DOCTORAL DISSERTATION

Performance changes during elite soccer matches: The effect of substitutions

Miguel Lorenzo Martínez

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Supervised by: Dr. Ezequiel Rey Eiras

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Dr. Ezequiel Rey Eiras

DECLARES that the present work, entitled “Performance changes during elite soccer matches: The effect of substitutions”, submitted by Miguel Lorenzo Martínez to obtain the title of Doctor, was carried out under his supervision in the PhD programme “Sports Science, Physical Education and Healthy Physical Activity”. This is a joint PhD programme integrating the Universities of A Coruña and Vigo.
Pontevedra, Novembre 16, 2021.

The supervisor,

Dr. Ezequiel Rey Eiras

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ABBREVIATIONS

CM	Central midfielders
CD	Central defenders
EM	External Midfielders
ED	External defenders
ES	Effect size
F	Forwards
HIR	High-intensity running
HSR	High-speed running
Hz	Hertz
km·h^{-1}	Kilometres per hour
LSR	Low-speed running
m·min^{-1}	Meters per minute
MSR	Medium-speed running
n·min^{-1}	Number per minute
SD	Standard deviation
SEs	Standard errors
TD	Total distance

LIST OF PUBLICATIONS

The current dissertation comprises three research articles published in scientific journals included in the Journal Citation Reports:

Rey, E., Kalén, A., **Lorenzo-Martínez, M.**, López-Del Campo, R., Nevado-Garrosa, F., & Lago-Peñas, C. (2020). Elite soccer players do not cover less distance in the second half of the matches when game interruptions are considered. *Journal of Strength and Conditioning Research.* Advance online publication. https://doi.org/10.1519/JSC.0000000000003935

Lorenzo-Martínez, M., Padrón-Cabo, A., Rey, E., & Memmert, D. (2020). Analysis of physical and technical performance of substitute players in professional soccer. R*esearch Quarterly for Exercise and Sport.* Advance online publication. https://doi.org/10.1080/02701367.2020.1755414

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Apart from these studies that are part of the dissertation, Miguel Lorenzo Martínez has also published other research articles during his pre-doctoral stage:

Lorenzo-Martínez, M., Rey, E., & Padrón-Cabo, A. (2020). The effect of age on between-match physical performance variability in professional soccer players. *Research in Sports Medicine, 28* (3), 351–359. https://doi.org/10.1080/15438627.2019.1680985

Lorenzo-Martínez, M., de Dios-Álvarez, V. M., Padrón-Cabo, A., Costa, P. B., & Rey, E. (2020). Effects of score-line on internal and external load in soccer small-sided games. *International Journal of Performance Analysis in Sport, 20* (2), 231–239. https://doi.org/10.1080/24748668.2020.1736938

Barcala-Furelos, R., Abelairas-Gomez, C., Aranda-García, S., **Lorenzo-Martínez, M.**, Martínez-Isasi, S., Durán-Álvarez, C., Palacios-Aguilar, J., & Rodríguez-Núñez, A. (2020). Is it feasible "scoop and run while playing" resuscitation on a rescue water craft? A randomized simulation study with lifeguards. *The American Journal of Emergency Medicine, 38* (3), 618–623. https://doi.org/10.1016/j.ajem.2019.10.045

Lago-Peñas, C., Kalén, A., **Lorenzo-Martinez, M.**, López-Del Campo, R., Resta, R., & Rey, E. (2021). Do elite soccer players cover longer distance when losing? Differences between attackers and defenders. *International Journal of Sports Science & Coaching, 16* (3), 840–847. https://doi.org/10.1177/1747954120982270

Padrón-Cabo, A., **Lorenzo-Martínez, M.**, Pérez-Ferreirós, A., Costa, P. B., & Rey, E. (2021). Effects of plyometric training with agility ladder on physical fitness in youth soccer players. *International Journal of Sports Medicine, 42* (10), 896–904. https://doi.org/10.1055/a-1308-3316

