013; Michalsik et al., 2013) or more modern technologies such as inertial measurement unit technology (IMU's) (Font et al., 2021). However, in order to improve team performance, it is also essential to know which tactical actions are more effective or less effective depending on the model of play developed by the team in the different phases of the game. There is a large body of research that has analysed what happens during handball matches. Which offensive systems are used (Lozano & Camerino, 2012), the differences in counterattack between seniors and young players same time, the effectiveness of the attack against certain defensive systems have been observed (Rogulj et al., 2004; Jiménez-Salas et al., 2020a;). Research has also been carried out on the effectiveness of attack at critical moments in the game types of last action happen (Meletakos et al., 2011).

At the defensive level, the effectiveness of the goalkeeper has been investigated (Pascual et al., 2010) assessing the interaction with teammates or the attacker/defender ratio (Prudente et al., 2010), the relevance of defensive actions in the functioning of the team has been analysed (Sáez et al., 2009; Antúnez et al., 2013) or the effect of fouls within the defensive phase and analysed their effectiveness (Fasold & Redlich, 2018). Other research has focused on looking at offensive and defensive coefficients in different phases of the game (Sáez et al., 2009), determining performance indicators to predict a match win (Daza et al., 2017), analysing the game according to the state of the score (Sáez et al., 2009; Meletakos & Bayios, 2010; Montoya et al., 2013), assessing the influence of symmetry/asymmetry on the number of players on the game (García et al., 2004; Prudente et al., 2022), and finding indicators of success or failure in the different phases of the game (Daza et al., 2017). Success or failure has always been understood as being linked in the offensive phases to scoring goals and not interrupting the rhythm of the game, and in the defensive phases, the opposite: not conceding a goal, recovering the ball and cutting the rhythm of the attacking play (Lozano & Camerino, 2012).

All this research has been based on observational methodology, a technique widely used and validated in the world of sport for this type of analysis (Anguera & Hernández, 2013). This methodology is developed in the usual context of sport. It is an ecological technique (Lozano et al., 2016) that does not change the usual behaviour of players and unites science and practical application (Pastrana-Brincones et al., 2021). The aim is to analyse perceptible behaviours in order to be able to record, in an organised way, what happens through an instrument containing the appropriate parameters created ad hoc (Morillo-Baro et al., 2015). The different tools created by these investigations have analysed criteria in defence, attack, and counterattack; the sequence, the score, and the numerical situation of the players; and the area where the action takes place, or, the final result of the action, be it offensive or defensive (Lozano & Camerino, 2012; Morillo-Baro et al., 2015; Lozano et al., 2016; Daza et al., 2017; Jiménez-Salas et al., 2020b, 2020a).

Within the observational methodology, a technique widely used in the field of sport is the analysis of polar coordinates (Castellano & Hernández, 2003). This technique was created by Sackett (1980) and subsequently improved with the "genuine technique" of Anguera (1997). Its great usefulness is that it allows a significant reduction in the volume of data and a vector representation of the relationships established between the focal and conditional categories (Hernández-Mendo & Anguera, 1999). This technique offers us the possibility of estimating the type of relationships established between the focal behaviour or criterion and the rest of those that make up the taxonomic system (Castellano & Hernández, 2002). The coordinate axis is divided into four quadrants. Depending on the quadrant where the categories are located, there will be a relationship with respect to the focal behaviour of activation or inhibition to the extent that this relationship exists (Castellano & Hernández, 2002). This technique has been used in handball for the following applications: observing the effectiveness in the attacking phase (Lozano & Camerino, 2012) and in close matches (Lozano et al., 2016), learning how different defensive systems are attacked (Jiménez-Salas et al., 2020a), identifying differences in counterattack between seniors and young players (Jiménez-Salas et al., 2020b), and observing the numerical ratio of players in attack and its tactical modification (Prudente et al., 2019).

The aim of this study is to identify which variables influence success or failure in the different phases of the game in an elite handball team with polar coordinates. For this reason, the multiple variables that intervene in the game and in each phase have been evaluated, considering the game model of the team analysed and how the other teams play. Knowing how we can achieve success in the different phases of the game and which variables determine performance should help the different technical staff to increase the work on these variables in training to obtain certain advantages over the rival team in order to win the game and improve performance.

Materials and Methods

Design

An observational methodology was used because it is adapted to the reality of sport, capturing the nature of sport with an ad hoc instrument and being able to obtain a systematic analysis (Anguera & Hernández, 2013; Lozano et al., 2016). It is a methodology widely used in sport analysis (Castellano & Hernández, 2003; García et al., 2004; Pastrana-Brincones et al., 2021). The design used was defined as nomothetic, punctual, and multidimensional, and placed in the IV quadrant of observational designs (Anguera et al., 2020). It is nomothetic, due to the analysis of the plurality of the observed teams facing each other; punctual, as we analyse different matches of the same team together in a season; and multidimensional, as there are different dimensions that correspond to the different criteria of the observational instrument. All the phases that make up a handball match were analysed: attack, counterattack, transition defence, and defence.

Sample

We analysed 14 FC Barcelona handball matches during the 2019–2020 season between the Spanish League and the European Champions League played at home (Table 5). We analysed FC Barcelona and the behaviour of their opponents when they played against them. In the 14 matches, the play of a total of 23 FC Barcelona players was analysed. These players played the entire season without an injury period in any of them that prevented them from being fit to play in 80% of the matches. It should be noted that the team played 39 games during the season, winning 38 and losing only 1, being a clear winning team. The videos used were publicly accessible, so according to the Belmont Report[1], it is not necessary to obtain the informed consent of the players (Pastrana-Brincones et al., 2021). Home matches were chosen because they were easier to obtain and of better quality than away matches as they were obtained directly from the TV production team.

The Belmont Report describes basic ethical principles and guidelines regarding ethical issues in human research. In addition, this study does not require a review by a research ethics committee, nor does it require written informed consent for the following reasons: (a) it involves observation of individuals in public places (sports hall); (b) the individuals or groups observed have no reasonable expectation of privacy; (c) it does not involve staged researcher intervention or direct interaction with individuals.

[1](https://student.societyforscience. org/human-participants)

Table 5. FC Barcelona matches played, competition and goal difference

Game	Competition	Goal difference
Anaitasuna	Spanish League	+17
Huesca	Spanish League	+23
Granollers	Spanish League	+14
Sagunto	Spanish League	+21
Cangas	Spanish League	+21
Sinfin	Spanish League	+24
Valladolid	Spanish League	+15
Celje	European Champions League	+24
Elverum	European Champions League	+9
Paris	European Champions League	+4
Aalborg	European Champions League	+9
Flensburg	European Champions League	+4
Zagreb	European Champions League	+9
Szeged	European Champions League	+2

Instruments

In order to carry out the research, an ad hoc observation instrument was constructed to analyse all variables that can occur in all phases of a handball match (Table 6). All categories fulfilled the requirement of completeness and mutual exclusivity (Anguera & Hernández, 2013; Jiménez-Salas et al., 2020b).

The different criteria observed were:

- **Criterion Competition:** Type of competition belongs to the observed match.
- **Criterion Observed Team:** Team that in the observed moment realizes the phase.
- **Criterion Phases of the Game:** Different game sequences that we can differentiate with the alternation of possession of the ball by a team.
- **Criterion Number of Players:** Relation of number of attackers and number of defenders in the observed situation.
- **Criterion Score:** Difference in goals between the two teams.
- **Criterion Sequences:** Number of attempts within the same phase of possession or recovery of the ball resulting from an interruption in the game.
- **Criterion Defence:** Team structure observed in the organized defence phase.
- **Criterion Attack:** Team structure observed in the system attack phase.
- **Criterion Rival Defence:** Structure of the rival team in the organized defence phase.
- **Criterion Rival Attack:** Structure of the rival team in the system attack phase.
- **Criterion Passive Play:** Tendency of the attacking team to retain possession of the ball without attacking or throwing at goal.
- **Criterion Player:** Which player performs the observed action.
- **Criterion Zone:** Delimitation of six zones of the playing field where the different actions of the game are developed.
- **Criterion Intermediate Results:** Situation that represents an interruption in the game, the teams continue within the same phase and there is no alternation in possession of the ball.
- **Criterion Final Result:** Different game actions that involve the change in possession of the ball.
- **Criterion Disciplinary Action:** Sanction on unsportsmanlike conduct on any of the components of the team observed.
- **Criterion Rival Disciplinary Action:** Sanction on unsportsmanlike conduct on any of the components of the rival team.

The different categories are described in Table 6.

Table 6. Observation instrument: tactical analysis success-failure (TAHSUFAIL)

Criteria	Categories	Description	Criteria	Categories	Description
Competition	ASO	Spanish League	**Rival Defence**	D60R	Defence 6:0 Rival
	CHA	Champions League		D51R	Defence 5:1 Rival
Team	TA	Team A		D42R	Defence 4:2 Rival
	TB	Team B		D33R	Defence 3:3 Rival
Phases game	AT	Attack		MDR	Mixed Defence Rival
	CA	Counterattack		MDDR	Mixed double defence Rival
	DF	Defence		IDR	Individual Defence Rival
	TD	Transition Defence		UDR	Unstructured defence Rival
Number of players	EQ	Equals		ODR	Other Defence Rival
	INF 1	1 player less without Gk	**Rival Attack**	ACWAR	Circulate wing Rival
	INF 2	1 player less with Gk		AWDPR	Double pivot wing Rival
	INF 3	2 players less without Gk		ABDPR	Double pivot back Rival
	SUP 1	1 more player (other No Gk)		A24R	Attack 2:4 with 2 Pivots Rival
	SUP 2	1 more player (other Gk)		A33RPI	Attack 3:3 with 2 Pivots
	SUP 3	2 more player (other no Gk)		A33R	Attack 3:3 Rival
	ONS	Other numerical situations		OAR	Other Attacks Rival
Score	W1	+1	**Passive play**	PP	Passive notice
	W2	+2	**Player**	Number	Player's number
	W3	+3	**Zone**	Z1	
	W4	+4		Z2	
	WPLUS4	>+4		Z3	
	DR	Draw		Z4	
	L1	-1		Z5	
	L2	-2		Z6	
	L3	-3	**Intermediate Result**	BI	Block but No Change Possession
	L4	-4		F	Foul No Change Possessions
	LPLUS4	>-4		TI	Throw but No Change Possession
Sequences	S1	Sequence 1		TO	Time out
	S2	Sequence 2		INTO	Interception but no change possession
	S3	Sequence 3		7m	Penalty
	S4	Sequence 4	**Final Result**	GL	Goal
	S5	Sequence 5		TR	Throw and Change Possession
	S6	Sequence 6		ST	Goalkeeper Save the Ball
Defence	D60	Defence 6:0		TF	Foul and Change Possession
	D51	Defence 5:1		INTIN	Interception of the Ball
	D42	Defence 4:2		BO	Block and Change Possession
	D33	Defence 3:3		PAS	Passive and Change Possession
	MD	Mixed Defence	**Disciplinary Action**	2M	Player 2 min Out
	MDD	Mixed Double Defence		YC	Yellow Card
	ID	Individual Defence		RC	Red Card
	UD	Unstructured Defence		BC	Blue Card
	OD	Other Defence	**Rival Disciplinary Action**	2MR	Player 2 min Out Rival
Attack	ACWA	Circulate Wing		YCR	Yellow Card Rival
	AWDP	Double Pivot Wing		RCR	Red Card Rival
	ABDP	Double Pivot Back		BCR	Blue Card Rival
	A24	Attack 2:4 with 2 Pivots			
	A33PI	Attack 3:3 with 2 Pivots			
	A33	Attack 3:3			
	OA	Other Attacks			

Data Quality

This tool, TAHSUFAIL for the identification of success or failure, was validated by a group of 13 experts**.** All of them have a degree in sports science and a minimum of experience as handball coaches in first division teams in different countries. The instrument was validated through the analysis of the Aiken V coefficient (Aiken, 1985) between the experts' ratings of the different categories determined 0.99 for belonging, 0.97 for clarity, and 0.98 for total. The observation of the matches was carried out by four observers, graduates in sports science and physical trainers with 10 years of experience in handball. After a period of observer training with the TAHSUFAIL observation instrument and the use of the software, the reliability of the observers was analysed through intra-observer and inter-observer concordance tests. Table 7 shows the different statistics that were used for the validation of the intra-observer and inter-observer tool: Cohen's Kappa (Krippendorff, 2018), Fleiss' Kappa (Fleiss et al., 2013) and Iota Coefficient (Conger, 1980). All the results obtained demonstrated reliability of the observers.

Table 7. Intra- and inter-observer agreement

Coefficient for entire session	Intra- observer agreement	Inter-observer agreement
Cohen's Kappa	0.98	0.97
Fleiss' Alpha	0.98	0.97
Iota Coefficient	0.98	0.97

Matches' Analysis

Once the tool was created and validated, all matches were analysed with the free software LINCE PLUS, version 1.3.2 (Soto-Fernández et al., 2021). A previous version of this software has been used in various research projects in the field of handball with observational methodology (Lozano et al., 2016). All the observation criteria and instruments were entered into the software. At the end of the analysis of all observed matches, we obtained a total of 2581 sequences. For each match, a coded record of all data was exported in Excel format. Once the match data had been obtained, the Hoisan programme was used (Hernández-Mendo et al., 2014) for coding and subsequent analysis with polar coordinates and the representation (Rodríguez-Medina et al., 2019).

Generalizability Analysis

A generalisability analysis (Cronbach et al., 1972) was performed using the SAGT software, version 1.0 (Hernández-Mendo et al., 2016) (see Table 8). Following the habitual attack system of Miranda et al. (2019), two measurement plans have been carried out to address: (A) the generalisability of the results obtained (number of plays that make up the sample) and (B) the validity of the observation instrument: (a) the generalisability coefficient (relative and absolute = 0.998) corresponding to the measurement plan [Categories]/[Plays] establishes that with the number of plays analysed a high reliability of generalisation accuracy is obtained; (b) with respect to the [Plays]/[Categories] measurement plan, the generalisability coefficient (relative and absolute = 0.000), supports—in the theoretical framework of the generalisability theory—the validity of the observation instrument designed (Blanco-Villaseñor & Escolano Pérez, 2017).

Table 8. Results corresponding to the generalizability design [Categories] [Plays].

Sources of variation	Sum of squares	Degree of freedom	Mean square	% Variance	Standard error
[PLAYS]	12.838	1667	0.008	0.000	0.000
[CATEGORIES]	3842.188	68	56.503	27.616	0.006
[PLAYS][CATEGORIES]	10048.711	113356	0.089	72.384	0.000

Procedures: Polar Coordinate Analysis

In order to find the most significant variables in the different phases of the game, the polar coordinates technique was used to reduce the large volume of data obtained (Castellano & Hernández, 2003). This technique is based on a sequential analysis of prospective and retrospective lags of the data obtained (Sackett, 1980; Anguera, 1997) and enables us to observe the relationships that exist between the behaviours that make up the taxonomic system we have created (Castellano & Hernández, 2003). From this analysis, we obtained contrast statistics, Zsum ($Zsum = \Sigma z/\sqrt{n}$, where n is the number of delays) (Cochran, 1954) with delay ranges from −5 to +5. Once we had the results, we made a graphical representation of the relationships found between the focal and conditioned categories at the vector level (Hernández-Mendo & Anguera, 1999). The length of the vector is the distance between the origin of coordinates Zsum (0,0) and the intersection point (Zsum value of the focal behaviour on the X-axis and Zsum value of the conditioned behaviour on the Y-axis). Relationships are considered significant ($p < 0.05$) when the lengths are greater than 1.96 (Tarragó et al., 2017). This value is obtained with the square root of the sum of the square of the Zsum of X (prospective) and the square of the Zsum of Y (retrospective). In addition, the angle of the vector (φ = Arc sine of Y/Radius) determines the nature of the relationship (Castellano & Hernández, 2003). The characteristics of each quadrant of the polar coordinates are expressed in Figure 13 (Castellano & Hernández, 2003). The focal behaviours used were SUCCESS and FAILURE and were related to the other criteria.

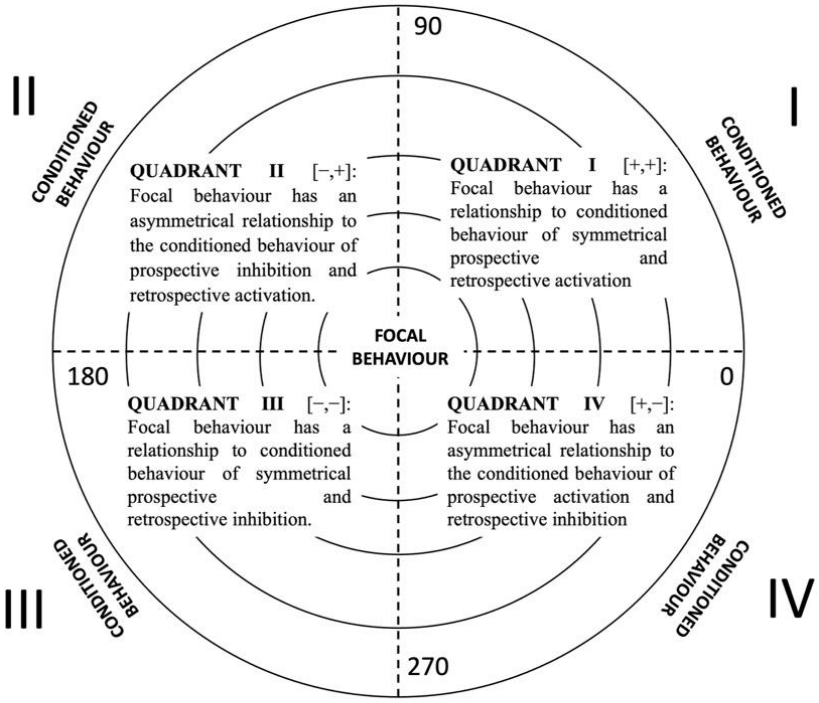

Figure 13. Quadrant characteristics of the polar coordinates. The focal behaviours were SUCCESS and FAILURE and were related to the other criteria.

All the categories observed through the observation tool should explain how we can achieve success or failure in the different phases of the game through this polar coordinate analysis. If we analyse only success, we considered that, at the defensive level, all criteria that entailed a disruption of the opposing team's attacking play or the recovery of the ball and possession were understood as success. On the offensive level, anything that was finishing an attack with a goal or achieving numerical superiority for the team was also considered a success. In terms of failure in the offensive phase, any interruption of play by the opposing team or loss of possession for various reasons was considered a failure. In the defensive phase, everything that led to conceding a goal or suffering a numerical inferiority in the number of players was also analysed as a failure.

Results

The analysis of the data with the polar coordinate's technique gave us a behavioural map of the focal behaviours, SUCCESS and FAILURE, with the other behaviours of the observation tool in the different quadrants (Table 9).

Quadrant I (Prospective and retrospective activation):

In Quadrant I, where the relationship between the behaviours is one of mutual prospective and retrospective activation, all the categories that relate to the focal behaviour mean that the more times they are performed during the match, the more they stimulate this success and vice versa; there is a double activation. With the results obtained in the behaviour SUCCESS (Figure 14), this is related to the 6:0 defensive system (9.49) itself and, in turn, to the defensive phase (9.53). There is also a relationship with the opposing team's attack when they attack with a circulation of the team's wing (2.18), attack with a double pivot by a wing (5,38) and attack with a double pivot by a back (2.68). There is also a relationship with the counterattack phase (5.86), Zone 1 finishing (2.58), sequence 1 (2.51), interception and recovery of the ball (2.20) and defensive blocking and change of possession (2.10). When analysing the focal behaviour FAILURE (Figure 15) in Quadrant I, there is a relationship with the circulation of the wing (2.84) and the transformation of a wing to a pivot (6.0). At the defensive level, there are relationships with the 5:1 defensive system, of the observed team (2.10) and the opponent's (2.24), other defences of the observed team (3.88) and opponent's (3.39), and unstructured defence (7.70). There is also a relationship with transition defence (9.02), Zone 2 (2.03), the throw-in without changes of possession (1.98), and sequence 2 (2.27).

Quadrant II (Prospective inhibition and retrospective activation):

In Quadrant II, where there is prospective inhibition and retrospective activation, the relationships with the successful focal cease to have positive activation as the match progresses. This is probably due to an adaptation of the opposing team to the situations presented. In this quadrant, there are relationships with the focal behaviour success with the attack phase (13.24), the own attack with the 3:3 system (11.26), and the opposing defence with the 6:0 system (10,60). We also found relationships with Zone 4 of completion (3.26), sequence 3 (2.25) and the penalty action (3.92). If we look for the relationship with focal behaviour failure, we see that there are relationships with the opposing 3:3 offensive system (5.08), the own defence phase (9.79) and the goalkeeper's save (2.18).

Quadrant III (Prospective and retrospective inhibition):

In Quadrant III, the existing relationship is one of mutual inhibition. The behaviours analysed in this quadrant indicate that we did not achieve any benefit at any time during the match, so we could consider their usefulness.

The relationships we found with the focal behaviour success were circulation of a wing (3.18) and attack with a wing as a double pivot (6.41). At the defensive level, we observed a relationship with other defences (4.07), unstructured defence (7.53) and other defences by the opposing team (3.52). There was also a relationship with transition defence (8.67), Zone 2 (2.11), sequence 2 (2.39) and the throw-in without change of possession (2.07). The relationships we found with the focal behaviour failure were inhibition in the 6:0 defensive system (9.82), the circulation of a wing (2.40), the double pivot attack by a wing (6.07) and the double pivot attack by a back (2.20) all by the opposing team. There is also a relationship in the counterattack phase (5.42), Zone 1 (2.24) and Zone 5 (2.46) finishing.

Quadrant IV (Prospective activation and retrospective inhibition):

In Quadrant IV, there is an asymmetrical relationship between prospective activation and retrospective inhibition behaviours. As the analysed category is realised, it becomes more effective in relation to the focal behaviour. Regarding focal behaviour success, there is a relationship with the rival attack with the 3:3 system (5.29) and with the goalkeeper's save (2.52). If we analyse the focal behaviour failure, can be observe relationships with the attack phase (1275), the 3:3 offensive system (11.06) and other attacks (1,.99). Additionally, with the opposing 6:0 defensive system (10.23), the finishing Zone 4 (3.54), the penalty action (3.97) and the interception and recovery of the ball (2.28)

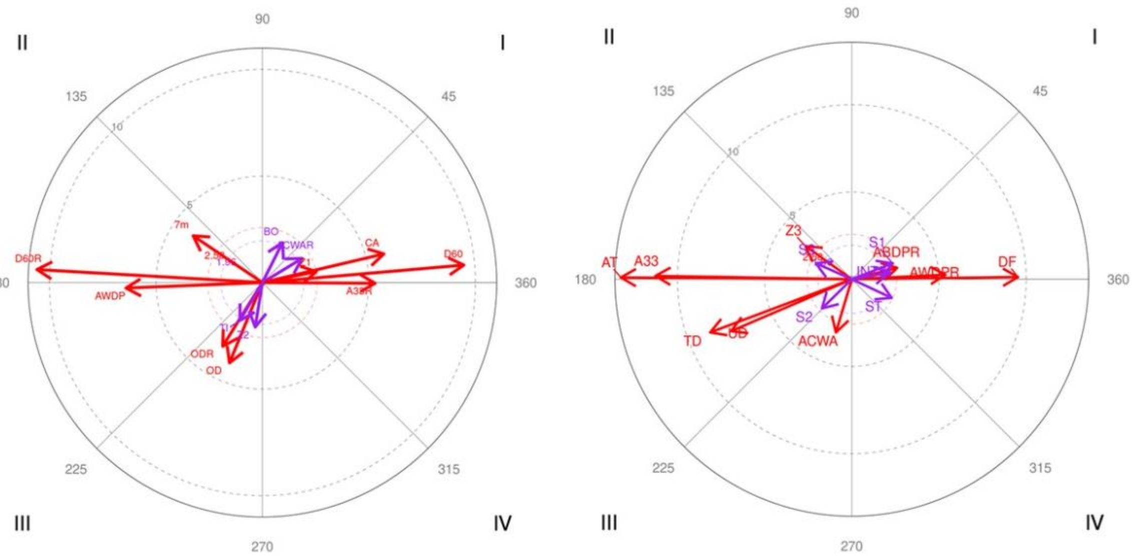

Figure 14. Vector maps for local behaviour SUCCESS.

NOTE: I: Quadrant I; II: Quadrant II, III: Quadrant III; IV: Quadrant IV

Table 9. Significant relationships between focal behaviours SUCCESS and FAILURE.

Criterion Behaviour	SUCCESS			FAILURE		
Q	Paring Behaviour	Vector Module	T-Angle	Paring Behaviour	Vector Module	T-Angle
I	Defence 60	9.49	4.97	Circulate Wing	2.84	77.53
	Circulate Wing Rival	2.18	31.25	Double Pivot Wing	6.01	3.22
	Double Pivot Wing Rival	5.38	2.71	Defence 51 Rival	2.24	33.81
	Double Pivot Back Rival	2.68	14.12	Other Defence Rival	3.39	49.56
	Defence	9.53	0.75	Defence 51	2.10	70.51
	Counterattack	586	13.27	Other Defence	3.88	66.62
	Zone 1	2.58	11.44	Unstructured Defence	7.70	20.18
	Sequence 1	2.51	21.23	Transition Defence	9.02	18.32
	Interception of the Ball	2.20	9.71	Zone 2	2.03	85.57
	Block and Change Possession	2.10	63.27	Throw but No Change Possession	1.98	62.61
				Sequence 2	2.27	55.12
II	Attack 33	11.26	179.05	Attack 33 Rival	5,.08	177.89
	Defence 60 Rival	10.60	176.70	Defence	9.79	178.68
	Attack	13.24	179.57	Goalkeeper Save the Ball	2.18	166.99
	Zone 4	3.26	144.47			
	Sequence 3	2.25	156.04			
	Penalty	3.92	145.98			
III	Circulate Wing	3.18	253.38	Defence 60	9.82	183.29
	Double Pivot Wing	6.41	182.30	Circulate Wing Rival	2.40	207.88
	Other Defence Rival	3.52	238.07	Double Pivot Wing Rival	6.07	181.81
	Other Defence	4.07	247.71	Double Pivot Back Rival	2.20	185.79
	Unstructured Defence	7.53	203.26	Counterattack	542	195.70
	Transition Defence	8.67	200.57	Zone 1	2.24	196.18
	Zone 2	2.11	260.82	Zone 5	2.46	247.55
	Sequence 2	2.39	224.36			
	Throw No Change Possession	2.07	239.26			
IV	Attack 33 Rival	5.29	359.63	Attack 33	11.06	359.06
	Goalkeeper Save the Ball	2.52	334.93	Other Attacks	1.99	331.99
				Defence 60 Rival	10.23	356.09
				Attack	12.75	358.45
				Zone 4	3.54	326.95
				Penalty	3.97	330.89
				Interception of Ball	2.28	194.42

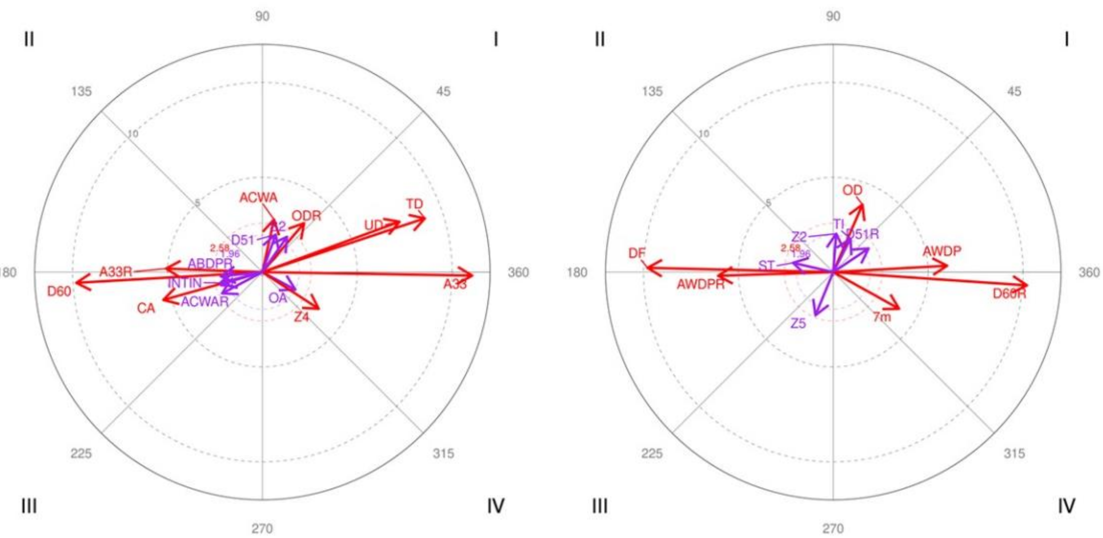

Figure 15. Vector maps for local behaviour FAILURE.

NOTE: I: Quadrant I; II: Quadrant II, III: Quadrant III; IV: Quadrant IV

Discussion

The aim of this study was to analyse the variables that influence success or failure in the different phases of the game in a season in an elite men's handball competition with polar coordinates. This analysis technique is novel for analysing all the variables that assess the performance of an elite men's handball team. There is research that has analysed with the same technique the performance of different factors at national team level in handball (Lozano & Camerino, 2012; Lozano et al., 2016; Prudente et al., 2019). This technique has also been used in other sports with two other analysis techniques (T-Patterns and sequential analysis) to analyse fencing (Tarragó et al., 2017). In basketball, this polar coordinate technique has also been used both in the analysis of the game (Nunes et al., 2021) and in the analysis of coaches' responses (Nunes et al., 2022).

In our research, on an offensive level, both in the positional attack phase and in the counterattack phase, success was understood as all actions that ended with a goal or where an advantage was achieved for the attacking team such as a disciplinary sanction of the opponent (yellow card, exclusion, or disqualification) or a clear action of completion such as a penalty. Failure was defined as any action where a shot was missed, either by a save by the goalkeeper or by throwing it wide, any defensive action that stopped the rhythm of play of the attack (foul), or the loss of the ball due to an opponent's interception or an own loss in a pass, for example.

To evaluate success in the defensive and transition defence phase, we defined it as any action that managed to recover the ball either by intercepting it, by a save or by a block. We also consider within success any action that stopped the rhythm of play of the rival attack (foul). All actions where a goal was conceded, a defensive player was penalised, or a clear penalty was awarded were defined as a failure.

In our search for references, we have not found any research where a regular season of an elite men's team is analysed in the different phases of the game through polar coordinates. From this analysis we have tried to find out which are the behavioural patterns that lead us to achieve our goals in the different moments of the game and the relationships with the different criteria of the game.

Defence

The observed team obtained a strong relationship in this phase with the focal behaviour success. The defence and, more specifically, the defensive system 6:0, were located in

Quadrant I, demonstrating this mutual excitation between the two behaviours, confirming the behavioural relationship in Quadrant III with the focal behaviour failure. The system 6:0 was the most used in most of the team's games, data that have also been demonstrated in another research (Lozano & Camerino, 2012; Jiménez-Salas et al., 2020a;). In turn, when the opposing team tried to overcome the defence with tactical actions common in handball such as the circulation of the wing, the transformation to double pivot by a wing or a first line, the defence was able to counter them efficiently. These data are also confirmed by the relationships obtained with the failure behaviour and the data from Quadrant III. In other research, they observed that attacks with transformation were more effective than those without (García et al., 2004). This could be argued from our results due to an evolution of the current game, being more direct, with more possessions and faster actions that do not slow down the game as much (Meletakos & Bayios, 2010). If we analyse another habitual attack system, the attack 33 rival behaviour (Jiménez-Salas et al., 2020a), we see that its location was found in Quadrant III in the success behaviour and in Quadrant II in the failure behaviour, indicating that, surely, as the minutes of the games progressed, the defensive system adapted better to this structured attack system, managing to counteract it and stimulate defensive success on the part of the team observed.

Different conditioned behaviours supported team success in this phase such as interception and block and their location in the first quadrant. Other research also showed that defensive performance was one of the indicators to adequately predict victory in a match at the men's national team (Daza et al., 2017) or club level (Sáez et al., 2009).

When analysing the pace of play of the opponent's attack, it was observed that in Sequence 1, the team was able to stop the opposing team effectively, and also in Sequence 3, although it was losing its relationship with success as the match progressed. This relationship was also observed in different studies where the winning team made moves, forcing the opposing team to find worse finishing situations or areas (Lozano et al., 2016; Lozano & Camerino, 2012). However, other research also showed that stopping the attacking pace of the opposing team with successive fouls did not improve the success of the defence (Fasold & Redlich, 2018). On the contrary, we were also able to observe that as the minutes progressed in the matches, more penalty actions were conceded, being a clear option of completion by the attacking team, bringing us closer to the focal failure behaviour.

The analysis has shown an important part of the success of a defensive system is related to the performance of the goalkeeper (Pascual et al., 2010). The data obtained showed that as the goalkeeper's performance improved, his relationship with success behaviour increased and decreased with failure behaviour. There is other research that supports these results, showing that the winning teams were those that achieved a greater number of saves by their goalkeepers (Sáez et al., 2009; Pascual et al., 2010), also demonstrated that the losing teams made more shots from areas far from the goal, being easier for the goalkeeper (Sáez et al., 2009; Lozano et al., 2016). It was also observed that the goalkeeper's performance plays a decisive role in the final result (Antúnez et al., 2013), combined with adequate offensive efficiency (Pascual et al., 2010).

The team was found to be more solid in its main defensive system, a formed and structured defence as when, for circumstances, it performed other defence or unstructured defence, the tendency was towards failure (Quadrant I), as demonstrated in other research where attacks were more successful in front of unorganised defences (Rogulj et al., 2004).

Counterattack

The fact that at the defensive level, the team observed had a significant relationship with success behaviour, influenced the relationships in this phase. Various studies have shown that good defensive efficiency leads to an increase in the number of counterattacks and a clear opportunity to shoot. This phase can start with ball stealing (Meletakos et al., 2011; Daza et al., 2017), a good performance by the goalkeeper (Sáez et al., 2009; Pascual et al., 2010) or a good relationship between defensive efficiency and the goalkeeper (Jiménez-Salas et al., 2020b).

If we look at the relationship between the focal success behaviour and the conditioned behaviours counterattack and Sequence 1, we can deduce that the team analysed obtained a high performance in this phase, and that their game, linked to the previous phase, promoted trying to finish more actions in this phase than in the static attack. These findings follow the same line as other research that showed that counterattacking is commonly performed in Sequence 1 (Lozano & Camerino, 2012) and is often more successful than structured attacking as it is attacked against unstructured defences (Rogulj et al., 2004). Other research showed that the difference between winning and losing teams was the goals scored in this phase (Rogulj et al., 2004). Looking at the results obtained by the team in Table 8, it could be said that the observed team was clearly a winner.

The reason that the game model deduced from the team was based on an efficient defence that allowed for easier finishing options in the counterattack phase is surely due to the direct relationship of this phase with success in the match demonstrated in multiple investigations (Rogulj et al., 2004; Antúnez et al., 2013; Daza et al., 2017), but also with a direct relationship with success in the defensive phase (Sáez et al., 2009). To confirm this argument, the data obtained with focal failure behaviour and this phase also reaffirm this assumption.

Attack

The results obtained in the research confirm those found in other research. They also showed that winning teams were characterised by fast attacks and not by the prolonged and interrupted attacks more typical of losing teams (Rogulj et al., 2004). In order to cut the pace of the game and increase the sequences, opposing defences tried to stop actions in Zone 2, the zone where the attack is created and where many free hits are usually produced. They also tried to lengthen the sequences so that they did not shoot easily in order to increase the error (Interception of Ball) (Lozano et al., 2016; Daza et al., 2017;). Even so, it was not enough to slow down the attack of the team observed by looking at the results obtained in the matches analysed (Table 5).

It can also be observed that the team was losing effectiveness in its offensive system 33, the most used in other research (Jiménez-Salas et al., 2020a), against the rival defence, making the attacking phase approaching failure and moving away from success. This loss of activation with success was probably caused by an adaptation of the opposing team’s defensive systems, by an increase in turnovers, by the increase in fatigue as the game progressed on the part of the attack or by the differences in the score, and the offensive relaxation on the part of the team observed (Lago et al., 2011). Another behaviour that confirms this tendency is Sequence 3, whereas the game progressed, it became less related to success. The attack tried to overcome the rival structured defence with different tactical actions (circulate wing; wing to double pivot), but their relationship was closer to the focal behaviour of failure rather than success. Even so, the observed team’s attack was superior to the opposing defence in general in the static phase, given the results obtained, confirming data from another research (Sáez et al., 2009; Daza et al., 2017).

Where the team observed had the most problems was in attacking the opposing team's defensive system 5:1 or other defensive systems. It is curious that, analysing this data, the opposing teams did not use these systems to try to stop the team's offensive success. This greater opposition of the defensive system 5:1 by the attack is in line with the results obtained in other studies that obtained the same conclusions, being the system that generated the most problems for the attack, but being an alternative, not being the main defensive system, with a clear relationship with the score, being either very much in favour or very much against. It seems that teams used this system as a desperate measure to stop the opponent's static attack as observed in other research (Jiménez-Salas et al., 2020a).

Transition Defence

Being a team that achieved a high level of success in the offensive phase, especially in the counterattacking phase, this phase probably did not occur too many times in the different matches, or its transition defence forced the opposing team not to carry out a large number of counterattacks. However, we must bear in mind that when this phase did occur, it was usually not very well organised, and the opposing team was successful. This could lead us to believe that this phase should be improved as they are easy finishing options for the opposing team as well as the counterattack of the team analysed. Having demonstrated the effectiveness and importance of the counterattacking phase for success, we can understand that this phase is associated more with failure, in any team, however little happens, rather than success (Antúnez et al., 2013; Daza et al., 2017; Rogulj et al., 2004).

Limitations

In handball, different game models, different offensive and defensive systems can be used depending on the choice of the coach and the opponent. In this research we have tried to analyse two different types of competitions, a national league and a European league, in order to try to observe different patterns of play and to have a much broader view. Since the same team has been observed in all 14 matches, its playing pattern may have influenced the results, more so since it is a clear winning team. It must be considered that the team's predominant defensive system was 60 and an offensive game based, above all, on counterattack. If we combine this model of play with the fact that the team's squad was made up of top international players, we can understand the pace of the game and the predominance of the counterattack phase.

Practical Applications

The results found in the research reaffirm those obtained in other studies. It is key to defend successfully to be able to carry out the most decisive phase for winning teams, the counterattack. This indicates that the technical staffs, must dedicate an important part of their training tasks to improve defensive success and insist on a high pace of play in the offensive phase, more specifically in the counterattack. Surely, to be able to carry out these tasks, a great relationship with the conditional work is needed, so that the players can withstand a high training load, as in competition, and do not suffer injuries typical of this model of play (Font et al., 2021).

Conclusions

The analysis of success or failure in the different phases of the game in an elite men's handball match suggests, as in other research, that one of the keys is the defensive phase, not conceding goals and recovering the ball. Another key, linked to recovering the ball, is the counterattack, to obtain clear goal scoring options. Success in these two phases is key to winning matches and being a winning team. This suggests that it is necessary to focus on training with a high pace of play, linking the different phases of the game to achieve the objectives set for the match, recovering the ball, and attacking with the least possible time in front of an unstructured defence. One limitation we have encountered is the lack of existing research on the transition defence phase. Conclusions could be drawn in this phase by comparing what happens in the counterattack, but an in-depth analysis of how to counteract the success of the counterattack should be developed in future research.

4.4. Estudio 4: *The effect of training schedule and playing positions in training loads and game demands in professional handball players*

* Font R., Karcher C., Loscos-Fàbregas E., Altarriba-Bartés A., Peña J., Vicens-Bordas J., Mesas J.A., Irurtia A. (2023). The effect of training schedule and playing positions in training loads and game demands in professional handball players. Biol Sport, 40(3):857–866.

Abstract

In this research, we aimed to (1) describe the differences in internal and external load between playing positions and (2) characterize the training demands of the days before competitive events for professional handball players. Fifteen players (5 wings, 2 centre backs, 4 backs, and 2 pivots) were equipped with a local positioning system device during training and 11 official matches. External (total distance, high-speed running, player load) and internal loads (rating of perceived exertion) were computed. Substantial differences were recorded between the external load variables depending on each playing position and depending on whether it was a training day (high-speed running: effect size (ES) $\geq$ 2.07; player load: ES$\geq$ 1.89) or a match (total distance: ES$\geq$ 1.27; high-speed running: ES$\geq$ 1.42; player load: ES$\geq$ 1.33). Differences in internal load were not substantial. The rating of perceived exertion, at this competitive level, does not seem to discriminate the differences registered in the external load, probably due to the degree of adaptation to the specific effort of these players. The large differences observed in external load variables should be used to tailor practices and better adjust the training demands in professional handball settings.

Keywords: external load, team sports, IMUs, internal load, RPE

Introduction

In-season load monitoring is relevant in high-performance team sports as this process gives critical information to the technical staff. This information allows coaches to adapt the training contents, helping players perform to the best of their abilities during games (Manzi et al., 2010) with reduced injury risk (Caparrós et al., 2018). Despite this relevance, no studies, to the best of our knowledge, have analysed the training demands in handball as in other team sports such as football (Martín-García et al., 2018) or basketball (Vázquez-Guerrero et al., 2020).

Previous studies in handball suggest that many factors affect the playing demands during games. Thus, gender (Luteberget, Trollerud, et al., 2018; Font et al., 2021;), playing level (amateur handball players accumulated a lower total distance) (González-Haro et al., 2020), or age (adolescent handball players showed lower levels of exercise intensity, in the second half of matches) (Ortega-Becerra et al., 2020) have been reported in different pieces of research. It is worth noting that many studies (Manchado et al., 2020; Font et al., 2021) show that playing positions modulate the game demands considerably because tactical roles attributed to each playing position are very specific (Karcher & Buchheit, 2014; Michalsik et al., 2015).

Thus, the external (Povoas et al., 2014; Cardinale et al., 2017; Manchado et al., 2020; Font et al., 2021) and internal load game demands (Chelly et al., 2011; Manchado et al., 2013) have been studied in different research studies. For instance, pivots (PIV) travel lower total distances (3149 ± 639 m) (Font et al., 2021), while wings perform the highest number of sprints (Manchado et al., 2020) and cover the highest high-speed running (HSR) distances (1229 ± 129.4 m) (Povoas et al., 2014). Playing position also influences internal load substantially (Chelly et al., 2011; Manchado et al., 2013). Povoas et al. (2014) found that back players and pivots had the highest average heart rate (HR) values and total game time at intensities >80% HRmax. Therefore, and considering these previous results, monitoring game demands is relevant. However, training sessions represent the most significant part of the weekly training load (at least in volume), and we should accurately monitor them. We hypothesize that training demands are influenced mainly by playing positions, and these differences could have substantial consequences in training load management (Ravé et al., 2020) and could explain injury rates (Caparrós et al., 2018). Understanding these variations may improve load management (Ravé et al.,

2020) and mitigate injury risks (Caparrós et al., 2018). Optimizing training to prepare players for competition with specific tasks also seems essential (Tarragó et al., 2019).

It is also worth noting that physical profiles differ between playing positions (Krüger et al., 2014; Schwesig et al., 2017), also influencing training loads (Impellizzeri et al., 2019). Thus, body dimensions are relevant as they can alter training load (Karcher et al., 2014; Martínez-Rodríguez et al., 2020). These differences add disparity to the training response, making training individualization necessary (Krüger et al., 2014; Schwesig et al., 2017).

Another aspect to consider is the management of training loads to help players perform during games to the maximum of their abilities. Many studies have shown that periodization is crucial for performance (Ravé et al., 2020) and injury prevention (Caparrós et al., 2018).

To be physically prepared for the match, players must train to develop specific physical skills (e.g., lower limb muscle power and ability to accelerate) in an optimal manner close to or superior to competitive demands (Tarragó et al., 2019). The knowledge of such game demands can lead professionals to apply the approach "train as you play" (Holt et al., 2006); however, despite its importance, there appears to be no study in handball that provides this information. We do not know, for example, whether games offer the highest load of the microcycle. It is paramount, then, to compare training and game demands. Training load management control is a crucial driver of performance in a team sport (Ravé et al., 2020) and a strategic advantage for the different coaching staff (Martin-Garcia et al., 2018).

The aims of this research are 1) to describe the internal and external training load differences between playing positions and 2) to characterize the training demands to compete for every training day. Therefore, we examined the differences in internal (RPE) and external (using inertial measurement units (IMUs)) loading concerning training days, playing positions, and competitive playing demands. Our findings should help coaches to design playing positions' specific training content related to game demands.

Material and methods

Experimental approach to the problem

We conducted a cross-sectional, observational study to determine the differences between playing positions during games and practices of a team playing in the second division of the Spanish handball competition during the 2018-19 season. The reported results consider the average values of 11 competitive home games and 25 weeks of practice. There were usually four training sessions a week; the day before the competition (match day; MD) was MD-1, two days before the competition (MD-2), and so on until MD-5. The research data emerged thanks to the daily monitoring of the players conducted in training and competition; therefore, relevant approval of the ethics committee was not required (Winter & Maughan, 2009). The study was conducted following the ethical principles for biomedical research with human beings, established in the Declaration of Helsinki of the World Medical Association (updated in 2013), and the club's managerial structure approved its implementation.

Subjects

Fifteen professional handball players participated in this study. Some of the players were internationals with their national teams as they were still in their formative stages. Players were grouped according to their usual playing position during the competition (Table 10).

Table 10. Physical characteristics of the players (mean ± standard deviation)

POSITION	MEAN (n)	AGE (years)	BODY MASS (kg)	HEIGHT (cm)
LEFT WINGS (LW)	3	23.0±0.0	78.5±3.5	176.0±0.0
RIGHT WINGS (RW)	2	23.5±0.7	73.0±2.8	179.0±1.4
CENTRE BACKS (CB)	3	24.0±1.0	90.3±9.3	190.3±7.5
LEFT BACK (LB)	3	23.7±0.6	93.0±6.6	192.3±3.5
RIGHT BACK (RB)	2	23.0±0.0	89.5±16.3	194.5±9.2
PIVOT (PIV)	2	29.5±4.9	100.5±7.8	192.5±3.5

Sessions and games monitoring

The study was carried out using the WIMU PRO system (RealTrack Systems SL, Almería, Spain). Each device, whose dimensions were 81x45x16 mm (height/width/depth) and which weighed 70 g, was fitted to the back of each player with an adjustable vest (Rasán®, Valencia, Spain). In training, the recording was uninterrupted. During games, playing time was only recorded when the players were on the court. The time spent between player rotation, team time outs (TTO) (a maximum of three per team), periods when the game was interrupted, and the disciplinary sanctions typical of handball, where players must leave the court for two minutes, were omitted. Table 11 describes the main characteristics (objectives, volume, duration, intensity, static or dynamic training) of the different training days.

Table 11. Aims, contents and orientation of volume and intensity related to training.

MD	Aim	Conditional work	Static phase (%)	Full court game (%)	Volume	Intensity	Training session time (min)
MD -5	Individual development	Structural	80	20	***	**	87.9±8.2
MD -4	Individual development	Structural	60	40	****	**	97.5±15.7
MD -3	Tactical session	Structural	60	40	****	***	95.0±11.4
MD -2	Match preparation	Optimising	50	50	***	***	90.1±11.5
MD -1	Match preparation	Optimising	70	30	**	*****	86.4±8.5

Data processing

The positioning data record was monitored in real-time and subsequently analysed using the SPRO™ software version 946-949 (SPRO™, RealTrack Systems, 2018). The system operates using triangulations between four antennas with patented ultra-wideband technology (18 Hz sampling frequency) placed 5 m away from each one of the corners of the court and at a height of 6 metres. These units include several sensors that record at different sampling frequencies. The sampling frequency used for 3-axis, accelerometer, gyroscope, and magnetometer was 100 Hz and 120 kPa for the barometer (Bastida-Castillo et al., 2018; Bastida-Castillo et al., 2019).

Total distance (TD, in metres) and in high-speed running (HSR, distance covered in metres above 18.1 kph) (Ortega-Becerra et al., 2020; Font et al., 2021) were extracted from the root data reported by the system using SPRO™ software. The player load (PL; arbitrary units, au) was calculated as the square root of the sum of the squared instantaneous rates of change in acceleration in each one of the three planes divided by 100 in absolute (Vázquez-Guerrero et al., 2019).

Internal load (IL) data were obtained through the RPE-based method (arbitrary units, au) (Foster et al., 2021) at 10-30 minutes following every handball training session and game. The recording of all training sessions and games resulted in 1033 individual records for the external load and 1008 files for the internal load.

Statistical analysis

Data in the text and figures are presented as means with standard deviation (SD). All data were first log-transformed to avoid bias arising from non-uniformity error. To compare external and internal load between and within the different playing positions during games and training sessions, standardized differences in the mean (Cohen's effect size) were calculated. Effect size comparisons were rated using the Hopkins scale: 0.2 (Small), 0.6 (Moderate), 1.2 (Large), 2.0 (Very Large) (Hopkins et al., 2009). The 90% confidence interval were also calculated for each effect size. Considering the high number of comparisons, the results were not analysed when the lower limit of the effect size was below 0.6. Percentages of game demands for each variable were also calculated following this formula: [(session demand – mean playing position game demand) / mean playing position game demand] x 100. Statistical analyses were performed using R Studio (v1.3) and the Esvis package (v0.3.1).

Results

Table 12 summarizes each variable's mean value and standard deviation for playing positions and game day. Figure 16 shows total distance (TD), high-speed running distance (HSR), player load (PL), and rating of perceived exertion for each day of training, for each playing position, and for each player.

Table 12. Comparison of mean value of each indicator related to training day and games.

		CB	LB	LW	PIV	RB	RW
Total distance (m)	Game	**4562.7±928.4**	**4699.5±974.2**	**4946.1±1051.0**	**4084.8±1263.83**	**3872.0±623.3**	**5306.6±1422.2**
	MD -1	↘ 3861.9±627.6	→ 4347.5±623.6	↓ 3826.0±654.7	→ 3526.4±623.9	→ 3888.2±663.9	↓ 3882.3±628.3
	MD -2	→ 4457.0±1008.2	→ 4731.6±871.8	↘ 4236.9±747.2	→ 3665.6±597.7	→ 4136.1±881.8	↘ 4394.7±897.5
	MD -3	→ 4650.1±1012.7	→ 4744.1±730.9	→ 4593.2±928.4	→ 3913.3±969.7	↗ 4413.1±947.4	→ 4828.7±1182.9
	MD -4	→ 5025.3±1197.2	→ 5154.4±1184.4	→ 4998.9±1212.8	→ 4145.6±819.5	↗ 4712.9±1167.6	→ 5060.4±1286.4
	MD -5	→ 4344.5±656.2	→ 4476.6±684.2	→ 4349.9±870.2	→ 3678.3±884.7	→ 4187.6±729.1	→ 4492.8±675.9
High speed (m)	Game	**208.9±90.54**	**267.2±119.0**	**549.7±186.2**	**228.9±139.9**	**179.9±79.2**	**668.4±307.5**
	MD -1	↘ 111.9±84.8	↘ 138.8±82.6	↓ 151.7±91.8	↓ 84.2±69.1	↘ 126.5±84.9	↓ 212.8±129.1
	MD -2	↘ 107.9±80.7	↓ 130.6±106.2	↓ 236.4±134.8	↘ 107.5±71.3	↘ 107.9±118.8	↓ 273.1±161.2
	MD -3	↘ 146.7±127.2	↘ 142.8±105.1	↘ 293.2±193.1	↘ 106.9±85.6	→ 145.8±141.0	↘ 338.8±219.8
	MD -4	→ 166.9±113.6	↘ 142.3±94.9	↘ 298.9±171.2	↘ 121.9±92.2	→ 146.2±100.1	↘ 313.4±192.0
	MD -5	↓ 82.7±99.0	↓ 61.1±82.6	↓ 167.5±218.6	↘ 59.1±63.5	↘ 74.2±89.0	↓ 181.2±232.4
RPE (AU)	Game	**6.7±1.73**	**6.6±1.9**	**7.0±1.5**	**5.7±2.3**	**6.1±1.3**	**7.4±1.3**
	MD -1	↘ 5.3±0.8	→ 5.6±0.9	↘ 5.8±0.7	→ 5.6±0.9	→ 6±1.0	↓ 5.5±0.9
	MD -2	→ 6.4±1.1	→ 6.9±1.1	→ 6.2±1.4	↗ 6.6±0.8	→ 6.6±0.9	↘ 6.6±1.1
	MD -3	→ 6.6±1.3	↗ 7.3±0.8	→ 6.9±1.3	↗ 7.0±0.9	↗ 6.9±0.8	→ 7.0±1.1
	MD -4	→ 6.8±1.1	→ 7.2±1.0	→ 6.8±1.4	↗ 6.8±0.9	→ 6.8±1.2	→ 7.1±1.4
	MD -5	→ 6.5±1.4	→ 7.1±1.1	→ 7.3±1.2	↗ 6.7±1.0	↗ 7.0±0.8	→ 6.9±1.4
PlayerLoad (AU)	Game	**69.7±15.9**	**74.1±17.6**	**82.5±21.9**	**56.3±18.9**	**60.1±10.1**	**89.9±30.2**
	MD -1	↘ 54.8±9.1	↘ 61.1±9.3	↓ 54.6±8.8	↘ 44.4±9.2	↘ 53.8±9.7	↓ 58.6±11.1
	MD -2	→ 63.6±12.7	→ 65.9±10.6	↘ 62.2±11.7	→ 49.4±9.8	→ 58.1±11.8	↘ 66.2±13.7
	MD -3	→ 67.7±13.2	→ 68.5±9.1	↘ 69.9±14.3	→ 54.1±13.5	→ 63.8±13.3	→ 75.7±15.9
	MD -4	→ 70.5±14.7	→ 73.1±16.4	→ 78.9±22.3	→ 55.5±13.1	→ 67.9±16.5	→ 80.4±20.1
	MD -5	→ 63.2±8.3	↘ 64.8±9.7	→ 71.4±14.4	→ 50.2±13.9	→ 61.0±10.9	↘ 72.9±11.4

NOTE: Direction of the arrow describe the magnitude of the standardized difference, horizontal arrow stand for an effect size between 0.6 and -0.6, down arrow for an effect size above 1.2, diagonal down arrow for an effect size between -0.6 and -1.2 and diagonal up for an effect size between 0.6 and 1.2

Game demands

During games, RB travelled (4187.6±729.1 m) less TD with an effect largely to very largely (ES range from 1.8 to 2) than the other playing positions (left backs (LB): 4476.6±684.2 m, CB: 4344.4±656.1 m, LW: 4349.8±870.2 m, RW: 4492.8±675.8 m) except when they were compared to PIV (PIV: 3678.2±884.6 m).