Lorenzo-Martínez, M., Kalén, A., Rey, E., López-Del Campo, R., Resta, R., & Lago-Peñas, C. (2021). Do elite soccer players cover less distance when their team spent more time in possession of the ball?. *Science and Medicine in Football, 5* (4), 310–316. https://doi.org/10.1080/24733938.2020.1853211

Alonso-Calvete, A., Lage-Rey, A., **Lorenzo-Martínez, M.**, & Rey, E. (2021). Does a short intervention with vibration foam roller recover lifeguards better after a water rescue? A pilot study. *The American Journal of Emergency Medicine*, *49,* 71–75. https://doi.org/10.1016/j.ajem.2021.04.089

Lorenzo-Martínez, M., Corredoira, F. J., Lago-Peñas, C., López-Del Campo, R., Nevado-Garrosa, F., & Rey, E. (2021). Effects of age on match-related acceleration and deceleration efforts in elite soccer players. *International Journal of Sports Medicine*. Advance online publication. https://doi.org/10.1055/a-1337-2961

Alonso-Calvete, A., Padrón-Cabo, A., **Lorenzo-Martínez, M.**, & Rey, E. (2021). Acute effects of foam rolling on blood flow measured by ultrasonography in soccer players. *Journal of Strength and Conditioning Research*. Advance online publication. https://doi.org/10.1519/JSC.0000000000004125

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RESUMEN

INTRODUCCIÓN GENERAL

En el ámbito de las ciencias del deporte, el análisis del rendimiento hace referencia a la observación y análisis sistemático del rendimiento deportivo real de un individuo o un equipo (O'Donoghue, 2009), con el objetivo fundamental de optimizar el proceso de entrenamiento y los resultados en la competición (McGarry, 2009). En este contexto, los analistas y entrenadores deportivos utilizan generalmente indicadores de rendimiento, es decir, variables relacionadas con un rendimiento o resultado exitoso en un determinado deporte (Hughes y Bartlett, 2002). No obstante, debe tenerse en cuenta que el rendimiento en el fútbol puede depender de múltiples factores técnicos, tácticos, físicos, fisiológicos o mentales (Stølen et al., 2005).

La literatura científica en el fútbol ha analizado ampliamente las demandas físicas de la competición (Carling et al., 2008; Castellano et al., 2014; Sarmento et al., 2014). De esta forma, se ha señalado que los esfuerzos realizados por los jugadores a alta intensidad y esprintando son generalmente las acciones físicas más determinantes del rendimiento (Faude et al., 2012; Yang et al., 2018). Del mismo modo, con respecto al rendimiento técnico, diversos estudios han demostrado que indicadores como los lanzamientos totales, los lanzamientos a portería, el porcentaje de posesión de balón o los pases con éxito se encuentran relacionados con el éxito y los resultados positivos en los partidos (Castellano et al., 2012; Harrop & Nevill, 2014; Lago-Peñas et al., 2010; Lago-Peñas et al., 2011; Lepschy et al., 2020; Liu et al., 2016; Liu et al., 2015; Moura et al., 2014). Asimismo, el análisis de las relaciones espacio-temporales entre los jugadores durante los partidos se ha convertido también en los últimos años en uno de los indicadores clave de rendimiento en el fútbol y juega un papel relevante en la comprensión del comportamiento táctico de los equipos durante la competición (Low et al., 2019; Memmert et al., 2017; Memmert y Raabe, 2018; Rein y Memmert, 2016; Sarmento et al., 2018).

Además de la identificación de indicadores de rendimiento, otra línea de investigación relevante en este contexto es el análisis de los cambios en el rendimiento durante los partidos de fútbol y la posible influencia de la fatiga física aguda (Carling et al., 2008; Sarmento et al., 2014; Sarmento et al., 2018). A este respecto, varios estudios han demostrado que el rendimiento físico de los jugadores disminuye entre la primera y la segunda mitad de los partidos de fútbol, sobre todo en lo referente a la distancia recorrida a alta intensidad (Carling & Dupont, 2011; Di Salvo et al., 2009; Mohr et al., 2003; Rampinini et al., 2009). Además, este decremento de la capacidad física de los jugadores parece estar relacionada también con la disminución en el número de acciones técnicas con balón (Rampinini et al., 2009; Russell