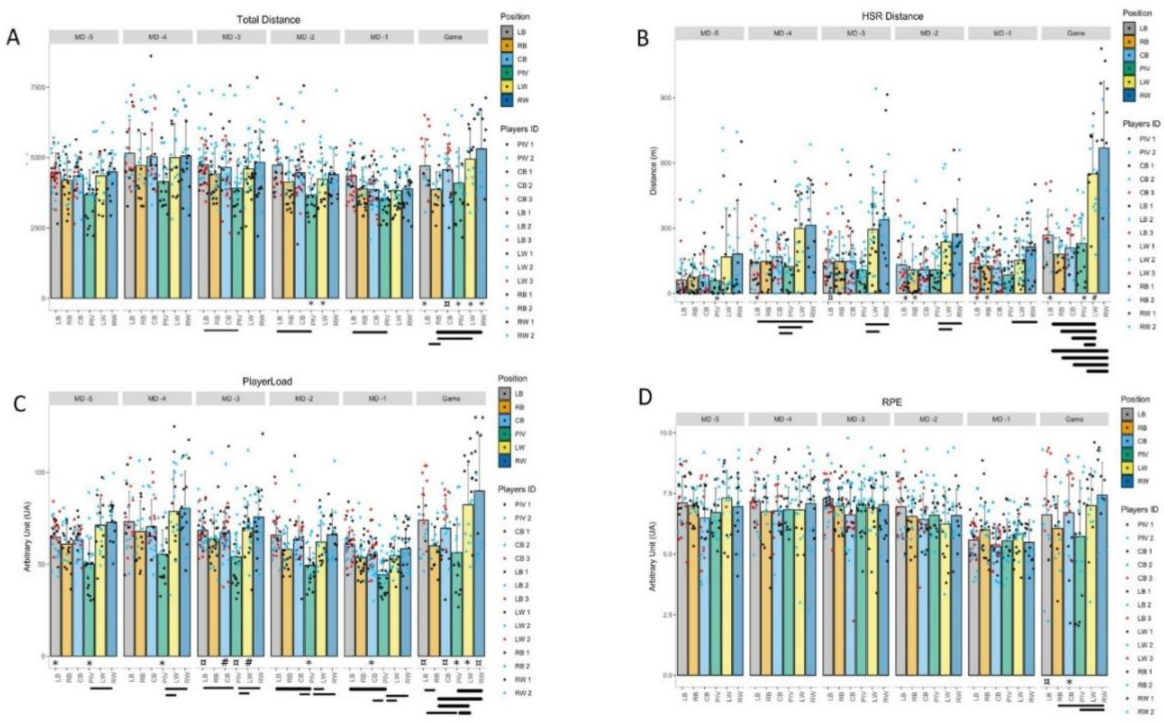

Figure 16. Comparison between playing position related to game day in total distance (A), high-speed running distance (B), player load (C) and rate of perceived exertion (D).

NOTE: Bar graphs represent mean and standard deviation for each playing position related to game day. Colored dots stand for individual value within the playing position and game day. The thickness of the lines represents the magnitude of the difference (effect size): ▬ very large difference; ▬ large difference; — moderate difference. The magnitude of the difference of the within playing position are represented by ¤ when they are large very large, * when they are large and # when they are moderate. Only effect sizes with a lower limit above 0.6 are shown.

Wing players (RW: 668.4 ± 307.5 m, LW: 549.6 ± 186.2 m) cover very largely more HSR distance (ES range from 2.3 to 3.3) during games when compared to the other playing positions (LB: 267.2 ± 119.0 m, PIV: 228.9 ± 139.9 m, CB: 208.92 ± 90.5 m, RB: 179.9 ± 79.2 m). During games, RB (60.1 ± 1 au) and PIV 56.3 ± 2 au) reported a lower PL (for RB, ES vs. LW = 2.3, vs. RW = 2.1, vs. LB and for RB vs. LW ES= 2.3, vs. RW = 2.03) than the other playing positions (range from 69.7±15 au for CB to 90.0±30.2 au for RW).

Training sessions

<u>Total distance</u>

PIV travelled moderately to largely less distance (ES range from 1.2 to 1.6) in MD-5, MD-2, MD-1 (3678.3±884.7 m, 3665.5±597.6 m, 3526.4±624.0 m) when compared to LB (4476.6±684.2 m, 4731.6±871.7 m, 4347.5±623.6 m, respectively).

High-speed running

In MD-4, MD-3, and MD-2, the HSR distance travelled by PIV (MD-4: 392.8±128.9 m, MD-3: 106.9±85.6 m, MD-2: 107.5±71.2 m) was largely to very largely lower (ES ranged from 1.3 to 2) than by wing players (MD-4, LW: 298.9±171.2 m, RW: 313.4±192 m, MD-3: LW: 293.2±193.1 m, RW: 338.79±219.8 m, MD-2: 236.4±134.8 m, RW: 273.1±161.2 m).

Player load

PIV showed the lowest PL value, up to largely less (ES ranged from 1.2 to 2.07) in all the training sessions and games (in MD-5: 50.2±13.9 au, in MD-4: 55.5±13.2 au, in MD-3: 54±13.5 au, in MD-2: 49.4±9.8 au, in MD-1: 44.4±9.2 au). Wing players produced up to very largely higher PL (ES ranging from 1.5 to 1.8) demands in MD-5 (RW: 72.9±11.4 au, LW: 71.4±14.3 au), MD-4 (RW: 80.4±20.1 au, LW: 78.8±22.3 au), MD-3 (RW: 75.7±15.9 au, LW: 69.9±14.3 au). LB showed the highest PL value in MD-1 (61.1±9.3 au vs. 44.4±9.1 au for PIV, LB vs. PIV, ES=2.03).

Rating of perceived exertion:

Like in matches, there were no substantial differences in the RPE, with values ranging from 5.72±2.32 au for PIV to 7.43±1.34 au for RW.

Games vs. training

Within playing position differences

PIV showed moderate to large within-playing-position differences during games in TD (4951.1±1047.6 m vs. 3218.4±779.7 m, ES=1.97), HSR (343.6±84.2 m and 114.2±70.3m, ES=1.91), PL (68.7±15.5 au vs. 44 ± 13.2 au, ES=1.77). There were moderate to very large differences (ES 1.44 to 2.06) for LB during games in TD (4161 ± 657.5 m vs. 5400.3±980.5 m), in PL (87.2±15.8 au vs. 75.3±10.9 au) and RPE (7.7±1 au vs. 5.6±1.1 au). There were large to very large within-playing-position differences in HSR distance travelled by LB (306.2±355.1 m vs. 83.1±162.3 m).

PIV also showed some individual differences (ES=1.84) in the PL in MD-5 (62.8±13.8 au vs. 43.8±9.2 au), MD-4 (63.0±10.2 au vs. 51±13 au), MD-3 (62.6±10.9 vs. 44.2±8.4 au), MD-2 (55.9±9 au vs. 43.5±6 au).

Figure 17 shows the coefficient of variation for all the metrics in each playing position for the different training days. HSR distance showed a higher variation (77.3% to 87.9%). When considering playing position and training days, HSR distance in MD-5 had the highest percentage of variation (107% for PIV to 135% for LB, 123.5±9.8%). Games were the sessions with lower CV (33.9% for LW to 61.1%, 45.5±8.8%) for HSR.

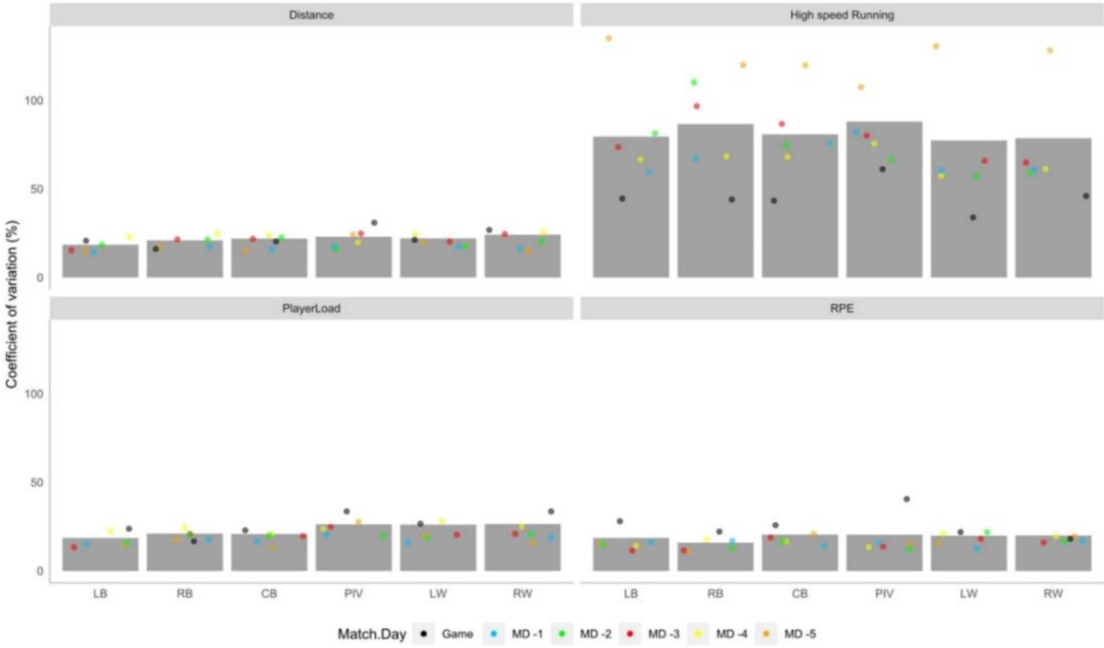

Figure 17. Coefficient of variation for all the metrics in each playing position in different training days.

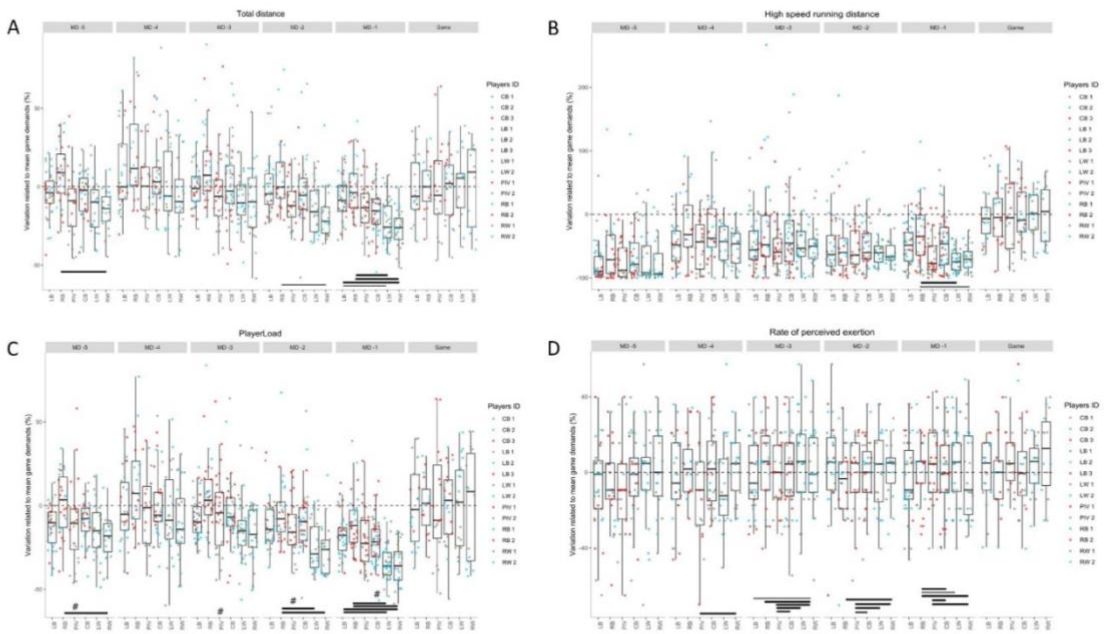

Figure 18. Comparison of mean percentage of game demands between playing position related to game day in total distance (A), high-speed running distance (B), player load (C) and rate of perceived exertion (D).

NOTE: Bar graphs represent mean and standard deviation percentage of mean game demands for each playing position related to game day. Colored dots stand for individual value within the playing position and game day. The thickness of the lines represents the magnitude of the difference (effect size): ▬ very large difference; ▬ large difference; — moderate difference.

Figure 18 illustrates the difference between playing positions expressed in the percentage of variation related to the mean game demands in the different variables. LB and RB showed a moderately to largely higher percentage of mean game demands in MD-1 when compared to wing players in TD (LB: -7.5 ± 13.3%, RB: 0.41 ± 17.15%, LW: -22.6 ± 13.2%, RW: -26.8 ± 11.8%; ES from 1.14 to 1.81), in PL (LB: -17.4 ± 12.5%, RB: -10.5 ± 16%, LW: -33.8 ± 10.6%, RW: -34.9 ± 12.3% and ES from 1.38 to 1.71)

PIV showed up to largely higher percentage of mean game demands in RPE value in all training sessions (MD-5: 17.3±17.6%, MD-4: 19.4±16.1%, MD-3: 22.9±16.8%, MD-2: 15.3±14.2%, MD-1: -3±15.5%, ES from 1.26 to 1.83) when compared to the other players (MD-1: from -15.6±13.8% to -26.2±12.5%, MD-2: range -11±14% to 8.19±13.9%, MD-3: 15±13.3%, MD-4: -4.6±18.5 to 11.4±19.9%, MD-5: -3.3±20% to 15.5±12.6%).

RB followed the same pattern in MD-5, MD-3, MD-2, and MD-1 (ES from 1.14 to 1.68). RB (29.7±47.17%) reached a moderately to large higher percentage of mean game demands in high-speed running compared to wing players (LW: -72.4±16.7%, ES=1.21, RW: -68.1±19.3%, ES=1.03) in MD-1.

There were large differences in the percentage of mean game demands between PIV in MD-2, MD-3, and MD-4 (respectively, -22.8±10.7% vs. -0.8±16.1%, ES=1.6, -21.5±14.9% vs. 11.1±19.5%, ES=1.85, -24.5±5.3% vs 5.4±23.5%, ES=1.51).

Discussion

To our knowledge, this is the first time a handball team has been monitored longitudinally during a season in practices and games with a combination of IMUs and RPE. The most significant differences between playing positions were noted on match days, showing that training does not replicate game demands. PL and HSR were the metrics with the most important differences. When the difference between playing positions was expressed as the percentage of variation related to the mean game demands, the most important differences were found in MD-1 and the RPE.

Match days

Regarding the external load in games, our results on match days are in line with previous studies. The wings (left (LW) and right (RW)) are, by far, the players who cover the most metres in HSR, both in training and in games. These results match those observed in earlier studies (Michalsik et al., 2015; Cardinale et al., 2017; Font et al., 2021). RW and

LW were the players who covered the highest distance and RB the lowest. A similar effect has been found in previous studies (Cardinale et al., 2017). Wings were also the players with the highest PL values compared to the other positions. These results differed from previous studies finding that CBs were the players with the highest PL value. Player rotation and team tactics could explain some of these differences because the nature of this playing time affects PL (Vázquez-Guerrero et al., 2020) substantially.

In team handball, player rotations are unlimited and very easy to implement. As a result, many factors could explain this variation, such as players' performance level (the better they are, the longer they tend to play), the tactical choice of the coach, or game model requirements. PL has been developed as a measure of physical performance based on changes in acceleration to capture non-running-based work (e.g., jumping, changes of direction, acceleration, contact) (Font et al., 2021). PIV and RB had the lowest IL concerning the other positions. This result could be related to different players' rotation strategies. In many teams, RB are the players involved in the offensive/defensive systematic rotations for various reasons, such as a lack of defensive ability or fatigue management (RB need to be tall and left-handed and are essential for most teams). PIVs' performances are paramount for many teams, and the physical demands they must cope with are high (Karcher & Buchheit, 2014). As a result, many coaches tend to establish more rotations for the PIVs.

Training session

Total distance

PIV covered less distance than the other players during all training sessions (up to moderate to largely less than LB). The tactical and technical demands of the playing position likely play an important role. PIV players were a fixing point in the opponents' defence when backs played more around the defensive system. A vital part of handball training is devoted to the stabilized phase (Table 11), accounting for most ball possession in matches (Rogulj et al., 2011). This result should be related to the main objective, the relative part of the session's static/full court phases, and the volume/intensity choice. It is expected that when training sessions are focused on static phases, PIVs do not accumulate many metres due to their defensive fixation function, performing more isometric or dynamic muscular actions. In turn, even if the training session is more dynamic (full-court situations), they tend to carry out the same function. Thus, they cover less distance and perform fewer running actions. These results are in line with those obtained in other studies where the PIV were the players who covered the lowest distance in official matches (Font et al., 2021). When expressed as a percentage of mean game demands, we can see that RB achieve a higher value than the other positions in many parts of training sessions.

It is very likely that when there is a less stabilized phase in training (when coaches want their players to run more), the RB achieve a higher percentage as they run less than the other players in games. In training, all players tend to train simultaneously and perform the same tasks. These differences in RB (and to a lesser extent for LB) could be attributed to a higher rotation in playing time due to the demands on these positions according to the team's playing model (Font et al., 2021).

<u>High-speed running distance</u>

Wings covered higher HSR distance in all training sessions than the other playing positions. These results confirm that training requirements are not always in line with game demands (Michalsik et al., 2015; Cardinale et al., 2017; Font et al., 2021;). HSR distance is an essential metric for performance (Martín-García et al., 2018) and injury prevention (Whiteley et al., 2021). Our findings support the idea of Karcher & Buchheit (2014) that there is a need for specific sprint training and hamstring prevention work for wings. The HSR percentage of mean game demands suggests that training sessions do not replicate the competition load as the HSR distance is lower than the match demands in all training sessions for all players (Figure 18). This lack of specificity can lead to some issues in some players, especially wings (who cover the highest HSR distance, such as decreasing their performance (Cardinale et al., 2017; Font et al., 2021) and increasing their risk of injury (Karcher & Buchheit, 2014). HSR distances should be close to or above those required by the competition to allow players to cope with these demands (Tarragó et al., 2019). Moreover, the coefficient of variation of HSR showed that this variable fluctuated a lot. Large differences were found in all playing positions depending on MD. This variation suggests that the technical and tactical objectives of the training largely influence the HSR content and that this variable is not always adequately managed (Karcher & Buchheit, 2014). Our results indicate that HSR distance is mainly subjected to tactical choices.

Player Load

Our results showed a large variation in PL when comparing the different playing positions. This fact confirms that each player needs a training load as individualized as possible; the external load demands differ for each playing position (Kniubaite et al., 2019; González-Haro et al., 2020; Font et al., 2021). At the same time, it was observed that MD-4 was the day that was closest in terms of PL to the competitive needs. As seen in Figure 17, MD-4 was the day when the greatest volume of work was carried out both in terms of time and full court work and when the highest PL values could be accumulated. PL is one of the most used variables to control the external load in training and competition in handball (Kniubaite et al., 2019; González-Haro et al., 2020; Font et al., 2021). PIV were the players with the lower PL values in competition and the different training sessions. The specific demands of the position at a physical, technical, and tactical level may explain this result (Font et al., 2021). Most of the needs of these players are based on isometric strength work, as they were the players who were the most involved in contact actions and with few accelerations and lower high-velocity displacement (Karcher & Buchheit, 2014; Martínez-Rodríguez et al., 2020). Wings showed the highest PL value in any training session, following the other external load variables (total distance and HSR). These differences between positions could be explained by the tactical demands of each position, their needs, and the game model used by the team (Font et al., 2021).

Rate of perceived exertion

Our results suggest that players rated the session with similar intensities despite many differences in the external load (e.g., HSR distance). Surprisingly, the internal load did not reproduce the same pattern as the external loading. We could suggest two explanations for this offset. Firstly, the extensive experience of the players in handball and years working with the same methodologies in the same club (3.3±2.2 years in the club) may have caused a specific adaptation (Tarragó et al., 2019). Secondly, many players' characteristics influence internal load values, such as muscle mass, substrate concentrations (Borg, 1982), body size (Martínez-Rodríguez et al., 2020), or fitness level (Novack et al., 2018). As a result, two players receive equivalent external loads, but the internal load could differ depending on individual characteristics. The player's physical characteristics and body dimensions are position-dependent (Karcher et al., 2014; Krüger et al., 2014; González-Haro et al., 2020). Overall, these factors mainly explain the results.

Comparing the values obtained during training sessions and games, we see that the results are often higher after training. These differences indicate that training and rest time density is much higher during the week than on MD. There are likely more in-game breaks due to the refereeing, the opponent's game pace, and the player's rotation strategies. The differences in the percentage of variation considering the mean game demands are probably caused by the discrepancies between training and game values. Game demands fluctuate greatly when compared to the training context.

Coefficient of variation

The coefficient of variation is related to periodization, as variations in training load are a key and widely studied factor in performance (Buchheit et al., 2021). Many studies suggest that poor training-load management and flawed prescription constitute significant risk factors for injury (Gabbett, 2016). Our results show that games are the moment with the highest fluctuations in most of the variables. This is logical, considering that teams do not have control over the opponent’s executions. Most CVs are low and show a small magnitude (18 to 29%) except for HSR. HSR’s CV showed values ranging from 57 to 135%. Large differences were found in all playing positions depending on MD. This variation suggests that the technical and tactical objectives of training largely influence HSR content and that this variable is not managed (Karcher & Buchheit, 2014). These results indicate that HSR distance is a by-product of tactical choices.

Too much variation in the same training days illustrates, from our point of view, that coaches do not control this variable. It is also worth noting that HSR distance was much higher during games than during training sessions, as training content does not replicate HSR game demands.

Limitations

We could only study one professional team with a particular match and training model. The team's profile (only one match per week) also allowed us to have stable microcycles that may not be generalizable to other contexts (teams playing more than one match per week, national teams). Another limitation is that the analysis of defensive specialists was not considered. Some players have a particular role, playing only during the defensive phase, and are not included in the attack. The type of training provided by the coaching staff, and its intensity, also influence the training demands to a large extent and can be a limitation. Other parameters, such as different playing strategies (Diana et al., 2017), the opponent's level (Gómez Carmona et al., 2019) and the use of a defensive specialist, may have revealed different results than ours.

Practical applications

Coaches must consider variables such as positional demands or the team's playing style to tailor training demands. Our results show that coaches should carefully evaluate several indicators to design the optimal training content. In our data, some values in the training sessions were above the game demands (total distance, RPE) and others under (HSR, PL). This scenario can be suboptimal to prepare players for the “worst case scenario” in competition. It is worth noting that training demands differ largely between positions (wings and PIV vs. RB). Handball staff should use this information before designing microcycles to adjust training loads more precisely.

Conclusions

We observed that internal load does not show the same pattern even if there are substantial differences in external load variables between playing positions. Our results confirm the need to control the load and the complementarity of the two types of load variables. One of the most relevant findings was the substantial variation in HSR between positions, games, and training sessions. Coaches must give special attention to HSR because it is an essential variable for injury prevention (Karcher & Buchheit, 2014) and performance (Cardinale et al., 2017). Further research is needed in handball to study the parameters that influences the behaviour of internal and external loading variables to optimize training.

5. Discusión

El deportista se conforma por diferentes estructuras que configuran un sistema altamente complejo. El proceso de entrenamiento debe estimular la generación de nuevas relaciones entre dichas estructuras, con el objeto de optimizar todo el sistema de manera integral y conseguir una mejor adaptación y evolución del HD para la práctica deportiva (Seirul·lo et al., 2017; Tarragó et al., 2019).

Todas estas estructuras las tendríamos que valorar de una forma lo más ecológica posible, para no interferir en la valoración del rendimiento de los jugadores y ver cómo estos se relacionan con su medio habitual que deberíamos reproducir en los entrenamientos. A su vez, deberían valorarse todas las estructuras, des de esta perspectiva global que se defiende con esta filosofía del EE. Como hemos ido describiendo en las diferentes referencias encontradas y puntos a lo largo de esta tesis, la mayoría de las estructuras han sido evaluadas de forma individual y sólo hemos encontrado algunas investigaciones que han relacionado a dos estructuras de forma complementaria en diferentes deportes (Seirul·lo et al., 2017; Tarragó et al., 2019).

Partiendo de esta metodología de trabajo del EE y de las diferentes estructuras que forman el HD (Seirul·lo, 1986; Seirul·lo et al., 2017; Gómez et al., 2019; Tarragó et al., 2019; Pons et al., 2020), hemos encontrado los mismos déficits en las investigaciones en balonmano a la hora de relacionar diferentes estructuras de forma ecológica.

La Estructura Condicional del jugador es la que valora la parte física del HD. Esta valoración se realiza de una forma más práctica, a través de pruebas analíticas dónde medimos, por ejemplo, la fuerza de salto, la potencia de lanzamiento, la intensidad de los metros recorridos, etc. Pero en los últimos años, dentro de esta visión más ecológica, se ha empezado a valorar con tecnología de última generación (IMUs), que sucede a nivel de carga externa en los partidos disputados y que carga externa deben soportar los jugadores (Luteberget & Spencer, 2017; Manchado et al., 2020). Aunque con esta tecnología no se puede valorar, hoy en día, ciertas manifestaciones como la fuerza isométrica de ciertas acciones de juego en el balonmano (acciones en la posición del pivote, sobre todo), la información que nos aporta es mucho más inmediata, real y ecológica que todas las pruebas que se puedan realizar en el laboratorio. Con ella obtenemos la información de las necesidades reales de los jugadores, tanto en función de su posición de juego como a nivel individual. Un déficit que hemos observado en el análisis de esta estructura es que no hemos encontrado ninguna investigación que exponga que nivel de carga condicional soportan los jugadores de balonmano durante los entrenamientos para valorar si el trabajo que les planteamos es óptimo para soportar la carga externa que van a tener que soportar en la competición como sí que pasa en otros deportes como el futbol (Martin-Garcia et al., 2018) o el baloncesto (Vázquez-Guerrero et al., 2020). Conocer la carga de competición y si la preparación que realizamos dentro del microciclo es la correcta, es clave, bajo nuestro punto de vista, para mejorar el rendimiento de los jugadores (Manzi et al., 2010) a la vez que prevenir posibles futuras lesiones (Caparrós et al., 2018).

A nivel de relaciones de diferentes estructuras del HD, existen diferentes investigaciones que nos aportan datos de que sucede nivel de carga interna con esta carga externa que tienen que soportar los jugadores (Michalsik, 2011; Povoas et al., 2014; Gupta & Goswami, 2017). Bajo nuestro punto de vista, es más importante analizar que sucede en la relación entre la Estructura Condicional y la Estructura Bioenergética, por ejemplo, que valorar el rendimiento de forma aislada con una sola Estructura al entender al HD como un ser multi-estructural. Muchas veces planteamos diferentes entrenamientos o nos podemos encontrar con partidos que la carga externa y la carga interna no vayan en la misma dirección a nivel individual de cada jugador debido a su experiencia en el balonmano, su conocimiento del modelo de juego, el nivel del rival o su condición física, por ejemplo, dando valor a la individualización del trabajo para cada jugador (Impellizzeri et al., 2019).

Si analizamos lo que le sucede al HD a nivel de carga interna, se puede describir la Estructura Bioenergética. Esta estructura se puede analizar de una forma absolutamente aislada del deporte en un laboratorio cómo se ha realizado en muchas investigaciones des de hace muchas décadas (Chelly et al., 2011; Wagner et al., 2019), o se puede hacer de una forma más específica integrada dentro de la Estructura Condicional. Podemos encontrar diferentes investigaciones donde buscan la relación existente entre estas dos estructuras (Kniubaite et al., 2019). El control de esta carga externa e interna es muy importante para ver cómo se adapta el jugador a la competición o a los entrenamientos e intentar controlar la carga total para disminuir, por ejemplo, el riesgo lesivo o valorar como se recuperan de los esfuerzos de los entrenamientos o los partidos (Impellizzeri et al., 2019).

También encontramos investigaciones dónde lo que se ha buscado analizar es la Estructura Cognitiva. En estas investigaciones se han analizado que variables del juego táctico son determinantes para conseguir el éxito (Daza et al., 2017) o la influencia en la toma de decisiones de los jugadores. El estudio de estas variables son claves para el éxito deportivo (Johnson & Raab, 2003; Raab & Johnson, 2007; Raab & Laborde, 2011). A su vez, se han analizado los comportamientos de los equipos delante de los diferentes modelos de juego a los que se enfrentan, tanto en las fases ofensivas y cómo defensivas del partido (Prudente et al., 2010; Lozano & Camerino, 2012; Fasold & Redlich, 2018; Jiménez-Salas et al., 2020a, 2020b). Los diferentes cuerpos técnicos tanto de élite como sub-élite, destinan muchas horas a analizar los rivales y su forma de jugar para ver como tienen que adaptar su propio modelo juego tanto ofensivo como defensivo para conseguir el éxito en las diferentes fases del juego y poder ganar el partido.

Hay otras investigaciones que han analizado la Estructura Coordinativa. Estas investigaciones han buscado analizar a los jugadores de balonmano des de una perspectiva más analítica y sin interrelacionarla con otras estructuras. Existe un gran volumen de investigaciones que han buscado analizar elementos técnicos del juego como puede ser el lanzamiento (Van Den Tillaar & Ettema, 2003; Van Den Tillaar & Ettema, 2006, 2007; Wagner et al., 2010a, 2010b, 2012) o elementos más específicos y determinante en el deporte como es el cambio de dirección (Wagner et al., 2016, 2019). Pero a su vez también existen otras investigaciones que han buscado comparar que sucede en esta Estructura y su relación con la Estructura Condicional midiendo, por ejemplo, la precisión del lanzamiento y la fuerza que puede desarrollar el jugador (Ortega-Becerra et al., 2019). Esta relación de estas dos estructuras debería verse reflejada en la modificación de los entrenamientos condicionales de fuerza y de prevención para mejorar el rendimiento en este gesto técnico a su vez que reducir la incidencia lesiva en este mecanismo y acción tan habitual en el balonmano (Mónaco et al., 2019).

Al ser el balonmano un deporte de equipo, creemos que es muy importante para conseguir los objetivos del equipo que el ambiente de entrenamiento y las relaciones entre los jugadores sean lo mejor posible a su vez que con el cuerpo técnico ya que el objetivo, sea cual sea este, es común para todos. La Estructura Socio-afectiva es la que se encarga de valorar las relaciones interpersonales entre todos los componentes del equipo. Una buena relación nos ayudaría a mejorar el rendimiento deportivo cómo se ha demostrado en jugadores y jugadoras en edades de formación (Gonzales & Coronado, 2011b, 2011a).

Pero para que un jugador tenga una buena relación con el grupo, es importante que él se encuentre bien y en un buen estado de ánimo personal para sumar en positivo dentro del colectivo. En balonmano se ha analizado el estado de ánimo de los jugadores a nivel de motivación (Gómez-López et al., 2014) o sus niveles de ansiedad (Kristjánsdóttir et al., 2018), claves para valorar como se encuentran los jugadores y su dominio y control de las diferentes situaciones de estrés que deben soportar a lo largo de la temporada. Si observamos un equipo de élite, los resultados, la clasificación, los minutos de juego, las situaciones contractuales, las lesiones, …pueden generar que el jugador no esté en su mejor situación anímica para rendir al máximo nivel necesario.

Relacionada con esta última estructura, tendríamos la Estructura Mental, donde el jugador se autoorganiza en función de las demás estructuras y de sus experiencias y conocimientos. Podríamos decir que es una estructura que da conciencia al jugador de lo que hace y para que lo hace. Esta última estructura muchas veces es la que hace que un jugador pueda llegar a un nivel más alto de rendimiento o no, teniendo una relación directa con todas las estructuras que conforman al HD impulsándolo a mejorar sus relaciones entre todas las estructuras y evolucionar su versión actual creando estructuras y relaciones nuevas.

Como podemos observar a lo largo de esta tesis doctoral, no hemos encontrado ninguna publicación o línea de investigación donde correlacionen todas las estructuras que forman al HD, seguramente debido a su alto nivel de complejidad y a la dificultad de encontrar una herramienta para valorarlas todas las estructuras juntas o a las máximas posibles a la vez. Debido a esta inquietud, este doctorado ha buscado empezar una línea de investigación donde se busque valorar el rendimiento deportivo de los jugadores de balonmano de una forma más amplia teniendo en cuenta a las diferentes estructuras que lo conforman a través de diferentes investigaciones y de la forma más ecológica posible teniendo claro que los vértices donde debe girar el trabajo son el HD y el balonmano.

En el primer estudio, hemos intentado describir que necesidades tienen los jugadores de balonmano de elite en competición, para tener un punto de partida sabiendo que valores condicionales de carga externa tienen que soportar los jugadores y como los deberíamos preparar en los entrenamientos de la mejor forma óptima posible.

Somos conscientes que solamente hemos analizado la Estructura Condicional y Bioenergética como otras investigaciones, pero creíamos interesante tener un punto de partido ya que, hasta la redacción de este estudio, no existía ninguna investigación realizada con tecnología IMUs que definiera estas variables en un equipo masculino de élite en competición oficial en una temporada regular. Sin saber que valores de carga externa tienen que soportar los diferentes jugadores, no podemos realizar entrenamientos lo más individualizados posibles adaptados a cada jugador, tanto a nivel de carga externa, de prevención de lesiones y de mejora del rendimiento.

En el estudio 2, debido a la situación de confinamiento vivido por la COVID-19, analizamos las mismas estructuras del estudio 1, pero des de una perspectiva analítica debido a la situación vivida a nivel global. Valoramos la eficiencia del trabajo que hicieron los jugadores en sus casas para mantener los niveles de fuerza de la extremidad inferior y de su capacidad aeróbica. Si que es verdad que valoramos este trabajo y lo controlamos día a día a través de la Estructura Emotivo-volitiva preguntando a los jugadores como se encontraban, pero estos datos no fueron analizados estadísticamente dentro de la investigación. Esta investigación nos aportó mucha información práctica para saber el estado de los jugadores del equipo. Nos encontramos delante de una situación absolutamente nueva en el mundo del deporte dónde los equipos de balonmano dejaron de entrenar y los jugadores no recibieron ningún estimulo específico de entrenamiento en pista durante muchos meses. Los resultados obtenidos nos permitieron observar los valores condicionales de los jugadores después de realizar un trabajo absolutamente general en sus casas y ver si este había sido efectivo o no. A parte, gracias a este análisis, pudimos programar un trabajo individualizado para cada jugador durante la *post-season* para llegar en las mejores condiciones al inicio de la siguiente pretemporada. El gran miedo del cuerpo técnico era que el índice lesivo del equipo aumentara considerablemente y no se pudieran conseguir los objetivos planteados a nivel competitivo.

En el tercer estudio que conforma esta tesis doctoral, analizamos la Estructura Creativa, observando el comportamiento táctico de un equipo de elite masculino durante los partidos disputados durante una temporada. A partir de este estudio, pudimos analizar en que fases del juego se conseguía más éxito y con que medios tácticos colectivos. A su vez observamos que acciones tácticas y que indicadores estaban más cerca del fracaso. Estos resultados deberían ayudar a los cuerpos técnicos a modular el tiempo de trabajo en las diferentes fases del juego de un partido reforzando aquellas situaciones dónde se consigue éxito de una forma más fácil, por ejemplo, una mayor intensidad defensiva para poder pasar a la fase de contraataque, a la vez que incrementar el trabajo en las fases dónde hay un mayor fracaso como es el repliegue defensivo. Si que encontramos investigaciones observacionales donde analizaban alguna fase concreta del juego y buscaban indicadores de éxito, pero en nuestra búsqueda, no encontramos ninguna investigación que analizara partidos de una temporada regular de un mismo equipo de élite masculino. Hay que tener en cuenta que una de las limitaciones fue que analizamos un modelo de juego muy concreto pero los resultados confirmaron el éxito de este modelo y que la forma de entrenar era la correcta viendo los resultados obtenidos por el equipo a lo largo de la temporada. Otra limitación en comparación con los demás estudios de la tesis fue la no inmediatez de estos resultados para poder ser aprovechados por el cuerpo técnico.

Una vez la pandemia nos permitió volver a entrenar y teníamos claro las necesidades que tenían que soportar los jugadores de elite de balonmano en la competición, consideramos clave analizar como distribuíamos las variables de carga externa analizadas en el estudio 1 más la percepción del esfuerzo del jugador (Estructura Emotivo-Volitiva), durante el microciclo. Hasta la fecha no éramos conscientes de si los entrenamientos planteados con el equipo eran suficientes para soportar la carga interna y externa que suponía la competición para cada posición de juego y para cada jugador de forma individual. Para ello, en el estudio 4, analizamos esta distribución con un equipo filial de élite de balonmano debido a que sólo disputaba un partido a la semana, teniendo más sesiones de entrenamiento y una estructura más estable del microciclo. Con esta investigación pudimos ver si la distribución y la forma de trabajar las variables preparaba a los jugadores de la forma óptima para soportar la carga competitiva y que diferencias debíamos tener en cuenta a nivel de posiciones de juego para realizar tareas lo más individualizadas posibles. Dentro del EE, no podemos plantear los mismos estímulos para todo el mundo por igual. Cada HD es absolutamente un ser especial y necesita un entrenamiento individualizado y óptimo para él y sólo para él donde va a depender de estas diferentes estructuras que lo forman, su posición de juego, su historial lesivo, sus preferencias, por ejemplo.

A partir de estas cuatro investigaciones que forman el doctorado, podríamos obtener una imagen más global de la valoración de los jugadores de élite de balonmano, pero nunca sacando conclusiones de las diferentes investigaciones o análisis de las estructuras por si solas. Hay que ser consciente de que es necesario tenerlas en cuenta todas debido a las diferentes estructuras que conforman al HD. En este sentido, sabemos que deberíamos plantear una siguiente investigación más global con un equipo de sujetos parecidos a los que hemos analizado, y realizar una futura o futuras investigaciones donde se analicen diferentes estructuras a la vez. Sería viable unir, por ejemplo, el análisis y control de la Estructura Condicional, la Estructura Bioenergética, la Estructura Creativa, la Estructura Emotivo-Volitiva y la Estructura Emocional, en una misma investigación para valorar el rendimiento del jugador de balonmano de forma multifactorial.

6. Conclusiones

A continuación, se resumen las conclusiones de cada una de las cuatro investigaciones que conforman esta tesis doctoral.

Conclusiones del estudio 1

1. Diferentes posiciones de juego suponen diferentes cargas de trabajo externas: los extremos y centrales asumen mayor carga, mientras que los laterales y pivotes, menor.
2. Diferentes cargas de trabajo externas suponen diferentes estrategias en el diseño de tareas, debiéndose ajustar según cada posición de juego.

Conclusiones del estudio 2

3. Un programa de entrenamiento estructurado, autocontrolado durante el confinamiento (Covid-19), mantuvo la capacidad de salto, pero no las aptitudes aeróbicas, de un equipo profesional de balonmano.
4. La competición y el propio proceso de entrenamiento del balonmano masculino de alto nivel, suponen recorrer grandes distancias a intensidades elevadas. Este hecho no pudo ser adaptado o compensado entrenando bajo las condiciones de confinamiento.

Conclusiones del estudio 3

5. No encajar goles y recuperar el balón en la fase defensiva, y contratacar inmediatamente a una defensa desestructurada, son determinantes para el éxito o fracaso competitivo en el balonmano masculino de alto nivel.
6. El alto ritmo de juego impuesto en las competiciones de balonmano de élite debe corresponder con el diseño de escenarios simulados durante los entrenamientos que integren a las diferentes fases del juego, especialmente recuperando el balón y atacando con el menor tiempo posible ante defensas no consolidadas.
7. La fase de transición de la defensa todavía requiere de un mayor análisis por parte de la literatura, especialmente a la hora de establecer estrategias sobre cómo contrarrestar el éxito del contraataque.

Conclusiones del estudio 4

8. La carga interna a la que los jugadores se ven sometidos en el microciclo previo a la competición y durante ésta, al contrario de lo que sucede con la carga externa, no registra diferencias significativas entre las diferentes posiciones de juego.
9. En relación a la carga externa, la variable HSR (*High Speed Running*), cuya modulación en el balonmano profesional es determinante tanto para la prevención de lesiones como para la optimización del rendimiento, es la que registra mayores diferencias entre posiciones de juego, partidos y sesiones de entrenamiento.
10. Atendiendo a los resultados obtenidos sobre la relación entre carga interna y externa a lo largo del microciclo previo a la competición y durante ésta, se constata la necesidad de monitorizar ambas para así cruzar sus registros e individualizar la dosis que cada jugador necesitará asimilar para contribuir al éxito colectivo del equipo durante el partido.

Finalmente, en base al conjunto de los cuatro estudios precedentes y como reflexión final, se concluye que, en el balonmano de alto nivel, de la misma manera que en otros deportes colectivos con elevadas exigencias competitivas, el cuerpo técnico diseña las diferentes tareas con el objeto de lograr estímulos óptimos y adecuados para las necesidades y demandas solicitadas según las diferentes estructuras del humano deportista (coordinativa, cognitiva, condicional…). Dichos estímulos, durante los entrenamientos, deben ser lógicamente multidimensionales y concordantes con los que los jugadores asumirán posteriormente durante los partidos de competición (escenarios simulados de juego).

7. Líneas futuras de investigación

Es necesario seguir implementando nuevas y diversas tecnologías y sistemas de análisis capaces de abordar el análisis del rendimiento deportivo del balonmano de alto nivel desde una perspectiva compleja y multidimensional, que nos reporte un tipo de información válida, veraz, efectiva y eficiente.

A continuación, se listan seis líneas de investigación que actualmente están desarrollándose y que aseguran la continuidad de las aportaciones relacionadas con la tesis doctoral:

- *Positional differences in the Most Demanding Scenarios of External Load Variables in Elite Handball Matches.* El objetivo es analizar cuáles son las situaciones más exigentes para las hay que preparar a los jugadores a nivel de carga externa extraídas de partidos oficiales y con tecnología IMUs.
- *Validación del countermovement jump como herramienta para el control de la fatiga y la recuperación en jugadores profesionales de balonmano post-partido.* En esta investigación, analizamos los datos obtenidos en el CMJ a nivel basal, post partido, +24 y +48 horas a la vez que buscamos correlaciones con la proteína cK y el lactato para analizar esta recuperación mecánica y fisiológica.
- *Análisis de la calidad del descanso a través del sueño en jugadores de élite de balonmano durante una temporada competitiva.* A través de los anillos de control de la calidad del sueño, registramos como descansaban los jugadores de élite de balonmano durante 6 meses analizando su calidad ya fuera en sus casas o durante los viajes con el equipo y sus equipos nacionales.
- *Análisis de la fase de repliegue defensivo en competición de élite de balonmano con coordenadas polares*. Cuando se realizó el estudio 4, observamos que no existe mucha bibliografía que hable de esta fase del juego, importante para contrarrestar la fase de mayor facilidad de finalización, el contraataque. Deberíamos ampliar el conocimiento en esta fase.
- *Análisis de los movimientos más habituales que realizan los jugadores de balonmano a nivel defensivo y su intensidad.* En esta investigación ya publicada, se generó un algoritmo para analizar que movimientos que realizan más habituales los jugadores de balonmano en competición a nivel defensivo y ver de forma automática su sistema defensivo.

Guignard B, Karcher C, Reche X, Font R, Komar J. (2022) Contextualizing physical data in professional handball: using local positioning systems to automatically define defensive organizations. *Sensors, 22*, 5692. https://doi.org/10.3390/s22155692.

- *Monitorización de la carga externa en jugadores sub20, sub18, sub16 y sub14 en competición durante tres temporadas en función de su posición de juego*. Estamos comparando la carga externa que tienen que soportar los jugadores según su posición de juego en los partidos y ver si es la misma en función de la edad en un mismo club con el mismo modelo de juego.

Con todo, el balonmano de alto nivel debe seguir avanzando hacia la monitorización de variables de carga externa e interna, detectando posibles relaciones entre éstas y el éxito o fracaso deportivo durante la competición o entre posibles cuadros potencialmente lesivos. La figura profesional del educador físico deportivo, denominada bajo el término anglosajón "*Sport Science*", emerge más necesaria que nunca: una persona que, mediante su experticia y conocimiento específico basado en la evidencia científica, aporte soluciones al *staff* técnico que les permita superar los factores que limitan el rendimiento deportivo y competitivo de sus jugadores.

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9. Anexos

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Monitoring external load in elite male handball players depending on playing positions

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ABSTRACT: Monitoring workload is critical for elite training and competition, as well as preventing potential sports injuries. The assessment of external load in team sports has been provided with new technologies that help coaches to individualize training and optimize their team's playing system. In this study we characterized the physical demands of an elite handball team during an entire sports season. Novel data are reported for each playing position of this highly strenuous body-contact team sport. Sixteen world top players (5 wings, 2 centre backs, 6 backs, 3 line players) were equipped with a local positioning system (WIMU PRO) during fourteen official Spanish first league matches. Playing time, total distance covered at different running speeds, and acceleration variables were monitored. During a handball match, wings cover the greater distance by high-speed running (> 5.0 m·s^{-1}): 410.3 ± 193.2 m, and by sprint (> 6.7 m·s^{-1}): 98.0 ± 75.4 m. Centre backs perform the following playing position that supports the highest speed intensities during the matches: high-speed running: 243.2 ± 130.2 m; sprint: 62.0 ± 54.2 m. Centre backs also register the largest number of high-intensity decelerations (n = 142.7 ± 59.5) compared to wings (n = 112.9 ± 56.0), backs (n = 105.2 ± 49.2) and line players: 99.6 ± 28.9). This study provides helpful information for professional coaches and their technical staff to optimize training load and individualize the physical demands of their elite male handball players depending on each playing position.

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INTRODUCTION

Global positioning systems are widely used in outdoor team sports such as rugby or football [1, 2]. This system also carries an embedded inertial measurement unit (IMUs) (e.g. accelerometer, magnetometer) recorder with a good level of validity [3], and a wide range of metrics (e.g., distance and number of sprints), although GPS cannot be used indoors (the GPS signal is blocked). Recently, many companies have developed ultra-wide band systems to collect real-time data in indoor sports [4]. This new technology has led to a better understanding of the players' responses to training and competition. [5, 6, 7].

Although there are still limitations that should not be overlooked [3], technical staff can now adjust player workloads more precisely according to game demands [8]. These aspects are essential in handball, since playing positions largely influence game demands [9]. As a result, coaches can design training content adapted to playing position and playing style, which should lead to better performance [5] and fewer injuries [10].

At present, despite greater access to technology, there are still few scientific contributions related to game demands in handball. Additionally, most of this research has been conducted with video tracking [11, 12] or hand notational analysis [13]. These technologies have been shown to be less adapted to recording explosive actions typical of handball than IMUs systems [8, 14]. In this indoor context, despite the proven accuracy [3] and reliability [15] of IMUs, more studies applied to official competitions in elite male handball players are needed. Previous studies have provided specific information, but only based on game-simulated situations in elite women [5, 16], training sessions in adolescent male players [14], or during 30 minutes outdoors [8].

The evolution of the total player load (TPL) was also analysed, reporting, for the first time ever, the external load indicator for each player in relation to actual playing time, i.e., providing information on the intensity level achieved per unit of time. These studies did not report any information about player displacement (e.g. distance covered at different speeds), which is of paramount information to coaches [5, 16]. It is worth noting that game demands are gender-dependent in elite handball [17], which makes these results useless for male elite players. To our knowledge, the physical demands in an elite men's handball team have never been described during a sports season.

Thus, the aim of this study was to characterise position-specific physical demands in elite handball players by measuring external load during a competitive season to provide a benchmark for coaches and the related training staff to optimise player preparation.

MATERIALS AND METHODS

Experimental approach to the problem

We conducted a cross-sectional, observational study to determine the differences between each playing position: wings (W), centre backs (CB), backs (B) and line players (LP). Results correspond to the average of 14 competitive official home matches disputed in the 2017–18 ASOBAL league (Spanish national premier league). We collected 188 records from the 16 players selected from the 14 games (61 from W, 18 from CB, 68 from B and 41 from LP).

Subjects

We analysed 16 professional elite male players from the same team throughout the season. The team comprised five W (26.6 ± 6.3 years; 183.1 ± 4.4 cm; 83.2 ± 4.1 kg), two CB (32.0 ± 7.1 years; 192.8 ± 1.0 cm; 93.8 ± 4.9 kg), six B (26.3 ± 4.8 years; 195.3 ± 2.8 cm; 97.8 ± 5.1 kg) and three LP (28.3 ± 4.0 years; 198.0 ± 8.4 cm; 101.5 ± 4.9 kg). The data came from daily monitoring of all the players in the team throughout the season both in training and in competition. Consequently, the approval of an ethics committee was not required [18].

Competitive match monitoring

The study was carried out using the WIMU PRO system (RealTrack Systems S.L., Almería, Spain). Each device, whose dimensions were 81x45x16 mm (height/width/depth) and which weighed 70 g, was fitted to the back of each player with adjustable bibs (Rasán, Valencia, Spain). All the players were used to this type of device and the way it is fastened, as they had trained with this system all season (3, 4).

Playing time was only recorded when the players were on court. The time spent between player rotation, timeouts (a maximum of three per match), periods when the game was interrupted and the disciplinary sanctions typical of handball where the players must leave the court for two minutes were omitted.

As 14 games were monitored, all the players included in the study participated in the game for an average of approximately 60 minutes per game. The team's game model used mainly a 6/0 defence (six players aligned near the 6-metre zone) and was conducive to a remarkably high game pace with many counterattacks.

Data processing

The positioning data record was monitored in real time and subsequently analysed using the SPRO software version 937 (SPRO, RealTrack Systems, 2018). The system operates by means of triangulations between four antennas with patented ultra-wideband technology (18 Hz sampling frequency) placed 5 m away from each one of the corners of the court and at a height of 6 metres. These units include several sensors that record at different sampling frequencies. The sampling frequency used for 3-axis, accelerometer, gyroscope, and magnetometer was 100 Hz and 120 kPa for the barometer [3, 4].

A previous validation study found a total bias in the mean velocity measurement between 1.18 and 1.32 km/h while the bias in distance was between 2.32 and 4.32 m (19) In addition, good inter-unit and intra-unit reliability was reported (intraclass correlation coefficients > 0.93) (19).

The effective playing time (PT, in min), distance covered (TD, in m), maximum speed achieved ($m \cdot s^{-1}$), average speed ($m \cdot s^{-1}$) and high-speed running (HSR, distance covered in metres above 5.0 $m \cdot s^{-1}$) [14, 20] were extracted from the raw data reported by the system using SPRO software. We retrieved the distance covered at different speeds: walking (0.0–1.7 $m \cdot s^{-1}$), jogging (1.8–3.3 $m \cdot s^{-1}$), slow running (3.4–5.0 $m \cdot s^{-1}$), running (5.1–5.8 $m \cdot s^{-1}$), high-intensity running (5.9–6.7 $m \cdot s^{-1}$) and sprint (> 6.7 $m \cdot s^{-1}$). The total number of accelerations, decelerations, high-intensity accelerations (HIA), high-intensity decelerations (HID) (in $m \cdot s^{-2}$) and HIA/HID per min ($m \cdot s^{-2} \cdot min^{-1}$) were recorded. HIA and HID were defined as events above 2 g [7, 8]. We calculated the TPL (total player load). The TPL is a vector magnitude expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each one of the three planes divided by 100 in absolute [7] or relative time – $TLP \cdot min^{-1}$ [16, 21].

Statistical analysis

Descriptive statistics are presented as means and standard deviations (SD). Differences between playing positions were analysed using Cohen's effect size (ES) statistics and ± 90% CL. The criterion for determining the size of the ES was: < 0.2 | 0.2 to 0.59 | 0.6 to 1.19 | 1.2 to 1.99 | ≥ 2.0, considering these values as trivial, small, moderate, large and very large, respectively [22]. The percentage likelihood of difference between groups was calculated and regarded

TABLE 1. Effect size and statistically significant differences between playing positions in IMU variables.

Variables	Wings (W)	ES	Rating	Center Backs (CB)	ES	Rating	Backs (B)	ES	Rating	Line players (LP)
TPL·min (AU·min^{-1})	1.1 ± 0.2			1.1 ± 0.2			1.1 ± 0.2			1.1 ± 0.2
		CB: 0.11	trivial		B: 0.20	trivial		LP: 0.08	trivial	
		B: 0.31	small		LP: 0.13	trivial				
		LP: 0.24	small							
MaxV (m·s^{-1})	6.4 ± 0.6 ^{b}			6.3 ± 0.6			5.9 ± 0.8			6.2 ± 0.8
		CB: 0.12	trivial		B: 0.52 *	small		LP: 0.36 *	small	
		B: 0.62 **	moderate		LP: 0.14	trivial				
		LP: 0.25	small							
HSR (m)	410.3 ± 193.2 ^{ab}			243.2 ± 130.2 ^{c}			161.7 ± 110.1			172.4 ± 96.0
		CB: 1.10 ***	moderate		B: 0.66 *	moderate		LP: 0.05	trivial	
		B: 1.65 ***	large		LP: 0.65 *	moderate				
		LP: 1.66 ***	large							
HSR · min^{-1} (m)	6.6 ± 2.3			3.7 ± 1.7			2.6 ± 1.6			3,2 ± 1.8
		CB: 1.64 ***	large		B: -0.50 *	small		LP: 0.20	trivial	
		B: -2.05 ***	very large		LP: -0.28	small				
		LP: -1.80 ***	large							
HSR (n)	39.6 ± 18.2			34.9 ± 18.1			23.4 ± 15.8			24.3 ± 11.2
		CB: 0.30	small		B: 0.64 *	moderate		LP: 0.04 *	trivial	
		B: 0.04 ***	moderate		LP: 0.69 *	moderate				
		LP: 1.02 ***	moderate							
HIA (m·s^{-2}) (n)	134.8 ± 60.7			148.7 ± 59.2			121.2 ± 53.9			112.0 ± 33.6
		CB: 0.23	small		B: 0.49 *	small		LP: 0.21 *	small	
		B: 0.24	small		LP: 0.76 *	moderate				
		LP: 0.46 *	small							
HID (m·s^{-2}) (n)	112.9 ± 56			142.7 ± 59.5			105.2 ± 49.2			99.6 ± 28.9
		CB: 0.51 *	small		B: 0.69 *	moderate		LP: 0.14	trivial	
		B: 0.15	trivial		LP: 0.91 **	moderate				
		LP: 0.30	small							
HIA·min (m·s^{-2}·min^{-1})	2.2 ± 0.8			2.3 ± 0.8			2.1 ± 0.8			2.0 ± 0.6
		CB: 0.06	trivial		B: 0.26	small		LP: -0.03	trivial	
		B: 0.24	trivial		LP: 0.32	small				
		LP: 0.46	small							
HID·min (m·s^{-2}·min^{-1})	1.8 ± 0.8			2.2 ± 0.8			1.8 ± 0.7			1.8 ± 0.5
		CB: 0.41 *	small		B: 0.50 *	small		LP: 0.05 *	trivial	
		B: 0.08	trivial		LP: 0.52 *	small				
		LP: 0.05*	trivial							

ES: effect size; substantial probability of difference between playing positions: * likely, ** very likely, and *** most likely. TPL: total player load; MaxV: maximum velocity; HSR: high-speed running; HIA: high-intensity acceleration; HID: high-intensity deceleration. Significant differences ($p < 0.001$): ^{a} line players; ^{b} backs; ^{c} wings.

as almost certainly not (< 0.5%), very unlikely (< 0.5%), unlikely (< 25%), possibly (25–75%), likely (> 75%), very likely (> 95%) or most likely (> 99.5%). A percentage likelihood of difference < 75% was regarded as a substantial magnitude. Threshold chances of 5% for substantial magnitudes were used, meaning that a likelihood of > 5% in both a positive and negative direction was considered unclear. We also calculated significant differences. The Kolmogorov-Smirnov test confirmed a non-normal distribution of all the variables analysed. The Kruskal-Wallis test was performed to compare the four playing positions, followed by the Wilcoxon signed-rank test with Holm adjustment to determine the differences between positions in pairs. In the statistical tests that required it, the significance level was $p < 0.05$. The statistical analysis was performed using the R Studio Software (v1.1.463 Studio, Boston, Massachusetts). The measurement errors of all the metrics we used are not available, so we could not include them in our statistical analysis.

RESULTS

The playing time did not present any significant difference between playing positions ($p = 0.06$), although CB (65.6 ± 12.6 min) played moderately more than LP (56.3 ± 12 min, ES = 0.75) and slightly more than B (59 ± 12.5 min, ES = 0.5) and W (60.8 ± 6.9 min, ES = 0.27). The total distances travelled were significantly different between playing positions ($p < 0.0001$). CB (4040 ± 1007 m) and W (3903 ± 1224 m) covered a moderately greater distance (ES = 1.06, $p < 0.001$ and ES = 0.77, $p < 0.0001$, respectively) than B (3571 ± 864 m) and LP (3149 ± 630 m) during a game. The distance travelled per minute was significantly different between playing positions ($p < 0.0001$). W (64.5 ± 10.4 $m \cdot min^{-1}$), CB (62.3 ± 11.6 $m \cdot min^{-1}$) and B (61.8 ± 7.8 $m \cdot min^{-1}$) travelled moderately faster on average than LP (56.5 ± 6.6 $m \cdot min^{-1}$, ES = 0.91, 0.62 and 0.74 respectively).

TPL was significantly different between playing positions ($p < 0.05$). CB (71.2 ± 12.6 UA) bore moderately more TPL than LP (59.5 ± 12 UA, ES = 0.7), slightly more than B (62.3 ± 17.7 UA, ES = 0.5), although W had a similar load (68.1 ± 23.1 UA, ES = 0.15). The total number of accelerations and decelerations performed during a game were equivalent for W, CB and B (acceleration: 1167.5 ± 337, 1166.9 ± 203.9, 1125.9 ± 271.6, respectively, ES = 0.01 to 0.15; deceleration: 1164.4 ± 336.2, 1161.4 ± 203.9, 1120.7 ± 271.1, respectively, ES = 0.01 to 0.18). LP differ only slightly from CB in this aspect (acceleration: 1102.5 ± 264.1, ES = 0.22: deceleration: 1106.15 ± 263.4, ES = 0.21). The analysis of the total number of accelerations and decelerations did not present any significant ($p = 0.82$ and $p = 0.79$, respectively) or substantial differences.

Table 1 presents the external load variable and Figure 1 the distance travelled at different speeds.

DISCUSSION

To our knowledge, this is the first time that an elite men's handball team has been monitored by IMUs during 14 official matches from a top-level national regular league. The main findings are that CB and W differ substantially from B and LP. The external load differences

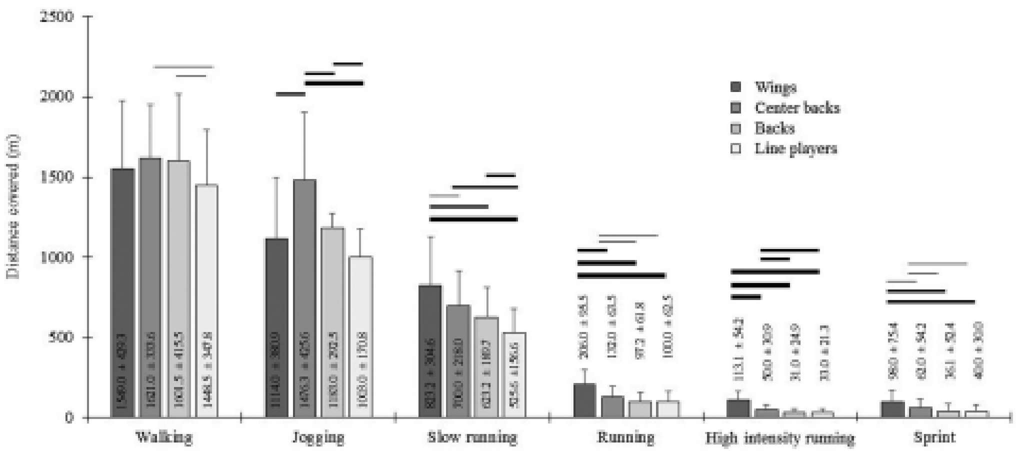

FIG. 1. Distance covered at different speeds according to each playing position.
Speed criteria: walking (0–1.7 $m \cdot s^{-1}$), jogging (1.8–3.3 $m \cdot s^{-1}$), slow running (3.4–5.0 $m \cdot s^{-1}$), running (5.1–5.8 $m \cdot s^{-1}$), high-intensity running (5.9–6.7 $m \cdot s^{-1}$), sprint (> 6.7 $m \cdot s^{-1}$). The thickness of the lines represents the magnitude of the difference (effect size) ━ stands for a large, — for a moderate and — for a small difference. Only effect sizes with a substantial probability of difference (> 75%) are shown.

between CB and B are as high as can be justified by a dedicated analysis.

Total distance, playing time and TPL

CB played more and travelled the greatest distance, followed by W, and LP had the lowest external physical load. Despite some controversies in the calculation and meanings of TPL, this metric is one of the most used variables to control external load during competition and training in team sports [6, 7, 15]. CB bore the highest TPL, followed by W, B and LP. To our knowledge, no study has been conducted with this metric.

One might think that time spent in the field (i.e. more opportunities to produce external load) should affect the TPL expressed by unit of time (minutes). Surprisingly, this metric was practically identical for all playing positions (≈ 1.1 ± 0.2 $AU \cdot min^{-1}$). This is a reminder of the complexity of the TPL formula, mainly based on acceleration, and therefore not simply dependent on effective playing time or distance covered [5, 15, 21]. Furthermore, it is difficult to compare the results of this paper with those from other handball studies, on account of different age [23], population type: level [5] and gender [6, 15] and game type: non-competitive games [8] and competitive games [6, 16, 21]. These results question the usefulness of this variable in assessing external load in handball.

Most of the works in the literature have merged CB and B [11, 20]. To our knowledge, only Cardinale et al. [12] and Barbero et al. [8] have studied CB separately, albeit with a different tracking technology or in non-ecological conditions. Our results confirm that the external loads borne by the CB are the highest and therefore call for a specific approach. The results obtained by the other players are consistent with previous studies conducted by video recording [9, 20].

Running pace, distance and running speed

Many authors have measured the distance travelled per minute in their work, although the different methodologies used to measure playing time (taking or not taking player rotations into account, team time out and actual playing time) have rendered this number virtually impossible to compare [8, 9].

Distance covered at different speeds is noteworthy since it is directly related to the game model. The technical staff can therefore use this indicator to design training content, particularly at the metabolic level. All players, regardless of position, covered between 70% and 78% of the total distance at a running pace of less than 3.3 $m \cdot s^{-1}$ (walking and/or jogging) and between 17% and 21% at between 3.3 and 5 $m \cdot s^{-1}$. W covered a significantly greater distance above 5 $m \cdot s^{-1}$ compared to the other players. These results are consistent with those of previous studies [13, 24], although it should be borne in mind that hand notational technologies were used.

Sprint and high-speed running

Playing elite handball calls for a substantial volume of high-speed running [8]. As stated before, IMU could have validity and reliability concerns when measuring high-speed running (25); therefore our results and conclusions could not be definitive. However, these variables are extremely important for training and the prevention of injury. Previous studies [8] conducted with GPS during 30-minute outdoor training games reported higher sprinting speeds for W (6.9 ± 0.3 $m \cdot s^{-1}$ vs. 6.4 ± 0.6 $m \cdot s^{-1}$), and similar results for CB (6.1 ± 0.3 vs. 6.3 ± 0.6 $m \cdot s^{-1}$) and B (6.1 ± 0.3 vs. 5.9 ± 0.8 $m \cdot s^{-1}$). LP reached a higher sprinting speed in our study (6.2 ± 0.8 vs. 5.5 ± 0.4 $m \cdot s^{-1}$), which is even higher than B. Many factors could explain these differences, such as the team's game model, the individual characteristics of each player, fatigue (our data were collected during whole games) and a higher number of games (i.e., 14). On comparing the value of maximal sprinting speed expressed during games to sprint testing (e.g. 30-m straight-line sprinting) some substantial differences emerge. In our study, the mean maximal sprinting performed by W was about 17% (1.8 vs. 2.1 $m \cdot s^{-1}$) lower than that which was obtained by players from the same level in a 30-m sprint [25]. This difference highlights the fact that it is highly likely that handball players do not frequently reach their maximal velocity during games. Coaches should consider this aspect.

W presented the greatest high-speed load, as they covered the greatest HSR distance each minute and performed the highest number of HSR. CB completed the highest number of HSR but with a low HSR value covered each minute (3.7 ± 1.7 $HSR \cdot min^{-1}$). This paradox could be related to the technical and tactical demands of this playing position. CB are a in a central position in which they perform many short, high-intensity runs towards the goal.

It is also useful to know how many metres players travel in HSR during a match. These values are especially important for coaches to manage HSR volume during a training session or a microcycle. Previous research conducted by means of video analysis yielded similar results to our study, in which W covered the greatest distance at speeds above 5 $m \cdot s^{-1}$ [12, 20]. It is worth noting that the distance covered above 5.8 $m \cdot s^{-1}$ fluctuates greatly. The CV ranged from 46% for the high-intensity runs to 145% (for running, high-intensity running and sprinting). These variations reflect the unpredictable character of game demands in team sports [7] and/or the limits of the device in high speed running measurement. Before drawing any definitive conclusion regarding high speed running and sprinting, we need to be more confident about the validity and the reliability of the device.

Acceleration and deceleration

Players' ability to accelerate and decelerate is particularly important in meeting tactical and technical demands in handball. This is evident in the numerous changes of direction that take place during a match [9]. Our results indicate that all players perform a similar amount of accelerations and decelerations. CB performed the highest number of HIA (148.7 ± 59.2 $n \cdot s^{-2}$) and HID (142.7 ± 59.5 $n \cdot s^{-2}$). This should also be related to the technical and tactical demands of the playing position and the HSR per minute. When these values were standardised by playing time ($m \cdot s^{-1} \cdot min^{-1}$), the results were similar (Table 1). These results coincide with those obtained in previous studies conducted by means of video recording [27], albeit not with others [8]. However, the comparison of both studies is once again difficult, either because they involved women or because they were based on GPS monitoring during outdoor training games, respectively. Decelerations lead to a significant eccentric demand on players, which could induce many negative effects (e.g., muscle damage) and injuries [28]. Thus, the technical staff should monitor this aspect. Even if the threshold is lower in our study (2 vs. 2.5 g), handball induces one of the highest deceleration loads for players in team sports [28].

Methodological considerations

In most studies, CB were included with the lateral backs (i.e., right and left) in the backs category [13]. This aspect is important, because this clustering potentially conceals some especially important information for the technical staff. Probably, physical demands on the court decrease for CB and increase for LB, so that it is difficult for the coach to adjust them. To our knowledge, only two studies have made a distinction between these players [8, 12].

Another important consideration is that neither video-based nor IMU analysis could measure the external load in handball extensively. The actions performed on the training field did not always produce a movement or an acceleration. For example, to block their opponent, LP use a high level of isometric strength and need to maneuverer vigorously with their arms to gain an advantageous position. IMUs could register some movement (e.g. acceleration) in these situations but their intensities are far from the level of isometric force required in this type of action. These activities produce a high cardiac output [24] but are not clearly observable with IMUs or video tracking.

While this study provides an analysis of the external load of male elite handball teams, it is limited to certain global metrics and does not provide a further insight into handball-specific movements such as sideways and backward displacements and jumps. Hence more work is necessary to elucidate these aspects further.

Limitations

A team can use different defensive systems (different spatial and functional organisation, e.g. 6/0, 5/1) depending on the coach's choice. These options rely on many factors (e.g., the opponents, coach philosophy and team characteristics). Each team chooses its own defensive system but also must contend with the opponent's. These tactical options are likely to have many consequences in terms of physical demands, although we are not aware of any study that confirms this hypothesis. The data presented in this investigation are based only on home games (with a predominantly 6/0 defensive system and an offensive game based on counterattack and speed) which can also affect game demands [29]. Since we monitored the same team over 14 games, it should be noted that many variables could have influenced outcomes, such as the level of the opponents [30] and game plan [31]. Another issue is that player rotation is unlimited in handball, and most teams use offensive and defensive specialists with systematic changes. These constant rotations pose numerous difficulties in analysing game demands.

Practical applications

Our results could provide external load reference values for other male elite handball teams. CB and W present a similar level of external load. This is important in designing appropriate training content, particularly for high-speed running. These findings have certain direct implications for injury prevention. Technical staff should apply the same amount of speed training for CB and W. LP and B bear the smallest external load in our study, but it should be remembered that IMUs could not accurately measure LP performance. As a result, the needs of these two playing positions should be different. It is important to adapt training load and training content to each playing position and coaches should establish at least three different groups: 1) CB and W, 2) B, 3) LP.

CONCLUSIONS

The analysis of all the variables monitored with an IMU system suggests that both CB and W positions have the highest external load, while by contrast B and especially LP have the lowest load. W and CB perform a substantially greater number of sprints and high-speed running than the other players. Some methodological and technological issues limit the analysis of handball-specific movements (e.g., jumps and sideways and backward movements) and research that overcomes these difficulties is called for. Coaches and practitioners will also need to understand how contextual factors (e.g., level of the opponent, game location, score and game plan) affect physical game demands. This knowledge could lead to better training load management and the design of specific training content.

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Disclosure statement

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The effects of COVID-19 lockdown on jumping performance and aerobic capacity in elite handball players

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ABSTRACT: The aim of this research was to analyse the capacity of a home-based training programme to preserve aerobic capacity and jumping performance in top-level handball players during the COVID-19 lockdown. Eleven top-level male handball players from the same team participated in the study. A submaximal shuttle run test and a counter-movement jump test were used to measure the players' aerobic fitness and lower limb explosive strength, respectively. A 9-week home-based training programme was followed during lockdown. Pre-test measurements were assessed before the pandemic on 29 January 2020 and ended on 18 May 2020. Moderate significant mean heart rate increases were found in the late stages of the submaximal shuttle run test after the lockdown (stage 5, 8.6%, $P = 0.015$; ES = 0.873; stage 6, 7.7%, $P = 0.020$; ES = 0.886; stage 7, 6.4%, $P = 0.019$; ES = 0.827). Moderate significant blood lactate increases were observed immediately after the submaximal shuttle run test following the lockdown (30.1%, $P = 0.016$; ES = 0.670). In contrast, no changes were found in jump performance. A structured home-based training programme during the COVID-19 lockdown preserved lower limb explosive strength but was an insufficient stimulus to maintain aerobic capacity in top-level handball players.

Key words:
Elite team sports
Detraining
Heart rate
Lactate
Pandemic
Jumping

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INTRODUCTION

The first cases of coronavirus disease 2019 (COVID-19, caused by SARS-CoV-2) were detected in Wuhan, China, at the end of 2019 [1]. Subsequently, due to the effects of the virus and its easy spread, different countries opted to quarantine and isolate their citizens, confining them to their homes. In Spain, a state of alarm was declared on 15 March, which affected the entire population [2]. At the sporting level, all territorial, national and international competitions were suspended. In handball, the last matches were played on 7 and 8 March 2020 and all players had to stay at home at least until 4 May 2020 [3]. The different competitions did not resume again until August 2020 and only for elite teams (national and European competitions).

The importance in handball of certain levels of strength, speed and aerobic endurance to withstand training and competition is well known [4, 5, 6, 7]. It is also true that high intensity work is increasingly important due to the increase in the number of possessions in the game and the pace of play [5].

During this entire period of home confinement, the players had to work in their respective homes to avoid partially or totally losing previously acquired morphological and physiological adaptations through detraining or a decrease in training [8, 9, 10, 11, 12]. The difficulties of finding optimal spaces to train or having adequate training material and the uncertainty as to when competitions would resume generated frustration and demotivation in many athletes during this period [13]. Individualized work routines were planned to reduce this training handicap as much as possible, and to counter lack of motivation, poor nutrition and resting issues that may affect the athletes' ability to maintain proper habits and routines [10, 14, 15, 16]. In many cases material was provided to the players and group sessions were held by videoconference [10, 17].

Most of the current research on detraining is characterized by much shorter periods of time than that of this pandemic [11, 12]. However, there is a lack of information regarding the capacity of home training programmes to preserve general fitness levels (lower limb explosive strength and aerobic capacity) in top handball players during the COVID-19 lockdown. To the best of our knowledge, only one previous study [14] has investigated the effects of a given training programme in the aerobic capacity of elite handball players. Such studies might provide valuable insights about the real impact of home training programmes to prevent detrimental effects on the general fitness of elite handball players.

Accordingly, the aim of this research was to analyse the effectiveness of a home training programme to preserve aerobic capacity and lower limb explosive strength in top-level handball players during the COVID-19 lockdown.

MATERIALS AND METHODS

Design

A retrospective design was used to compare the change in submaximal shuttle run test and jump test performance. A 9-week home-based training programme was followed during lockdown. Pre-test measurements were assessed before the pandemic on 29 January 2020 and ended on 18 May 2020. The tests were conducted on the same day, first performing the submaximal shuttle run test in two groups of five and six players, respectively, and then the counter-movement jump (CMJ) test. The submaximal shuttle run and the CMJ tests were used to measure the players' aerobic fitness and lower limb explosive strength (both bilateral and unilateral), respectively.

Subjects

The study was conducted on 11 top-level male professional handball players from the same team throughout the same season. These were all international players with their respective national teams during the season in which they participated in this study. The players were three wings (26.3 ± 3.7 years; 185.3 ± 4.7 cm; 83.2 ± 6.5 kg), four backs (29.5 ± 7.0 years; 193.3 ± 5.1 cm; 98.3 ± 7.4 kg), three line players (27.9 ± 6.4 years; 195.0 ± 3.0 cm; 105.3 ± 9.2 kg) and one goalkeeper (27.9 ± 0 years; 190.0 ± 0 cm; 84.0 ± 0 kg). The data were obtained from the periodic monitoring of the players during training sessions. All players signed a contractual clause accepting their participation in research projects; therefore approval by an ethics committee was not required [18]. However, all players were informed about the purpose of the study, the known risks and possible associated hazards. The research was in accordance with the Declaration of Helsinki, and professional players gave informed consent prior to participation through their contracts.

Submaximal shuttle run test

To assess the aerobic capacity of the players, the multistage 20-metre shuttle run test [19] was performed up to stage number 8. The test consisted of running continuously between two lines placed 20 m apart at running speeds increased by appropriate intervals at a pre-recorded beep. Mean velocity started at 8.5 $km \cdot h^{-1}$ for the first minute (stage 1), increasing by 0.5 $km \cdot h^{-1}$ every minute up to 12 $km \cdot h^{-1}$ (stage 8).

During the test, heart rate (HR) was registered using a Garmin HR strap. The HR monitor was linked to the WIMU PRO system (Realtrack Systems, S.L., Almeria, Spain) and data were analysed thereafter using mean HR values for each submaximal shuttle run test stage.

One minute after the end of the test, players were pricked in the earlobe to analyse blood lactate levels [20, 21, 22]. The analysis was performed with a Lactate Scout + lactate analyser and Lactate Scout test strips (Nova Biomedical, Waltham, MA, USA).

Jump

The CMJ test was used to assess vertical jump performance as an indicator of lower limb explosive strength [23]. Players performed a fast flexion movement of the knee joint followed by a maximum-effort vertical jump, maintaining the hands-on-hips position until the final phase of the jump. A contact platform (Chronojump Boscosystem, Barcelona, Spain) was used to assess CMJ height. The hardware was connected to a computer which displayed the vertical jump height (cm) using free software (2.0.2., Chronojump Boscosystem Software, Barcelona, Spain). This type of technology has proven its reliability and validity in other types of research with vertical jump tests [24]. Players performed two bilateral CMJs and two unilateral CMJs with each leg. The best result of each test (height, cm) was recorded and used for further analysis.

Home training programme during COVID-19 lockdown

Each week during confinement, players received a structured training programme to follow at home. Basically, the home-based training programme consisted of five training days, from Monday to Friday, with a break over the weekend. During the first eight weeks, three strength training sessions were performed per week (on Mondays, Wednesdays, and Fridays) and two endurance-oriented sessions (on Tuesdays and Thursdays). During the last week (week 9), two strength training sessions and five endurance sessions (three outdoor running sessions and two stationary bike sessions at home) were performed. There was around a 40% reduction in workload volume between what the players actually did at home during the COVID-19 lockdown and what they would have performed under normal training and competition.

During confinement, players performed an average of 27 strength training sessions, including both individual sessions and online group sessions. All sessions conducted at home followed the medical recommendations derived from the COVID-19 pandemic [9, 25]. All sessions were preceded by a general warm up consisting of ~10 min of low intensity cycling (stationary bike), mobility and lumbo-pelvic stability exercises. In the first four weeks, strength training was endurance-oriented and over the last four weeks strength training was hypertrophy-oriented [26]. Individual hypertrophy-oriented training programmes were organized in super-sets in which a combination of low specificity level exercises (i.e., bilateral squat-based exercises) preceded slightly more specific exercises (more dynamic correspondence with

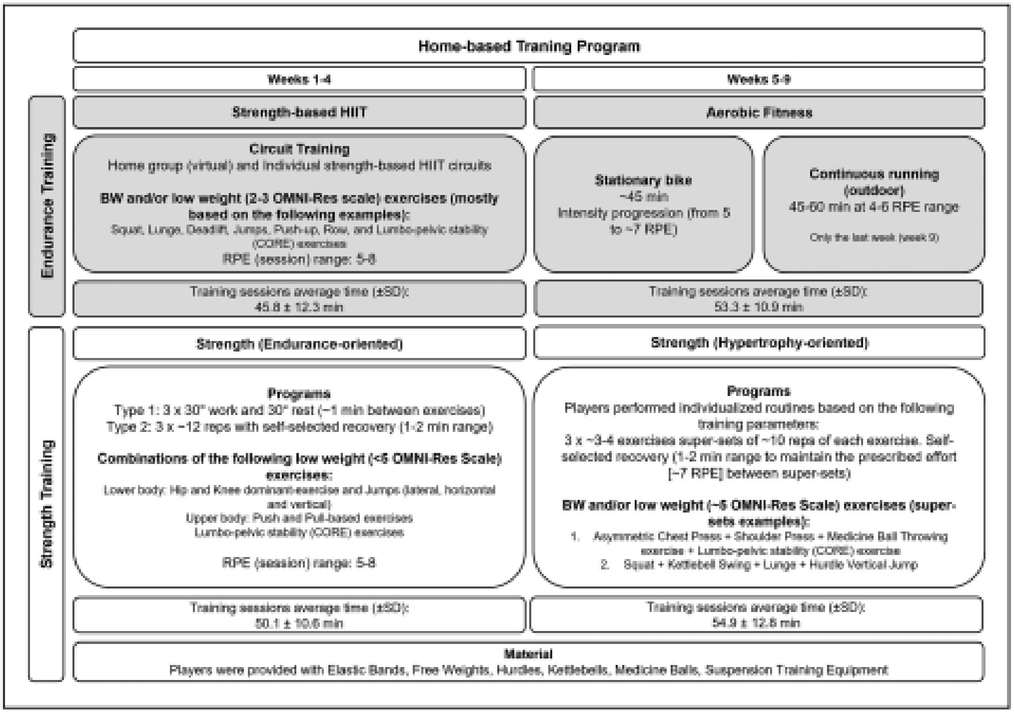

FIG. 1. Home training programme overview. BW, body weight; HIIT, high-intensity interval training; OMNI-Res Scale, Perceived Exertion Scale for Resistance Exercise; RPE, rating of perceived exertion.

handball-specific movements, i.e., vertical jump exercises) [26]. Regarding endurance training, players performed an average of 19 sessions. In the first four weeks, players performed individual strength-based high-intensity interval training (HIIT) circuits, and from the fifth week onwards they were prescribed general aerobic fitness training sessions based on continuous and progressive exercises. Both subjective ratings of perceived exertion (RPE) [27, 28] and the OMNI Perceived Exertion Scale (OMNI-Res Scale) for Resistance Exercise [29] were used to prescribe intensity during training sessions. See Figure 1 for a complete overview of the basic characteristics of the home-based training programme.

Statistics

Data were tested for approximation to a normal distribution using the Shapiro–Wilk test. A paired Student's t-test was used to evaluate differences in variables of interest (body mass, mean heart rate, capillary blood lactate concentration, CMJ height) from pre- and post-lockdown periods. Cohen's d was used to calculate the effect size (ES). Thresholds for ES statistics were trivial (ES < 0.20); small (0.20 < ES < 0.59); moderate (0.60 < ES < 1.19); large (1.20 < ES < 1.99); and very large (ES > 2.0) [30]. All data were reported as mean ± standard deviation and the level of significance was set at $P < 0.05$. All statistical analyses were conducted using SPSS version 23.0 (SPSS Statistics, IBM Corp., Armonk, NY, USA).

RESULTS

No significant differences (ES = -0.036, trivial) were found in body mass following the home training programme (Pre-lockdown: 99.0 ± 12.4 kg and Post-lockdown: 98.6 ± 12.7 kg).

Submaximal shuttle run test

Moderate, non-significant mean HR increases were observed in the early stages of the submaximal shuttle run test (aerobic capacity) (from stage 1, 108 ± 15 and 117 ± 11 bpm; stage 2, 127 ± 11 and 141 ± 21 bpm; stage 3, 133 ± 12 and 147 ± 20 bpm; stage 4, 140 ± 12 and 153 ± 19 bpm of HR mean values from before and after the home training programme, respectively) and moderate, significant changes were observed in later stages (from stage 5,

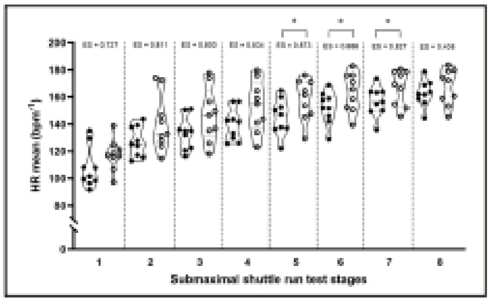

FIG. 2. Mean heart rate values from each multistage 20-metre shuttle run test. Black circles, pre-lockdown; White circles, post-lockdown. ES, Cohen's d effect size. *Significantly different at $P < 0.05$.

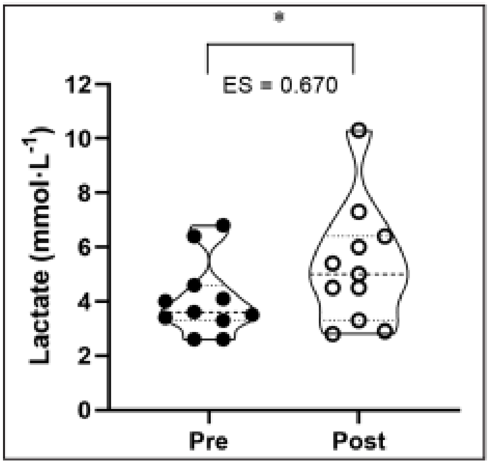

FIG. 3. Capillary blood lactate concentration. Black circles, pre-lockdown (Pre); White circles, post-lockdown (Post). ES, Cohen's d effect size. *Significantly different at $P < 0.05$.

145 ± 13 and 158 ± 15 bpm [$P = 0.015$]; stage 6, 152 ± 12 and 164 ± 14 bpm [$P = 0.020$]; stage 7, 157 ± 11 and 167 ± 13 bpm [$P = 0.019$] of HR mean values from before and after the home training programme, respectively) (see Figure 2). Finally, only small, non-significant increases were found in the last stage (stage 8, 163 ± 10 and 168 ± 13 bpm of HR mean values from before and after the home training programme, respectively). The results from this test were derived from 9 players due to HR band registration problems with 2 of the players from the sample.

Regarding lactate, moderate, significant increases (4.1 ± 1.4 and 5.3 ± 2.2 [$P = 0.016$] mmol/L mean values from before and after the home training programme, respectively) were found (see Figure 3).

Jump test

No changes were found in jump performance (41.8 ± 8.3 and 41.0 ± 7.0 cm of bilateral CMJ, 20.9 ± 7.3 and 22.3 ± 4.7 cm of unilateral CMJ [right], and 21.7 ± 4.4 and 22.4 ± 3.2 cm of unilateral CMJ [left] height from before and after the home training programme, respectively) (see Figure 4).

DISCUSSION

The aim of this research was to analyse the ability of a home training programme to preserve aerobic capacity and jumping performance in top-level handball players during the COVID-19 lockdown. The home training programmes followed by the players maintained lower limb explosive strength, measured as CMJ performance (jump height), but appeared to be insufficient to maintain aerobic capacity.

Aerobic capacity

Moderate, significant HR increases were observed in the last stages of the submaximal shuttle run test after the COVID-19 lockdown (see Figure 2). This might be indicative of a loss of aerobic capacity [31, 32]. It has been well established that detraining, due to training suppression or inadequate training, induces maximum HR increases (between 5% and 10%) [11]. Although this was not exactly the case during the lockdown scenario, the home training programmes probably failed to provide a sufficient stimulus to maintain aerobic capacity in elite handball players. This was also previously described by Fikenzer et al. [14], who found that endurance capacity, measured by the maximum mean velocity achieved in a multistage 20-metre shuttle run test, was diminished in most elite handball players from a given team due to the unspecific and inadequate stimuli provided by a home-based training programme during the COVID-19 lockdown. Dauty et al. [32] obtained similar results with the yo-yo test in young football players. The dependence on volume of endurance training responses [33] would explain the incapacity of home training programmes to maintain aerobic capacity in highly trained top handball players. In fact, the home training volumes were approximately 40% lower than those achieved during the regular season immediately before the lockdown. Moreover, our players only received running-specific stimuli during the last two weeks of the lockdown (see Figure 1), reinforcing the notion that the lack of training specificity also contributed, to some extent, to the loss of aerobic capacity [14, 32].

The moderate, significant increases in lactate after the COVID-19 lockdown were also indicative of a decrease in the players' aerobic capacity (see Figure 3) [11, 34]. Specifically, lactate increases are indicative of a reduction in the oxidative capacity of the

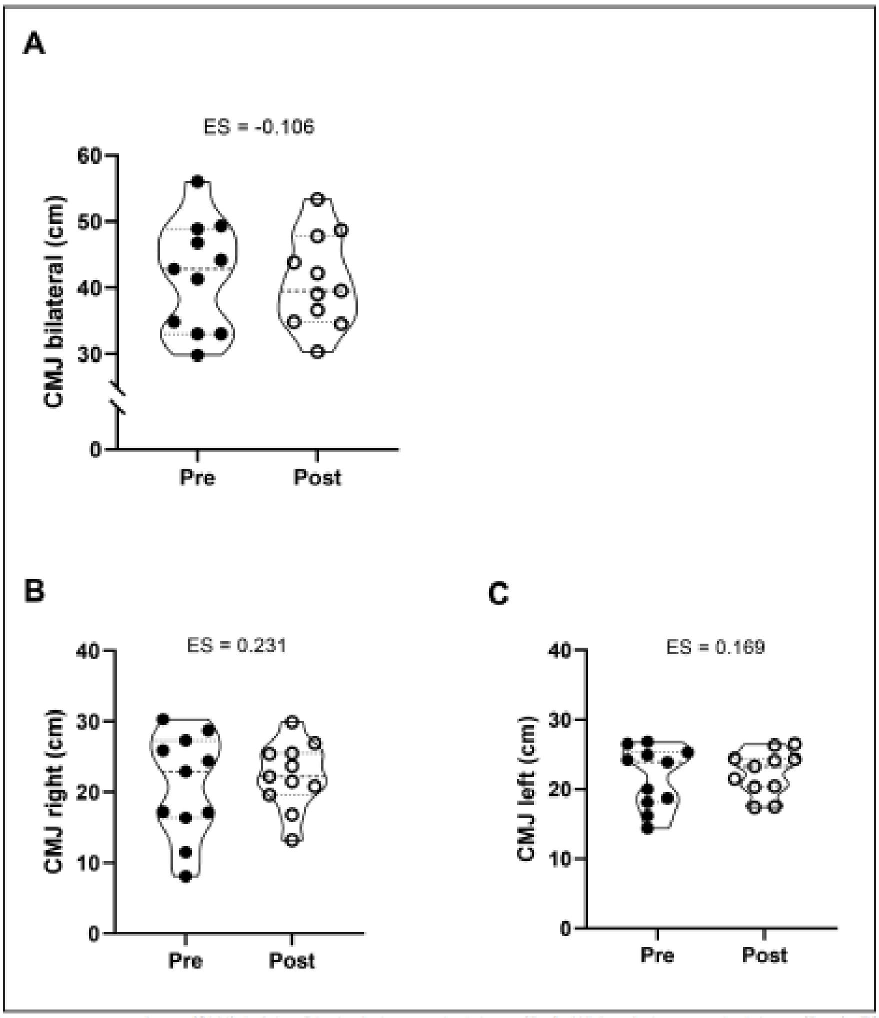

FIG. 4. Counter movement jump (CMJ) height. Black circles, pre-lockdown (Pre); White circles, post-lockdown (Post). ES, Cohen's d effect size.

muscle [11] and present a high correlation with endurance capacity in trained populations [35]. Together with HR values, these results confirmed that home-based endurance training was insufficient to maintain aerobic fitness in top-level handball players. However, it must be considered that since only moderate (ES) changes in aerobic fitness indicators (HR and lactate) were found after the lockdown, it seems reasonable to expect a rapid recovery of pre-lockdown values when players returned to on-court sport-contextualized training regimes.

Lower limb explosive strength

Regarding CMJ performance as an indicator of lower limb explosive strength [23], no changes were found between the two test periods (see Figure 4), showing that the training stimuli provided by the strength home-based training programme (Figure 1) were adequate to preserve jump capacity. Despite certain signs of detraining in neuromuscular-related qualities and peak power output, similar results have been previously reported in the literature about home training programmes' capacity to preserve jump performance (height) in professional football players [36, 37] and futsal players [38]. Specifically, Rampinini et al. [37] analysed fifty professional football players and found that 2–3 bodyweight or small weight strength training sessions per week at home during the COVID-19 lockdown preserved CMJ height despite a moderate (ES) loss in peak power output. Those authors [37] also obtained similar results following the transition period, where similar bodyweight training strategies were implemented. In this regard, it has also been observed in national level handball players that a 7-week interruption of the external weight-based strength training, where players only performed sport-specific training and bodyweight exercises, was enough to maintain jump performance (height) [39]. Therefore, and although a certain degree of loss in jump-related neuromuscular qualities might be expected, home-based lower limb strength training programmes, despite the differences in training contents and strategies (including equipment), seem to be capable of maintaining jump performance measured as CMJ height.

Limitations

An important limitation of this study was the impossibility of assessing the whole team after the lockdown because many players were in their respective home countries. Despite this limitation, 11 top-level handball players were analysed, all of whom were international players with their respective national teams. Finally, since the findings of this study come from 11 high-level handball players from a single team, caution is advised when generalising from these results, as different home training strategies in different team sport athletes might induce different adaptations.

Practical applications

A structured home-based training programme based on body weight and low weight exercises provides a sufficient stimulus to maintain jump performance (jumping height), an indicator of lower limb explosive strength, in top-level handball players. In contrast, the home-based training programme described did not succeed in preserving aerobic fitness in the cohort under study. Earlier implementation of aerobic fitness training strategies might have helped in the preservation of players' endurance capacity. However, since the loss in aerobic fitness indicators was moderate (ES), a rapid recovery of pre-lockdown values may be expected when players return to on-court sport-contextualized training regimes. Overall, the results of this study support existing general recommendations on the training approach during COVID-19 lockdown periods [40].

CONCLUSIONS

In conclusion, a structured home-based training programme during the COVID-19 lockdown preserved lower limb explosive strength but was an insufficient stimulus to maintain endurance capacity in top-level handball players.

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Disclosure statement

The authors declare no potential conflicts of interest.

Conflict of interest declaration

The authors declare no potential conflict of interest.

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Article

Analysis of the Variables Influencing Success in Elite Handball with Polar Coordinates

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Abstract: In today's elite handball, coaching staff seek to know as much as possible about all the details of their sport to gain an advantage by adapting their model of play or by looking for the opponent's weak points. Therefore, the aim of this study was to analyse which variables can influence success in each phase of the match with polar coordinates. Observational methodology was used to analyse success or failure within the nature of handball by means of an ad hoc observation instrument designed and validated for this research. A total of 14 elite men's handball matches from the 2019–2020 season were analysed. The relationships between success and failure of all behaviours were performed with polar coordinates. The results show that one of the keys to achieving victory in matches is centred on a high level of success in the defensive phase that allows the team to recover the ball and to be able to go on the counterattack to obtain a clear option for a goal. This research allows us to see how we can achieve success in the different phases of the game and improve team performance with these indicators. These results suggest that it is necessary for teams to train at a high pace of play, linking the different phases of the game in order to recover the ball in the defensive phase and attack in the shortest possible time against an unstructured defence to achieve success in the match and the final victory.

Keywords: team sports; observational methodology; competition; performance indicators; key behaviour

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1. Introduction

There is a lot of research that has shown that knowing what the players need to endure on a conditional level in handball is key to improving performance [1–3] and, in turn, preventing injuries [4].

In handball, these needs have also been described either through the video tracking [5], hand notational analysis [6,7] or more modern technologies such as inertial measurement unit technology (IMU's) [1].

However, in order to improve team performance, it is also essential to know which tactical actions are more effective or less effective depending on the model of play developed by the team in the different phases of the game. There is a large body of research that has analysed what happens during handball matches. Which offensive systems are used [8], the differences in counterattack between seniors and young players same time, the effectiveness of the attack against certain defensive systems have been observed [9,10]. Research has also been carried out on the effectiveness of attack at critical moments in the game types of last action happen [11].

At the defensive level, the effectiveness of the goalkeeper has been investigated [12] assessing the interaction with teammates or the attacker/defender ratio [13], the relevance of defensive actions in the functioning of the team has been analysed [14,15] or the effect of fouls within the defensive phase and analysed their effectiveness [16].

Other research has focused on looking at offensive and defensive coefficients in different phases of the game [15], determining performance indicators to predict a match win [17], analysing the game according to the state of the score [15,18,19], assessing the influence of symmetry/asymmetry on the number of players on the game [20,21], and finding indicators of success or failure in the different phases of the game [17]. Success or failure has always been understood as being linked in the offensive phases to scoring goals and not interrupting the rhythm of the game, and in the defensive phases, the opposite: not conceding a goal, recovering the ball and cutting the rhythm of the attacking play [8].

All this research has been based on observational methodology, a technique widely used and validated in the world of sport for this type of analysis [22]. This methodology is developed in the usual context of sport. It is an ecological technique [23] that does not change the usual behaviour of players and unites science and practical application [24]. The aim is to analyse perceptible behaviours in order to be able to record, in an organised way, what happens through an instrument containing the appropriate parameters created ad hoc [25]. The different tools created by these investigations have analysed criteria in defence, attack, and counterattack; the sequence, the score, and the numerical situation of the players; and the area where the action takes place, or, the final result of the action, be it offensive or defensive [8,9,17,23,25,26].

Within the observational methodology, a technique widely used in the field of sport is the analysis of polar coordinates [27]. This technique was created by Sackett [28] and subsequently improved with the "genuine technique" of Anguera [29]. Its great usefulness is that it allows a significant reduction in the volume of data and a vector representation of the relationships established between the focal and conditional categories [30]. This technique offers us the possibility of estimating the type of relationships established between the focal behaviour or criterion and the rest of those that make up the taxonomic system [31]. The coordinate axis is divided into four quadrants. Depending on the quadrant where the categories are located, there will be a relationship with respect to the focal behaviour of activation or inhibition to the extent that this relationship exists [31].

This technique has been used in handball for the following applications: observing the effectiveness in the attacking phase [8] and in close matches [23], learning how different defensive systems are attacked [9], identifying differences in counterattack between seniors and young players [26], and observing the numerical ratio of players in attack and its tactical modification [32].

The aim of this study is to identify which variables influence success or failure in the different phases of the game in an elite handball team with polar coordinates. For this reason, the multiple variables that intervene in the game and in each phase have been evaluated, considering the game model of the team analysed and how the other teams play. Knowing how we can achieve success in the different phases of the game and which variables determine performance should help the different technical staff to increase the work on these variables in training to obtain certain advantages over the rival team in order to win the game and improve performance.

2. Materials and Methods

2.1. Design

An observational methodology was used because it is adapted to the reality of sport, capturing the nature of sport with an ad hoc instrument and being able to obtain a systematic analysis [22,23]. It is a methodology widely used in sport analysis [20,24,27].

The design used was defined as nomothetic, punctual, and multidimensional, and placed in the IV quadrant of observational designs [33]. It is nomothetic, due to the analysis of the plurality of the observed teams facing each other; punctual, as we analyse different matches of the same team together in a season; and multidimensional, as there are different dimensions that correspond to the different criteria of the observational instrument. All the phases that make up a handball match were analysed: attack, counterattack, transition defence, and defence.

2.2. Sample

We analysed 14 FC Barcelona handball matches during the 2019–2020 season between the Spanish League and the European Champions League played at home (Table 1). We analysed FC Barcelona and the behaviour of their opponents when they played against them. In the 14 matches, the play of a total of 23 FC Barcelona players was analysed. These players played the entire season without an injury period in any of them that prevented them from being fit to play in 80% of the matches. It should be noted that the team played 39 games during the season, winning 38 and losing only 1, being a clear winning team. The videos used were publicly accessible, so according to the Belmont Report (https://student.societyforscience.org/human-participants, accessed on 19 Novembre 2022), it is not necessary to obtain the informed consent of the players [24]. Home matches were chosen because they were easier to obtain and of better quality than away matches as they were obtained directly from the TV production team.

Table 1. FC Barcelona matches played, competition and goal difference.

Game	Competition	Goal Difference
Anaitasuna	Spanish League	+17
Huesca	Spanish League	+23
Granollers	Spanish League	+14
Sagunto	Spanish League	+21
Cangas	Spanish League	+21
Sinfin	Spanish League	+24
Valladolid	Spanish League	+15
Celje	European Champions League	+24
Elverum	European Champions League	+9
Paris	European Champions League	+4
Aalborg	European Champions League	+9
Flensburg	European Champions League	+4
Zagreb	European Champions League	+9
Szeged	European Champions League	+2

The Belmont Report describes basic ethical principles and guidelines regarding ethical issues in human research. In addition, this study does not require a review by a research ethics committee, nor does it require written informed consent for the following reasons: (a) it involves observation of individuals in public places (sports hall); (b) the individuals or groups observed have no reasonable expectation of privacy; (c) it does not involve staged researcher intervention or direct interaction with individuals.

2.3. Instruments

In order to carry out the research, an ad hoc observation instrument was constructed to analyse all variables that can occur in all phases of a handball match (Table 2). All categories fulfilled the requirement of completeness and mutual exclusivity [22,26].

The different criteria observed were:

Criterion Competition: Type of competition belongs to the observed match.
Criterion Observed Team: Team that in the observed moment realizes the phase.
Criterion Phases of the Game: Different game sequences that we can differentiate with the alternation of possession of the ball by a team.
Criterion Number of Players: Relation of number of attackers and number of defenders in the observed situation.
Criterion Score: Difference in goals between the two teams.
Criterion Sequences: Number of attempts within the same phase of possession or recovery of the ball resulting from an interruption in the game.

Criterion Defence: Team structure observed in the organized defence phase.
Criterion Attack: Team structure observed in the system attack phase.
Criterion Rival Defence: Structure of the rival team in the organized defence phase.
Criterion Rival Attack: Structure of the rival team in the system attack phase.
Criterion Passive Play: Tendency of the attacking team to retain possession of the ball without attacking or throwing at goal.
Criterion Player: Which player performs the observed action.
Criterion Zone: Delimitation of six zones of the playing field where the different actions of the game are developed.
Criterion Intermediate Results: Situation that represents an interruption in the game, the teams continue within the same phase and there is no alternation in possession of the ball.
Criterion Final Result: Different game actions that involve the change in possession of the ball.
Criterion Disciplinary Action: Sanction on unsportsmanlike conduct on any of the components of the team observed.
Criterion Rival Disciplinary Action: Sanction on unsportsmanlike conduct on any of the components of the rival team.

The different categories are described in Table 2.

2.4. Data Quality Control

This tool, TAHSUFAIL for the identification of success or failure, was validated by a group of 13 experts. All of them have a degree in sports science and a minimum of experience as handball coaches in first division teams in different countries. The instrument was validated through the analysis of the Aiken V coefficient [34] between the experts' ratings of the different categories determined 0.99 for belonging, 0.97 for clarity, and 0.98 for total.

Table 2. Observation instrument for the games: Tactical analysis handball success–failure (TAHSUFAIL).

Criteria	Categories	Description	Criteria	Categories	Description
Competition	ASO	Spanish League	Rival Defence	D60R	Defence 6:0 Rival
	CHA	Champions League		D51R	Defence 5:1 Rival
Team	TA	Team A		D42R	Defence 4:2 Rival
	TB	Team B		D33R	Defence 3:3 Rival
Phases game	AT	Attack		MDR	Mixed Defence Rival
	CA	Counterattack		MDDR	Mixed Double Defence Rival
	DF	Defence		IDR	Individual Defence Rival
	TD	Transition Defence	Rival Attack	UDR	Unstructured Defence Rival
Number of players	EQ	Equals		ODR	Other Defence Rival
	INF 1	1 player less without Gk		ACWAR	Circulate Wing Rival
	INF 2	1 player less with Gk		AWDPR	Double Pivot Wing Rival
	INF 3	2 players less without Gk		ABDPR	Double Pivot Back Rival
	SUP 1	1 more player (other no Gk)		A24R	Attack 2:4 with 2 Pivots Rival
	SUP 2	1 more player (other Gk)		A33RPI	Attack 3:3 with 2 Pivots
	SUP 3	2 more player (other no Gk)		A33R	Attack 3:3 Rival
	ONS	Other numerical situations		OAR	Other Attacks Rival

Table 2. *Cont.*

Criteria	Categories	Description	Criteria	Categories	Description
Score	W1	+1	Passive play	PP	Passive Notice
	W2	+2	Player	Number	Player's Number
	W3	+3	Zone	Z1	
	W4	+4		Z2	
	WPLUS4	>+4		Z3	
	DR	Draw		Z4	
	L1	−1		Z5	
	L2	−2		Z6	
	L3	−3	Intermediate Result	BI	Block but No Change Possession
	L4	−4		F	Foul No Change Possessions
	LPLUS4	>−4		TI	Throw but No Change Possession
Sequences	S1	Sequence 1		TO	Time Out
	S2	Sequence 2		INTO	Interception but No Change Possession
	S3	Sequence 3		7m	Penalty
	S4	Sequence 4	Final Result	GL	Goal
	S5	Sequence 5		TR	Throw and Change Possession
	S6	Sequence 6		ST	Goalkeeper Save the Ball
				TF	Foul and Change Possession
				INTIN	Interception of the Ball
				BO	Block and Change Possession
				PAS	Passive and Change Possession
Defence	D60	Defence 6:0	Disciplinary Action	2M	Player 2 min Out
	D51	Defence 5:1		YC	Yellow Card
	D42	Defence 4:2		RC	Red Card
	D33	Defence 3:3		BC	Blue Card
	MD	Mixed Defence	Rival Disciplinary Action	2MR	Player 2 min Out Rival
	MDD	Mixed Double Defence		YCR	Yellow Card Rival
	ID	Individual Defence		RCR	Red Card Rival
	UD	Unstructured Defence		BCR	Blue Card Rival
	OD	Other Defence			
Attack	ACWA	Circulate Wing			
	AWDP	Double Pivot Wing			
	ABDP	Double Pivot Back			
	A24	Attack 2:4 with 2 Pivots			
	A33PI	Attack 3:3 with 2 Pivots			
	A33	Attack 3:3			
	OA	Other Attacks			

The observation of the matches was carried out by four observers, graduates in sports science and physical trainers with 10 years of experience in handball. After a period of observer training with the TAHSUFAIL observation instrument and the use of the software, the reliability of the observers was analysed through intra-observer and inter-observer concordance tests. Table 3 shows the different statistics that were used for the validation of the intra-observer and inter-observer tool: Cohen's Kappa [35], Fleiss' Kappa [36] and Iota Coefficient [37]. All the results obtained demonstrated reliability of the observers.

Table 3. Intra- and inter-observer agreement.

Coefficient for Entire Session	Intra-Observer Agreement	Inter-Observer Agreement
Cohen's Kappa	0.98	0.97
Fleiss' Alpha	0.98	0.97
Iota Coefficient	0.98	0.97

2.5. Matches' Analysis

Once the tool was created and validated, all matches were analysed with the free software LINCE PLUS [38]. A previous version of this software has been used in various research projects in the field of handball with observational methodology [23]. All the observation criteria and instruments were entered into the software. At the end of the analysis of all observed matches, we obtained a total of 2581 sequences. For each match, a coded record of all data was exported in Excel format.

Once the match data had been obtained, the Hoisan programme was used [39] for coding and subsequent analysis with polar coordinates and the representation [40].

2.6. Generalisability Analysis

A generalisability analysis [41] was performed using the SAGT software, version 1.0 [42] (see Table 4). Following the habitual attack system of Miranda et al. [43], two measurement plans have been carried out to address: (A) the generalisability of the results obtained (number of plays that make up the sample) and (B) the validity of the observation instrument: (a) the generalisability coefficient (relative and absolute = 0.998) corresponding to the measurement plan [Categories]/[Plays] establishes that with the number of plays analysed a high reliability of generalisation accuracy is obtained; (b) with respect to the [Plays]/[Categories] measurement plan, the generalisability coefficient (relative and absolute = 0.000), supports—in the theoretical framework of the generalisability theory—the validity of the observation instrument designed [44].

Table 4. Results corresponding to the Generalisability design [Categories] [Plays].

Sources of Variation	Sum of Squares	Degree of Freedom	Mean Square	% Variance	Standard Error
[PLAYS]	12.838	1667	0.008	0	0
[CATEGORIES]	3842.188	68	56.503	27.616	0.006
[PLAYS][CATEGORIES]	10,048.711	113.356	0.089	72.384	0

2.7. Procedures: Polar Coordinate Analysis

In order to find the most significant variables in the different phases of the game, the polar coordinates technique was used to reduce the large volume of data obtained [27]. This technique is based on a sequential analysis of prospective and retrospective lags of the data obtained [28,29] and enables us to observe the relationships that exist between the behaviours that make up the taxonomic system we have created [27]. From this analysis, we obtained contrast statistics, Zsum ($Zsum = \Sigma z/\sqrt{n}$, where n is the number of delays) [45] with delay ranges from -5 to $+5$.

Once we had the results, we made a graphical representation of the relationships found between the focal and conditioned categories at the vector level [30]. The length of the vector is the distance between the origin of coordinates Zsum (0,0) and the intersection point (Zsum value of the focal behaviour on the X-axis and Zsum value of the conditioned behaviour on the Y-axis). Relationships are considered significant ($p < 0.05$) when the lengths are greater than 1.96 [46]. This value is obtained with the square root of the sum of the square of the Zsum of X (prospective) and the square of the Zsum of Y (retrospective). In addition, the angle of the vector (φ = Arc sine of Y/Radius) determines the nature of the relationship [27].

The characteristics of each quadrant of the polar coordinates are [27] (Figure 1):

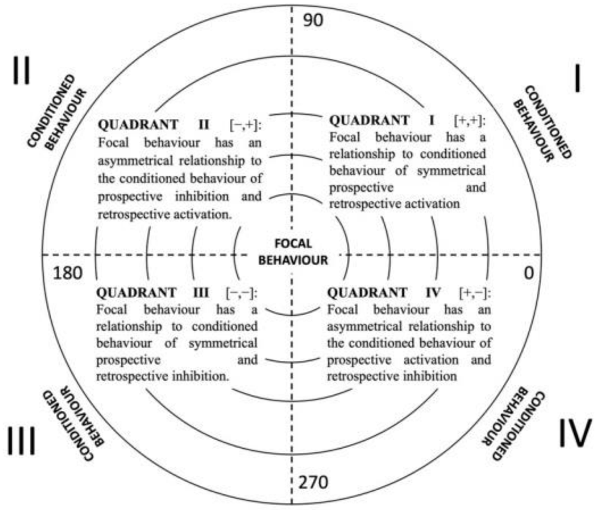

Figure 1. Characteristics of each quadrant of the polar coordinates.

The focal behaviours used were SUCCESS and FAILURE and were related to the other criteria.

All the categories observed through the observation tool should explain how we can achieve success or failure in the different phases of the game through this polar coordinate analysis. If we analyse only success, we considered that, at the defensive level, all criteria that entailed a disruption of the opposing team's attacking play or the recovery of the ball and possession were understood as success. On the offensive level, anything that was finishing an attack with a goal or achieving numerical superiority for the team was also considered a success. In terms of failure in the offensive phase, any interruption of play by the opposing team or loss of possession for various reasons was considered a failure. In the defensive phase, everything that led to conceding a goal or suffering a numerical inferiority in the number of players was also analysed as a failure.

3. Results

The analysis of the data with the polar coordinate's technique gave us a behavioural map of the focal behaviours, SUCCESS and FAILURE, with the other behaviours of the observation tool in the different quadrants (Table 5).

Quadrant I (Prospective and retrospective activation):

In Quadrant I, where the relationship between the behaviours is one of mutual prospective and retrospective activation, all the categories that relate to the focal behaviour mean that the more times they are performed during the match, the more they stimulate this success and vice versa; there is a double activation.

With the results obtained in the behaviour SUCCESS (Figure 2), this is related to the 6:0 defensive system (9.49) itself and, in turn, to the defensive phase (9.53). There is also a relationship with the opposing team's attack when they attack with a circulation of the team's wing (2.18), attack with a double pivot by a wing (5.38) and attack with a double pivot by a back (2.68). There is also a relationship with the counterattack phase (5.86), Zone 1 finishing (2.58), sequence 1 (2.51), interception and recovery of the ball (2.20) and defensive blocking and change of possession (2.10).

Table 5. Significant relationships found with the focal behaviours SUCCESS and FAILURE.

Criterion Behaviour	SUCCESS			FAILURE		
Q	Paring Behaviour	Vector Module	T-Angle	Paring Behaviour	Vector Module	T-Angle
I	Defence 60	9.49	4.97	Circulate Wing	2.84	77.53
	Circulate Wing Rival	2.18	31.25	Double Pivot Wing	6.01	3.22
	Double Pivot Wing Rival	5.38	2.71	Defence 51 Rival	2.24	33.81
	Double Pivot Back Rival	2.68	14.12	Other Defence Rival	3.39	49.56
	Defence	9.53	0.75	Defence 51	2.10	70.51
	Counterattack	5.86	13.27	Other Defence	3.88	66.62
	Zone 1	2.58	11.44	Unstructured Defence	7.70	20.18
	Sequence 1	2.51	21.23	Transition Defence	9.02	18.32
	Interception of the Ball	2.20	9.71	Zone 2	2.03	85.57
	Block and Change Possession	2.10	63.27	Throw but No Change Possession	1.98	62.61
				Sequence 2	2.27	55.12
II	Attack 33	11.26	179.05	Attack 33 Rival	5.08	177.89
	Defence 60 Rival	10.60	176.70	Defence	9.79	178.68
	Attack	13.24	179.57	Goalkeeper Save the Ball	2.18	166.99
	Zone 4	3.26	144.47			
	Sequence 3	2.25	156.04			
	Penalty	3.92	145.98			
III	Circulate Wing	3.18	253.38	Defence 60	9.82	183.29
	Double Pivot Wing	6.41	182.30	Circulate Wing Rival	2.40	207.88
	Other Defence Rival	3.52	238.07	Double Pivot Wing Rival	6.07	181.81
	Other Defence	4.07	247.71	Double Pivot Back Rival	2.20	185.79
	Unstructured Defence	7.53	203.26	Counterattack	5.42	195.70
	Transition Defence	8.67	200.57	Zone 1	2.24	196.18
	Zone 2	2.11	260.82	Zone 5	2.46	247.55
	Sequence 2	2.39	224.36			
	Throw No Change Possession	2.07	239.26			
IV	Attack 33 Rival	5.29	359.63	Attack 33	11.06	359.06
	Goalkeeper Save the Ball	2.52	334.93	Other Attacks	1.99	331.99
				Defence 60 Rival	10.23	356.09
				Attack	12.75	358.45
				Zone 4	3.54	326.95
				Penalty	3.97	330.89
				Interception of Ball	2.28	194.42

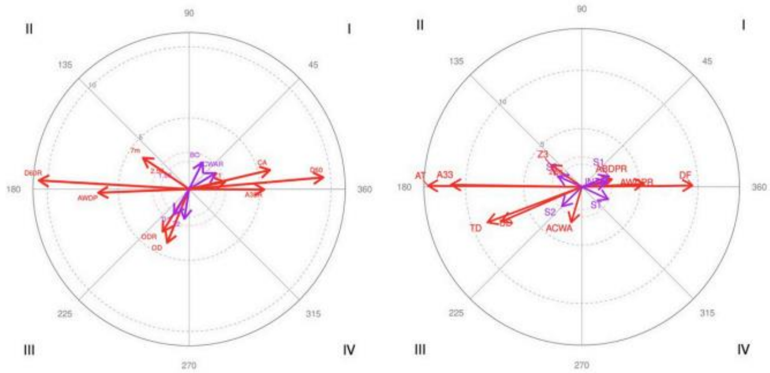

Figure 2. Vector maps for local behaviour SUCCESS. I: Quadrant I; II: Quadrant II, III: Quadrant III; IV: Quadrant IV.

When analysing the focal behaviour FAILURE (Figure 3) in Quadrant I, there is a relationship with the circulation of the wing (2.84) and the transformation of a wing to a pivot (6.0). At the defensive level, there are relationships with the 5:1 defensive system, of the observed team (2.10) and the opponent's (2.24), other defences of the observed team (3.88) and opponent's (3.39), and unstructured defence (7.70). There is also a relationship with transition defence (9.02), Zone 2 (2.03), the throw-in without change of possession (1.98), and sequence 2 (2.27).

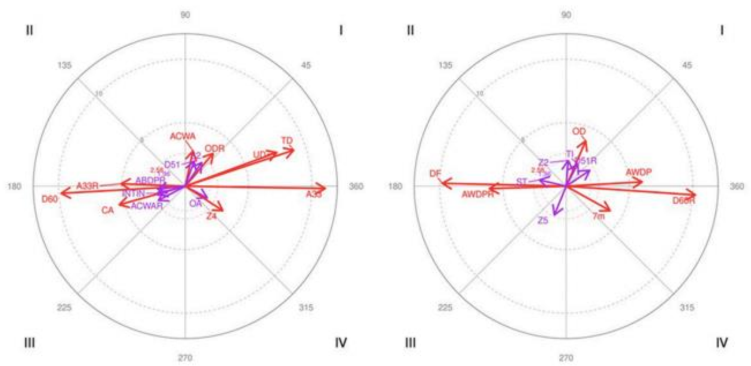

Figure 3. Vector maps for local behaviour FAILURE. I: Quadrant I; II: Quadrant II, III: Quadrant III; IV: Quadrant IV.

Quadrant II (Prospective inhibition and retrospective activation):

In Quadrant II, where there is prospective inhibition and retrospective activation, the relationships with the successful focal cease to have positive activation as the match progresses. This is probably due to an adaptation of the opposing team to the situations presented.

In this quadrant, there are relationships with the focal behaviour success with the attack phase (13.24), the own attack with the 3:3 system (11.26), and the opposing defence with the 6:0 system (10.60). We also found relationships with Zone 4 of completion (3.26), sequence 3 (2.25) and the penalty action (3.92).

If we look for the relationship with focal behaviour failure, we see that there are relationships with the opposing 3:3 offensive system (5.08), the own defence phase (9.79) and the goalkeeper's save (2.18).

Quadrant III (Prospective and retrospective inhibition):

In Quadrant III, the existing relationship is one of mutual inhibition. The behaviours analysed in this quadrant indicate that we did not achieve any benefit at any time during the match, so we could consider their usefulness.

The relationships we found with the focal behaviour success were circulation of a wing (3.18) and attack with a wing as a double pivot (6.41). At the defensive level, we observed a relationship with other defences (4.07), unstructured defence (7.53) and other defences by the opposing team (3.52). There was also a relationship with transition defence (8.67), Zone 2 (2.11), sequence 2 (2.39) and the throw-in without change of possession (2.07).

The relationships we found with the focal behaviour failure were inhibition in the 6:0 defensive system (9.82), the circulation of a wing (2.40), the double pivot attack by a wing (6.07) and the double pivot attack by a back (2.20) all by the opposing team. There is also a relationship in the counterattack phase (5.42), Zone 1 (2.24) and Zone 5 (2.46) finishing.

Quadrant IV (Prospective activation and retrospective inhibition):

In Quadrant IV, there is an asymmetrical relationship between prospective activation and retrospective inhibition behaviours. As the analysed category is realised, it becomes more effective in relation to the focal behaviour.

Regarding focal behaviour success, there is a relationship with the rival attack with the 3:3 system (5.29) and with the goalkeeper's save (2.52).

If we analyse the focal behaviour failure, can be observe relationships with the attack phase (12.75), the 3:3 offensive system (11.06) and other attacks (1.99). Additionally, with the opposing 6:0 defensive system (10.23), the finishing Zone 4 (3.54), the penalty action (3.97) and the interception and recovery of the ball (2.28).

4. Discussion

The aim of this study was to analyse the variables that influence success or failure in the different phases of the game in a season in an elite men's handball competition with polar coordinates. This analysis technique is novel for analysing all the variables that assess the performance of an elite men's handball team. There is research that has analysed with the same technique the performance of different factors at national team level in handball [8,23,32]. This technique has also been used in other sports with two other analysis techniques (T-Patterns and sequential analysis) to analyse fencing [46]. In basketball, this polar coordinates technique has also been used both in the analysis of the game [47] and in the analysis of coaches' responses [48].

In our research, on an offensive level, both in the positional attack phase and in the counterattack phase, success was understood as all actions that ended with a goal or where an advantage was achieved for the attacking team such as a disciplinary sanction of the opponent (yellow card, exclusion, or disqualification) or a clear action of completion such as a penalty. Failure was defined as any action where a shot was missed, either by a save by the goalkeeper or by throwing it wide, any defensive action that stopped the rhythm of play of the attack (foul), or the loss of the ball due to an opponent's interception or an own loss in a pass, for example.

To evaluate success in the defensive and transition defence phase, we defined it as any action that managed to recover the ball either by intercepting it, by a save or by a block. We also consider within success any action that stopped the rhythm of play of the rival attack (foul). All actions where a goal was conceded, a defensive player was penalised, or a clear penalty was awarded were defined as a failure.

In our search for references, we have not found any research where a regular season of an elite men's team is analysed in the different phases of the game through polar coordinates. From this analysis we have tried to find out which are the behavioural patterns that lead us to achieve our goals in the different moments of the game and the relationships with the different criteria of the game.

4.1. Defence

The observed team obtained a strong relationship in this phase with the focal behaviour success. The defence and, more specifically, the defensive system 6:0, were located in Quadrant I, demonstrating this mutual excitation between the two behaviours, confirming the behavioural relationship in Quadrant III with the focal behaviour failure. The system 6:0 was the most used in most of the team's games, data that have also been demonstrated in other research [8,9]. In turn, when the opposing team tried to overcome the defence with tactical actions common in handball such as the circulation of the wing, the transformation to double pivot by a wing or a first line, the defence was able to counter them efficiently. These data are also confirmed by the relationships obtained with the failure behaviour and the data from Quadrant III. In other research, they observed that attacks with transformation were more effective than those without [20]. This could be argued from our results due to an evolution of the current game, being more direct, with more possessions and faster actions that do not slow down the game as much [19]. If we analyse another habitual attack system, the attack 33 rival behaviour [9], we see that its location was found in Quadrant III in the success behaviour and in Quadrant II in the failure behaviour, indicating that, surely, as the minutes of the games progressed, the defensive system adapted better to this structured attack system, managing to counteract it and stimulate defensive success on the part of the team observed.

Different conditioned behaviours supported team success in this phase such as interception and block and their location in the first quadrant. Other research also showed that defensive performance was one of the indicators to adequately predict victory in a match at the men's national team [17] or club level [15].

When analysing the pace of play of the opponent's attack, it was observed that in Sequence 1, the team was able to stop the opposing team effectively, and also in Sequence 3, although it was losing its relationship with success as the match progressed. This relationship was also observed in different studies where the winning team made moves, forcing the opposing team to find worse finishing situations or areas [8,23]. However, other research also showed that stopping the attacking pace of the opposing team with successive fouls did not improve the success of the defence [16]. On the contrary, we were also able to observe that as the minutes progressed in the matches, more penalty actions were conceded, being a clear option of completion by the attacking team, bringing us closer to the focal failure behaviour.

The analysis has shown an important part of the success of a defensive system is related to the performance of the goalkeeper [12]. The data obtained showed that as the goalkeeper's performance improved, his relationship with success behaviour increased and decreased with failure behaviour. There is other research that supports these results, showing that the winning teams were those that achieved a greater number of saves by their goalkeepers [12,15], also demonstrated that the losing teams made more shots from areas far from the goal, being easier for the goalkeeper [15,23]. It was also observed that the goalkeeper's performance plays a decisive role in the final result [14], combined with adequate offensive efficiency [12].

The team was found to be more solid in its main defensive system, a formed and structured defence as when, for circumstances, it performed other defence or unstructured defence, the tendency was towards failure (Quadrant I), as demonstrated in other research where attacks were more successful in front of unorganised defences [10].

4.2. Counterattack

The fact that at the defensive level, the team observed had a significant relationship with success behaviour, influenced the relationships in this phase. Various studies have shown that good defensive efficiency leads to an increase in the number of counterattacks and a clear opportunity to shoot. This phase can start with ball stealing [11,17], a good performance by the goalkeeper [12,15] or a good relationship between defensive efficiency and the goalkeeper [26].

If we look at the relationship between the focal success behaviour and the conditioned behaviours counterattack and Sequence 1, we can deduce that the team analysed obtained a high performance in this phase, and that their game, linked to the previous phase, promoted trying to finish more actions in this phase than in the static attack. These findings follow the same line as other research that showed that counterattacking is commonly performed in Sequence 1 [8] and is often more successful than structured attacking as it is attacked against unstructured defences [10]. Other research showed that the difference between winning and losing teams was the goals scored in this phase [10]. Looking at the results obtained by the team in Table 1, it could be said that the observed team was clearly a winner.

The reason that the game model deduced from the team was based on an efficient defence that allowed for easier finishing options in the counterattack phase is surely due to the direct relationship of this phase with success in the match demonstrated in multiple investigations [10,14,17], but also with a direct relationship with success in the defensive phase [15]. To confirm this argument, the data obtained with focal failure behaviour and this phase also reaffirm this assumption.

4.3. Attack

The results obtained in the research confirm those found in other research. They also showed that winning teams were characterised by fast attacks and not by the prolonged and interrupted attacks more typical of losing teams [10]. In order to cut the pace of the game and increase the sequences, opposing defences tried to stop actions in Zone 2, the zone where the attack is created and where many free hits are usually produced. They also tried to lengthen the sequences so that they did not shoot easily in order to increase the error (Interception of Ball) [17,23]. Even so, it was not enough to slow down the attack of the team observed by looking at the results obtained in the matches analysed (Table 1).

It can also be observed that the team was losing effectiveness in its offensive system 33, the most used in other research [9], against the rival defence, making the attacking phase approaching failure and moving away from success. This loss of activation with success was probably caused by an adaptation of the opposing team’s defensive systems, by an increase in turnovers, by the increase in fatigue as the game progressed on the part of the attack or by the differences in the score, and the offensive relaxation on the part of the team observed [49]. Another behaviour that confirms this tendency is Sequence 3, where as the game progressed, it became less related to success. The attack tried to overcome the rival structured defence with different tactical actions (circulate wing; wing to double pivot), but their relationship was closer to the focal behaviour of failure rather than success. Even so, the observed team’s attack was superior to the opposing defence in general in the static phase, given the results obtained, confirming data from other research [15,17].

Where the team observed had the most problems was in attacking the opposing team’s defensive system 5:1 or other defensive systems. It is curious that, analysing this data, the opposing teams did not use these systems to try to stop the team’s offensive success. This greater opposition of the defensive system 5:1 by the attack is in line with the results obtained in other studies that obtained the same conclusions, being the system that generated the most problems for the attack, but being an alternative, not being the main defensive system, with a clear relationship with the score, being either very much in favour or very much against. It seems that teams used this system as a desperate measure to stop the opponent’s static attack as observed in other research [9].

4.4. Transition Defence

Being a team that achieved a high level of success in the offensive phase, especially in the counterattacking phase, this phase probably did not occur too many times in the different matches, or its transition defence forced the opposing team not to carry out a large number of counterattacks. However, we must bear in mind that when this phase did occur, it was usually not very well organised, and the opposing team was successful.

This could lead us to believe that this phase should be improved as they are easy finishing options for the opposing team as well as the counterattack of the team analysed. Having demonstrated the effectiveness and importance of the counterattacking phase for success, we can understand that this phase is associated more with failure, in any team, however little happens, rather than success [10,14,17].

5. Conclusions

The analysis of success or failure in the different phases of the game in an elite men's handball match with polar coordinates suggests, as in other research, that one of the keys is the defensive phase: not conceding goals and recovering the ball. The counterattack, another key to obtaining clear goal scoring options, is also linked to recovering the ball. Success in these two phases is key to winning matches and being a winning team. This suggests that it is necessary to focus on training with a high pace of play, linking the different phases of the game to achieve the objectives set for the match, recovering the ball, and attacking with the shortest possible time in front of an unstructured defence. It is essential to know what the performance indicators are in order to improve the team's results. Therefore, it is necessary to train the different categories where there is an activation of success throughout the game or in those that improve performance as the game progresses and reduce failure with those that do not achieve success. One limitation we have encountered is the lack of existing research on the transition defence phase. Conclusions could be drawn in this phase by comparing what happens in the counterattack, but an in-depth analysis of how to counteract the success of the counterattack should be developed in future research.

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The effect of training schedule and playing positions on training loads and game demands in professional handball players

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ABSTRACT: In this research, we aimed to (1) describe the differences in internal and external load between playing positions and (2) characterize the training demands of the days before competitive events for professional handball players. Fifteen players (5 wings, 2 centre backs, 4 backs, and 2 pivots) were equipped with a local positioning system device during training and 11 official matches. External (total distance, high-speed running, player load) and internal loads (rating of perceived exertion) were computed. Substantial differences were recorded between the external load variables depending on each playing position and depending on whether it was a training day (high-speed running: effect size (ES) ≥ 2.07; player load: ES ≥ 1.89) or a match (total distance: ES ≥ 1.27; high-speed running: ES ≥ 1.42; player load: ES ≥ 1.33). Differences in internal load were not substantial. The rating of perceived exertion, at this competitive level, does not seem to discriminate the differences registered in the external load, probably due to the degree of adaptation to the specific effort of these players. The large differences observed in external load variables should be used to tailor practices and better adjust the training demands in professional handball settings.

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INTRODUCTION

In-season load monitoring is relevant in high-performance team sports as this process gives critical information to the technical staff. This information allows coaches to adapt the training contents, helping players perform to the best of their abilities during games [1] with reduced injury risk [2]. Despite this relevance, no studies, to the best of our knowledge, have analysed the training demands in handball as in other team sports such as football [3].

Previous studies in handball suggest that many factors affect the playing demands during games. Thus, gender (women travelled higher total distance than men) [4, 5], playing level (amateur handball players accumulated a lower total distance) [6], or age (adolescent handball players showed lower levels of exercise intensity, in the second half of matches) [7] have been reported in different pieces of research. It is worth noting that many studies [5, 8] show that playing positions modulate the game demands considerably because tactical roles attributed to each playing position are very specific [9, 10].

Thus, the external [5, 8, 11, 12] and internal load game demands [13, 14]. For instance, pivots (PIV) travel lower total distances (3149 ± 639 m) [5], while wings perform the highest number of sprints [8] and cover the highest high-speed running (HSR) distances (1229 ± 129.4 m) [11]. Playing position also influences internal load substantially [13, 14]. Povoas et al. [15] found that back players and pivots had the highest average heart rate (HR) values and total game time at intensities > 80% HRmax. Therefore, and considering these previous results, monitoring game demands is relevant. However, training sessions represent the most significant part of the weekly training load (at least in volume), and we should accurately monitor them. We hypothesize that training demands are influenced mainly by playing positions, and these differences could have substantial consequences in training load management [16] and could explain injury rates [2]. Understanding these variations may improve load management [16] and mitigate injury risks [2]. Optimizing training to prepare players for competition with specific tasks also seems essential [17].

It is also worth noting that physical profiles differ between playing positions [18, 19], also influencing training loads [20]. Thus, body dimensions are relevant as they can alter training load [21, 22]. These differences add disparity to the training response, making training individualization necessary [18, 19].

Another aspect to consider is the management of training loads to help players perform during games to the maximum of their abilities. Many studies have shown that periodization is crucial for performance [16] and injury prevention [2].

To be physically prepared for the match, players must train to develop specific physical skills (e.g., lower limb muscle power and ability to accelerate) in an optimal manner close to or superior to competitive demands [17]. The knowledge of such game demands can lead professionals to apply the approach "train as you play" [23]; however, despite its importance, there appears to be no study in handball that provides this information. We do not know, for example, whether games offer the highest load of the microcycle. It is paramount, then, to compare training and game demands. Training load management control is a crucial driver of performance in a team sport [16] and a strategic advantage for the different coaching staff [3].

The aims of this research are 1) to describe the internal and external training load differences between playing positions and 2) to characterize the training demands to compete for every training day. Therefore, we examined the differences in internal (RPE) and external (using inertial measurement units (IMUs)) loading concerning training days, playing positions, and competitive playing demands. Our findings should help coaches to design playing positions' specific training content related to game demands.

MATERIALS AND METHODS

Experimental approach to the problem

We conducted a cross-sectional, observational study to determine the differences between playing positions during games and practices of a team playing in the second division of the Spanish handball competition during the 2018–19 season. The reported results consider the average values of 11 competitive home games and 25 weeks of practice. There were usually four training sessions a week; the day before the competition (match day; MD) was MD-1, two days before the competition (MD-2), and so on until MD-5. The research data emerged thanks to the daily monitoring of the players conducted in training and competition; therefore, relevant approval of the ethics committee was not required [24]. The study was conducted

TABLE 1. Physical characteristics of the players (mean ± standard deviation).

Position	Mean (n)	Age (years)	Body mass (kg)	Height (cm)
Left wings (LW)	3	23.0 ± 0.0	78.5 ± 3.5	176.0 ± 0.0
Right wings (RW)	2	23.5 ± 0.7	73.0 ± 2.8	179.0 ± 1.4
Centre backs (CB)	3	24.0 ± 1.0	90.3 ± 9.3	190.3 ± 7.5
Left back (LB)	3	23.7 ± 0.6	93.0 ± 6.6	192.3 ± 3.5
Right back (RB)	2	23.0 ± 0.0	89.5 ± 16.3	194.5 ± 9.2
Pivot (PIV)	2	29.5 ± 4.9	100.5 ± 7.8	192.5 ± 3.5

TABLE 2. Description of the objectives, contents and orientation of the volume and intensity related to the training days.

MD	Aim	Conditional work	Static phase (%)	Full court game (%)	Volume	Intensity	Training session time (min)
MD -5	Individual development	Structural	80	20	***	**	87.9 ± 8.2
MD -4	Individual development	Structural	60	40	****	**	97.5 ± 15.7
MD -3	Tactical session	Structural	60	40	****	***	95.0 ± 11.4
MD -2	Match preparation	Optimising	50	50	***	***	90.1 ± 11.5
MD -1	Match preparation	Optimising	70	30	**	*****	86.4 ± 8.5

Note: MD: match day.

following the ethical principles for biomedical research with human beings, established in the Declaration of Helsinki of the World Medical Association (updated in 2013), and the club's managerial structure approved its implementation.

Subjects

Fifteen professional handball players participated in this study. Some of the players were internationals with their national teams as they were still in their formative stages. Players were grouped according to their usual playing position during the competition (Table 1).

Sessions and games monitoring

The study was carried out using the WIMU PRO system (RealTrack Systems SL, Almería, Spain). Each device, whose dimensions were 81 × 45 × 16 mm (height/width/depth) and which weighed 70 g, was fitted to the back of each player with an adjustable vest (Rasán, Valencia, Spain).

In training, the recording was uninterrupted. During games, playing time was only recorded when the players were on the court. The time spent between player rotation, team time outs (TTO) (a maximum of three per team), periods when the game was interrupted, and the disciplinary sanctions typical of handball, where players must leave the court for two minutes, were omitted.

Table 2 describes the different training days' main characteristics (objectives, volume, duration, intensity, static or dynamic training).

Data processing

The positioning data record was monitored in real time and subsequently analysed using the SPRO software version 946–949 (SPRO, RealTrack Systems, 2018). The system operates using triangulations

TABLE 3. Comparison of the mean value of each indicator related to training day and games. Direction of the arrow describe the magnitude of the standardized difference, horizontal arrow stand for an effect size between 0.6 and -0.6, down arrow for an effect size above 1.2, diagonal down arrow for an effect size between -0.6 and -1.2 and diagonal up for an effect size between 0.6 and 1.2.

		CB	LB	LW	PIV	RB	RW
Total distance (m)	Game	**4562.7 ± 928.4**	**4699.5 ± 974.2**	**4946.1 ± 1051.0**	**4084.8 ± 1263.83**	**3872.0 ± 623.3**	**5306.6 ± 1422.2**
	MD -1	↘ 3861.9 ± 627.6	→ 4347.5 ± 623.6	↓ 3826.0 ± 654.7	→ 3526.4 ± 623.9	→ 3888.2 ± 663.9	↓ 3882.3 ± 628.3
	MD -2	→ 4457.0 ± 1008.2	→ 4731.6 ± 871.8	↘ 4236.9 ± 747.2	→ 3665.6 ± 597.7	→ 4136.1 ± 881.8	↘ 4394.7 ± 897.5
	MD -3	→ 4650.1 ± 1012.7	→ 4744.1 ± 730.9	→ 4593.2 ± 928.4	→ 3913.3 ± 969.7	↗ 4413.1 ± 947.4	→ 4828.7 ± 1182.9
	MD -4	→ 5025.3 ± 1197.2	→ 5154.4 ± 1184.4	→ 4998.9 ± 1212.8	→ 4145.6 ± 819.5	↗ 4712.9 ± 1167.6	→ 5060.4 ± 1286.4
	MD -5	→ 4344.5 ± 656.2	→ 4476.6 ± 684.2	→ 4349.9 ± 870.2	→ 3678.3 ± 884.7	→ 4187.6 ± 729.1	→ 4492.8 ± 675.9
High speed (m)	Game	**208.9 ± 90.54**	**267.2 ± 119.0**	**549.7 ± 186.2**	**228.9 ± 139.9**	**179.9 ± 79.2**	**668.4 ± 307.5**
	MD -1	↘ 111.9 ± 84.8	↘ 138.8 ± 82.6	↓ 151.7 ± 91.8	↓ 84.2 ± 69.1	↘ 126.5 ± 84.9	↓ 212.8 ± 129.1
	MD -2	↘ 107.9 ± 80.7	↓ 130.6 ± 106.2	↓ 236.4 ± 134.8	↘ 107.5 ± 71.3	↘ 107.9 ± 118.8	↓ 273.1 ± 161.2
	MD -3	↘ 146.7 ± 127.2	↘ 142.8 ± 105.1	↘ 293.2 ± 193.1	↘ 106.9 ± 85.6	→ 145.8 ± 141.0	↘ 338.8 ± 219.8
	MD -4	→ 166.9 ± 113.6	↘ 142.3 ± 94.9	↘ 298.9 ± 171.2	↘ 121.9 ± 92.2	→ 146.2 ± 100.1	↘ 313.4 ± 192.0
	MD -5	↓ 82.7 ± 99.0	↓ 61.1 ± 82.6	↓ 167.5 ± 218.6	↘ 59.1 ± 63.5	↘ 74.2 ± 89.0	↓ 181.2 ± 232.4
RPE (AU)	Game	**6.7 ± 1.73**	**6.6 ± 1.9**	**7.0 ± 1.5**	**5.7 ± 2.3**	**6.1 ± 1.3**	**7.4 ± 1.3**
	MD -1	↘ 5.3 ± 0.8	→ 5.6 ± 0.9	↘ 5.8 ± 0.7	→ 5.6 ± 0.9	→ 6 ± 1.0	↓ 5.5 ± 0.9
	MD -2	→ 6.4 ± 1.1	→ 6.9 ± 1.1	→ 6.2 ± 1.4	↗ 6.6 ± 0.8	→ 6.6 ± 0.9	↘ 6.6 ± 1.1
	MD -3	→ 6.6 ± 1.3	↗ 7.3 ± 0.8	→ 6.9 ± 1.3	↗ 7.0 ± 0.9	↗ 6.9 ± 0.8	→ 7.0 ± 1.1
	MD -4	→ 6.8 ± 1.1	→ 7.2 ± 1.0	→ 6.8 ± 1.4	↗ 6.8 ± 0.9	→ 6.8 ± 1.2	→ 7.1 ± 1.4
	MD -5	→ 6.5 ± 1.4	→ 7.1 ± 1.1	→ 7.3 ± 1.2	↗ 6.7 ± 1.0	↗ 7.0 ± 0.8	→ 6.9 ± 1.4
PlayerLoad (AU)	Game	**69.7 ± 15.9**	**74.1 ± 17.6**	**82.5 ± 21.9**	**56.3 ± 18.9**	**60.1 ± 10.1**	**89.9 ± 30.2**
	MD -1	↘ 54.8 ± 9.1	↘ 61.1 ± 9.3	↓ 54.6 ± 8.8	↘ 44.4 ± 9.2	↘ 53.8 ± 9.7	↓ 58.6 ± 11.1
	MD -2	→ 63.6 ± 12.7	→ 65.9 ± 10.6	↘ 62.2 ± 11.7	→ 49.4 ± 9.8	→ 58.1 ± 11.8	↘ 66.2 ± 13.7
	MD -3	→ 67.7 ± 13.2	→ 68.5 ± 9.1	↘ 69.9 ± 14.3	→ 54.1 ± 13.5	→ 63.8 ± 13.3	→ 75.7 ± 15.9
	MD -4	→ 70.5 ± 14.7	→ 73.1 ± 16.4	→ 78.9 ± 22.3	→ 55.5 ± 13.1	→ 67.9 ± 16.5	→ 80.4 ± 20.1
	MD -5	→ 63.2 ± 8.3	↘ 64.8 ± 9.7	→ 71.4 ± 14.4	→ 50.2 ± 13.9	→ 61.0 ± 10.9	↘ 72.9 ± 11.4

Note: MD: Match day; CB: Centre Backs; LB: Left Backs; LW: Left Wings ; PIV: Pivots; RB: Right Backs; RW: Right Wings; RPE: Rating of perceived exertion ; AU: Arbitray Units.

between four antennas with patented ultra-wideband technology (18 Hz sampling frequency) placed 5 m away from each one of the corners of the court and at the height of 6 m. These units include several sensors that record at different sampling frequencies. The sampling frequency used for 3-axis accelerometer, gyroscope, and magnetometer was 100 Hz and 120 kPa for the barometer [25, 26].

Total distance (TD, in metres) and high-speed running (HSR, distance covered in metres above 18.1 kph) [5, 7] were extracted from the root data reported by the system using SPRO software. The player load (PL; arbitrary units, au) was calculated as the square root of the sum of the squared instantaneous rates of change in acceleration in each of the three planes divided by 100 in absolute [27].

Internal load (IL) data were obtained through the RPE-based method (arbitrary units, au) [28, 29] at 10–30 minutes following every handball training session and game.

The recording of all training sessions and games resulted in 1033 individual records for the external load and 1008 files for the internal load.

Statistical analysis

Data in the text and figures are presented as means with standard deviation (SD). All data were first log-transformed to avoid bias arising from non-uniformity errors. Standardized differences in the mean (Cohen's effect size) were calculated to compare external and internal load between and within the different playing positions during games and training sessions. Effect size comparisons were rated using the Hopkins scale: 0.2 (small), 0.6 (moderate), 1.2 (large), 2.0 (very large) [30]. The 90% confidence interval was also calculated for each effect size. Considering the high number of comparisons, the results were not analysed when the lower limit of the effect size was below 0.6. The percentage of game demands for each variable was also calculated following this formula:

Statistical analyses were performed using RStudio (v1.3) and the Esvis package (v0.3.1).

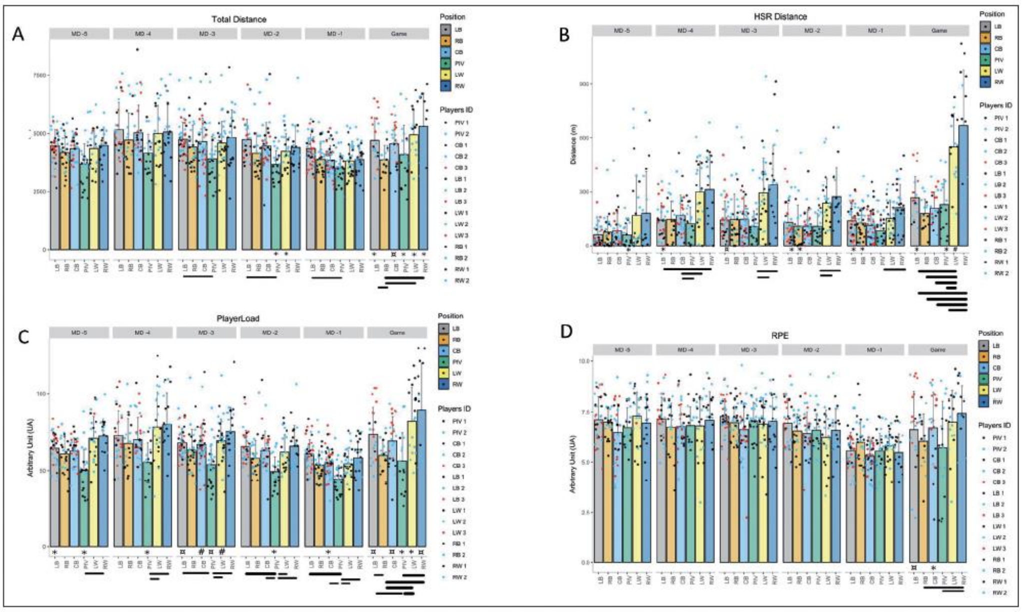

FIG. 1. Comparison between playing position related to game day and total distance (A), high-speed running distance (B), player load (C), and rate of perceived exertion (D). Bar graphs represent the mean and standard deviation for each playing position related to game day. Coloured dots stand for individual value within the playing position and game day. The thickness of the lines represents the magnitude of the difference (effect size): ▬ very large difference; ━ large difference; — moderate difference. The magnitude of the difference of the within playing position is represented by ¤ when it is large very large, * when it is large and # when it is moderate. Only effect sizes with a lower limit above 0.6 are shown.

RESULTS

Table 3 summarizes each variable's mean value and standard deviation for playing positions and game day. Figure 1 shows total distance (TD), high-speed running distance (HSR), player load (PL), and rating of perceived exertion for each day of training, for each playing position, and for each player.

Game demands

During games, right backs (RB) travelled (4187.6 ± 729.1 m) largely to very largely less TD (ES range from 1.8 to 2) than the other playing positions (left backs (LB): 4476.6 ± 684.2 m, RB: 4187.6 ± 729.1 m, CB: 4344.4 ± 656.1 m, LW: 4349.8 ± 870.2 m, RW: 4492.8 ± 675.8 m) except when they were compared to PIV (PIV: 3678.2 ± 884.6 m). Wing players (RW: 668.4 ± 307.5 m, LW: 549.6 ± 186.2 m) cover very largely more HSR distance (ES range from 2.3 to 3.3) during games when compared to the other playing positions (LB: 267.2 ± 119 m, PIV: 228.9 ± 139.9 m, CB: 208.92 ± 90.5 m, RB: 179.9 ± 79.2 m). During games, RB (60.1 ± 1 au) and PIV 56.3 ± 2 au) reported up to very largely less value (for RB, ES vs. LW = 2.3, vs. RW = 2.1, vs. LB and for RB vs. LW ES = 2.3, vs. RW = 2.03) than the other playing positions (range from 69.7 ± 15 au for CB to 90 ± 30.2 au for RW). They were no substantial differences in the RPE.

Training sessions

Total distance

PIV travelled moderately to largely less distance (ES range from 1.2 to 1.6) in MD-5, MD-2, MD-1 (3678.3 ± 884.7 m, 3665.5 ± 597.6 m, 3526.4 ± 624.0 m) when compared to LB (4476.6 ± 684.2 m, 4731.6 ± 871.7 m, 4347.5 ± 623.6 m, respectively).

High-speed running

In MD-4, MD-3, and MD-2, the HSR distance travelled by PIV (MD-4: 392.8 ± 128.9 m, MD-3: 106.9 ± 85.6 m, MD-2: 107.5 ± 71.2 m) was largely to very largely lower (ES ranged from 1.3 to 2) than by wing players (MD-4, LW: 298.9 ± 171.2 m, RW: 313.4 ± 192 m, MD-3: LW: 293.2 ± 193.1 m, RW: 338.79 ± 219.8 m, MD-2: 236.4 ± 134.8 m, RW: 273.1 ± 161.2 m).

Player load

PIV showed the lowest PL value, up to largely less (ES ranged from 1.2 to 2.07) in all the training sessions and games (in MD-5: 50.2 ± 13.9 au, in MD-4: 55.5 ± 13.2 au, in MD-3: 54 ± 13.5 au, in MD-2: 49.4 ± 9.8 au, in MD-1: 44.4 ± 9.2 au). Wing players produced up to very largely higher PL (ES ranging from 1.5 to 1.8) demands in MD-5 (RW: 72.9 ± 11.4 au, LW: 71.4 ± 14.3 au), MD-4 (RW: 80.4 ± 20.1 au, LW: 78.8 ± 22.3 au), MD-3 (RW: 75.7 ± 15.9 au, LW: 69.9 ± 14.3 au).
LB showed the highest PL value in MD-1 (61.1 ± 9.3 au vs. 44.4 ± 9.1 au for PIV, LB vs. PIV, ES = 2.03).

Rating of perceived exertion

Like in matches, there were no substantial differences in the RPE, with values ranging from 5.72 ± 2.32 au for PIV to 7.43 ± 1.34 au for RW.

Games vs. training

Within playing position differences

PIV showed moderate to large within-playing-position differences during games in TD (4951.1 ± 1047.6 m vs. 3218.4 ± 779.7 m, ES = 1.97), HSR (343.6 ± 84.2 m and 114.2 ± 70.3 m, ES = 1.91), PL (68.7 ± 15.5 au vs. 44 ± 13.2 au, ES = 1.77). There were moderate to very large differences (ES 1.44 to 2.06) for LB during games in TD (4161 ± 657.5 m vs. 5400.3 ± 980.5 m), in PL (87.2 ± 15.8 au vs. 75.3 ± 10.9 au) and RPE (7.7 ± 1 au vs. 5.6 ± 1.1 au). There were large to very large within-playing-position differences in HSR distance travelled by LB (306.2 ± 355.1 m vs. 83.1 ± 162.3 m).

PIV also showed some individual differences (ES = 1.84) in the PL in MD-5 (62.8 ± 13.8 au vs. 43.8 ± 9.2 au), MD-4 (63.0 ± 10.2 au vs. 51 ± 13 au), MD-3 (62.6 ± 10.9 vs. 44.2 ± 8.4 au), MD-2 (55.9 ± 9 au vs. 43.5 ± 6 au).

Figure 2 shows the coefficient of variation for all the metrics in each playing position for the different training days. HSR distance showed a higher variation (77.3% to 87.9%). When considering playing position and training days, HSR distance in MD-5 had the highest percentage of variation (107% for PIV to 135% for LB, 123.5 ± 9.8%). Games were the sessions with the lower CV (33.9% for LW to 61.1%, 45.5 ± 8.8%) for HSR.

Figure 3 illustrates the difference between playing positions expressed in the percentage of variation related to the mean game demands in the different variables. LB and RB showed a moderately to largely higher percentage of mean game demands in MD-1 when compared to wing players in TD (LB: -7.5 ± 13.3%, RB: 0.41 ± 17.15%, LW: -22.6 ± 13.2%, RW: -26.8 ± 11.8%; ES from 1.14 to 1.81), in PL (LB: -17.4 ± 12.5%, RB: -10.5 ± 16%, LW: -33.8 ± 10.6%, RW: -34.9 ± 12.3% and ES from 1.38 to 1.71).

PIV showed up to largely higher percentage of mean game demands in RPE value in all training sessions (MD-5: 17.3 ± 17.6%, MD-4: 19.4 ± 16.1%, MD-3: 22.9 ± 16.8%, MD-2: 15.3 ± 14.2%, MD-1: -3 ± 15.5%, ES from 1.26 to 1.83) when compared to the other players (MD-1: from -15.6 ± 13.8% to -26.2 ± 12.5%, MD-2: range -11 ± 14% to 8.19 ± 13.9%, MD-3: 15 ± 13.3%, MD-4: -4.6 ± 18.5 to 11.4 ± 19.9%, MD-5: -3.3 ± 20% to 15.5 ± 12.6%).

RB followed the same pattern in MD-5, MD-3, MD-2, and MD-1 (ES from 1.14 to 1.68). RB (29.7 ± 47.17%) reached a moderately to large higher percentage of mean game demands in high-speed running compared to wing players (LW: -72.4 ± 16.7%, ES = 1.21, RW: -68.1 ± 19.3%, ES = 1.03) in MD-1.

There were large differences in the percentage of mean game demands between PIV in MD-2, MD-3, and MD-4 (respectively, -22.8 ± 10.7% vs. -0.8 ± 16.1%, ES = 1.6, -21.5 ± 14.9% vs. 11.1 ± 19.5%, ES = 1.85, -24.5 ± 5.3% vs 5.4 ± 23.5%, ES = 1.51).

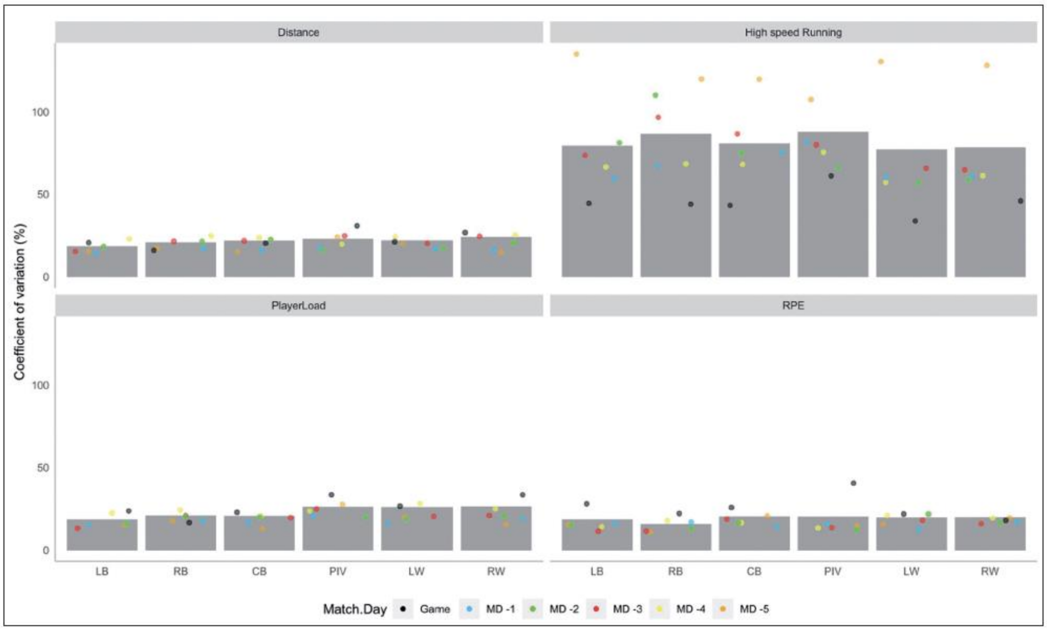

FIG. 2. Coefficient of variation for all the metrics in each playing position for the different training days.

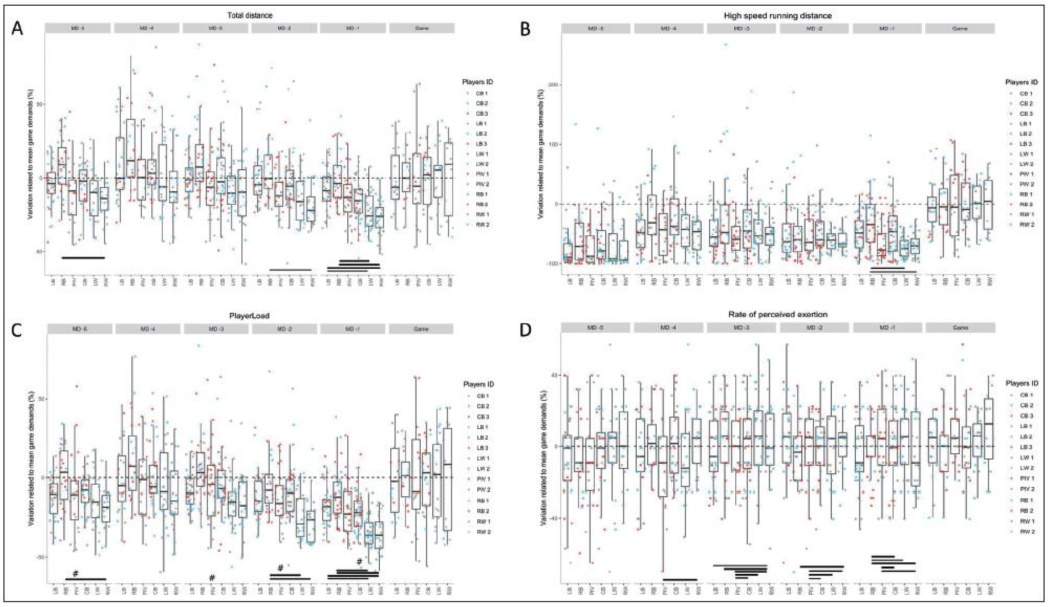

FIG. 3. Comparison of mean percentage of game demands between playing position related to game day in total distance (A), high-speed running distance (B), player load (C), and rate of perceived exertion (D). Bar graphs represent the mean and standard deviation percentage of mean game demands for each playing position related to game day. Coloured dots stand for individual value within the playing position and game day. The thickness of the lines represents the magnitude of the difference (effect size): ▬ very large difference; — large difference; — moderate difference.

DISCUSSION

To our knowledge, this is the first time a handball team has been monitored longitudinally during a season in practices and games with a combination of IMUs and RPE. The most significant differences between playing positions were noted on match days, showing that training does not replicate game demands. PL and HSR were the metrics with the most important differences. When the difference between playing positions was expressed as the percentage of variation related to the mean game demands, the most important differences were found in MD-1 and the RPE.

Match days

Regarding the external load in games, our results on match days are in line with previous studies. The wings (left (LW) and right (RW)) are, by far, the players who cover the most metres in HSR, both in training and in games. These results match those observed in earlier studies [5, 10, 12]. RW and LW were the players who covered the highest distance and RB the lowest. A similar effect has been found in previous studies [12].

Wings were also the players with the highest PL values compared to the other positions. These results differed from previous studies finding that CBs were the players with the highest PL value. Player rotation and team tactics could explain some of these differences because the nature of this playing time affects PL [31] substantially. In team handball, player rotations are unlimited and very easy to implement. As a result, many factors could explain this variation, such as players' performance level (the better they are, the longer they tend to play), the tactical choice of the coach, or game model requirements. PL has been developed as a measure of physical performance based on changes in acceleration to capture non-running-based work (e.g., jumping, changes of direction, acceleration, contact) [5].

PIV and RB had the lowest IL concerning the other positions. This result could be related to different players' rotation strategies. In many teams, RB are the players involved in the offensive/defensive systematic rotations for various reasons, such as a lack of defensive ability or fatigue management (RB need to be tall and left-handed and are essential for most teams). PIVs' performances are paramount for many teams, and the physical demands they must cope with are high [9]. As a result, many coaches tend to establish more rotations for the PIVs.

Training session

Total distance

PIV covered less distance than the other players during all training sessions (up to moderate to largely less than LB). The tactical and technical demands of the playing position likely play an important role. PIV players were a fixing point in the opponents' defence when backs played more around the defensive system. A vital part of handball training is devoted to the stabilized phase (Table 2), accounting for most ball possession in matches [32]. This result should be related to the main objective, the relative part of the session's static/full court phases, and the volume/intensity choice. It is expected that when training sessions are focused on static phases, PIVs do not accumulate many metres due to their defensive fixation function, performing more isometric or dynamic muscular actions. In turn, even if the training session is more dynamic (full-court situations), they tend to carry out the same function. Thus, they cover less distance and perform fewer running actions. These results are in line with those obtained in other studies where the PIV were the players who covered the lowest distance in official matches [5].

When expressed as a percentage of mean game demands, we can see that RB achieve a higher value than the other positions in many parts of training sessions. It is very likely that when there is a less stabilized phase in training (when coaches want their players to run more), the RB achieve a higher percentage as they run less than the other players in games. In training, all players tend to train simultaneously and perform the same tasks. These differences in RB (and to a lesser extent for LB) could be attributed to a higher rotation in playing time due to the demands on these positions according to the team's playing model [5].

High-speed running distance

Wings covered higher HSR distance in all training sessions than the other playing positions. These results confirm that training requirements are not always in line with game demands [5, 10, 12]. HSR distance is an essential metric for performance [33] and injury prevention [34]. Our findings support the idea of Karcher & Buchheit [9] that there is a need for specific sprint training and hamstring prevention work for wings. The HSR percentage of mean game demands suggests that training sessions do not replicate the competition load as the HSR distance is lower than the match demands in all training sessions for all players (Figure 3). This lack of specificity can lead to some issues in some players, especially wings (who cover the highest HSR distance, such as decreasing their performance [5, 12] and increasing their risk of injury [9]. HSR distances should be close to or above those required by the competition to allow players to cope with these demands [17].

Moreover, the coefficient of variation of HSR showed that this variable fluctuated a lot. Large differences were found in all playing positions depending on MD. This variation suggests that the technical and tactical objectives of the training largely influence the HSR content and that this variable is not always adequately managed [9]. Our results indicate that HSR distance is mainly subjected to tactical choices.

Player load

Our results showed a large variation in PL when comparing the different playing positions. This fact confirms that each player needs a training load as individualized as possible; the external load demands differ for each playing position [5, 6, 29]. At the same time, it was observed that MD-4 was the day that was closest in terms of PL to the competitive needs. As seen in Figure 2, MD-4 was the day when the greatest volume of work was carried out both in terms of time and full court work and when the highest PL values could be accumulated.

PL is one of the most used variables to control the external load in training and competition in handball [5, 6, 29]. PIV were the players with the lower PL values in competition and the different training sessions. The specific demands of the position at a physical, technical, and tactical level may explain this result [5]. Most of the needs of these players are based on isometric strength work, as they were the players who were the most involved in contact actions and with few accelerations and lower high-velocity displacement [9, 22]. Wings showed the highest PL value in any training session, following the other external load variables (total distance and HSR). These differences between positions could be explained by the tactical demands of each position, their needs, and the game model used by the team [5].

Rate of perceived exertion

Our results suggest that players rated the session with similar intensities despite many differences in the external load (e.g., HSR distance). Surprisingly, the internal load did not reproduce the same pattern as the external loading. We could suggest two explanations for this offset. Firstly, the extensive experience of the players in handball and years working with the same methodologies in the same club (3.3 ± 2.2 years in the club) may have caused a specific adaptation [17]. Secondly, many players' characteristics influence internal load values, such as muscle mass, substrate concentrations [35], body size [22], or fitness level [36]. As a result, two players receive equivalent external loads, but the internal load could differ depending on individual characteristics. The player's physical characteristics and body dimensions are position-dependent [6, 18, 21]. Overall, these factors mainly explain the results.

Comparing the values obtained during training sessions and games, we see that the results are often higher after training. These differences indicate that training and rest time density is much higher during the week than on MD. There are likely more in-game breaks due to the refereeing, the opponent's game pace, and the player's rotation strategies.

The differences in the percentage of variation considering the mean game demands are probably caused by the discrepancies between training and game values. Game demands fluctuate greatly when compared to the training context.

Coefficient of variation

The coefficient of variation is related to periodization, as variations in training load are a key and widely studied factor in performance [37]. Many studies suggest that poor training-load management and flawed prescription constitute significant risk factors for injury [38]. Our results show that games are the moment with the highest fluctuations in most of the variables. This is logical, considering that teams do not have control over the opponent's executions. Most CVs are low and show a small magnitude (18 to 29%) except for HSR. HSR's CV showed values ranging from 57 to 135%. Large differences were found in all playing positions depending on MD. This variation suggests that the technical and tactical objectives of training largely influence HSR content and that this variable is not managed [9]. These results indicate that HSR distance is a by-product of tactical choices. Too much variation in the same training days illustrates, from our point of view, that coaches do not control this variable. It is also worth noting that HSR distance was much higher during games than during training sessions, as training content does not replicate HSR game demands.

Limitations

We could only study one professional team with a particular match and training model. The team's profile (only one match per week) also allowed us to have stable microcycles that may not be generalizable to other contexts (teams playing more than one match per week, national teams). Another limitation is that the analysis of defensive specialists was not considered. Some players have a particular role, playing only during the defensive phase, and are not included in the attack. The type of training provided by the coaching staff, and its intensity, also influence the training demands to a large extent and can be a limitation. Other parameters, such as different playing strategies [39], the opponent's level [40] and the use of a defensive specialist, may have revealed different results than ours.

Practical applications

Coaches must consider variables such as positional demands or the team's playing style to tailor training demands. Our results show that coaches should carefully evaluate several indicators to design the optimal training content. In our data, some values in the training sessions were above the game demands (total distance, RPE) and others under (HSR, PL). This scenario can be suboptimal to prepare players for the "worst case scenario" in competition.

It is worth noting that training demands differ largely between positions (wings and PIV vs. RB). Handball staff should use this information before designing microcycles to adjust training loads more precisely.

CONCLUSIONS

We observed that internal load does not show the same pattern even if there are substantial differences in external load variables between playing positions. Our results confirm the need to control the load and the complementarity of the two types of load variables. One of the most relevant findings was the substantial variation in HSR between positions, games, and training sessions. Coaches must give special attention to HSR because it is an essential variable for injury prevention (9) and performance (12).

Further research is needed in handball to study the parameters that influences the behaviour of internal and external loading variables to optimize training.

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The authors declare no potential conflict of interest.

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