et al., 2013), así como a nivel táctico, con la menor dispersión de los equipos en la segunda mitad de los partidos (Clemente et al., 2013; Coutinho et al., 2018; Moura et al., 2013). Estos cambios en el rendimiento pueden atribuirse al desarrollo de fatiga física (Bangsbo et al., 2007; Mohr et al., 2005; Reilly et al., 2008) o mental (Smith et al., 2018), aunque también debe considerarse la utilización de estrategias de dosificación por parte de los jugadores o la influencia de factores contextuales (Bradley & Noakes, 2013; Drust et al., 2007; Paul et al., 2015; Waldron & Highton, 2014).

Más concretamente, en cuanto a los factores contextuales, varios estudios se han centrado recientemente en el análisis del tiempo efectivo de juego y su relación con los cambios en el rendimiento durante los partidos (Carling & Dupont, 2011; Castellano et al., 2011; Lago-Peñas et al., 2012; Linke et al., 2018). De esta forma, se ha demostrado que el porcentaje de tiempo efectivo disminuye hacia el final de los partidos debido a un aumento en la duración de las interrupciones del juego (Carling & Dupont, 2011; Linke et al., 2018; Morgulev & Galily, 2019). Por consiguiente, este hecho podría influir en los cambios en el rendimiento de la primera a la segunda mitad de los partidos reportados en estudios previos, sobreestimando los efectos de la fatiga sobre el rendimiento físico (Lago-Peñas et al., 2012; Linke et al., 2018).

Por otro lado, el análisis de las sustituciones es un tópico de investigación emergente en el fútbol de alto rendimiento (Hills et al., 2018). De acuerdo con la literatura científica actual, la realización de sustituciones hacia el final de los partidos puede suponer una estrategia eficaz para contrarrestar los efectos de la fatiga en todo el equipo (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2008; Reilly et al., 2008). A este respecto, la mayoría de los estudios de investigación se han centrado en el análisis del rendimiento físico (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010; Liu et al., 2020; Mohr et al., 2003; Padrón-Cabo et al., 2018), mostrando que los jugadores substitutos recorren mayores distancias por minuto que los jugadores reemplazados o los que juegan el partido completo. En cuanto al rendimiento técnico, solamente Bradley et al. (2014) analizaron el porcentaje de pases acertados en jugadores de la Premier League inglesa, mostrando diferencias no significativas entre los jugadores sustitutos y los que completaban todo el partido o eran reemplazados.

Sin embargo, diversos estudios han coincidido en señalar que la razón principal para la realización de sustituciones durante un partido es modificar el comportamiento táctico de los equipos (Bradley et al., 2014; Del Corral et al., 2008; Gomez et al., 2016; Hirotsu & Wright, 2002; Reilly et al., 2008; Rey et al., 2015). Desde esta perspectiva táctica, las sustituciones en el fútbol se han clasificado comúnmente como neutrales, defensivas u ofensivas según el rol posicional de los jugadores involucrados (Del Corral et al., 2008; Gomez et al., 2016; Rey et al., 2015). No obstante, la literatura científica actual es escasa con respecto al análisis del impacto de las sustituciones sobre indicadores del comportamiento táctico colectivo (Hills et al., 2018; Hills et al., 2020).

De este modo, teniendo en cuenta la información mencionada con anterioridad, las sustituciones de jugadores pueden ser una estrategia eficaz para contrarrestar los efectos de la fatiga hacia el final de los partidos. Sin embargo, para determinar las posiciones de juego más afectadas por esta fatiga, parece necesario analizar el rendimiento físico de los jugadores considerando la influencia del tiempo efectivo de juego. Además, también parece necesaria más información sobre el efecto de las sustituciones en el rendimiento técnico y táctico. Por consiguiente, el propósito general de esta tesis fue analizar los cambios en el rendimiento durante los partidos de fútbol de élite teniendo en cuenta el efecto de las sustituciones. Para ello, se proponen tres objetivos específicos, correspondientes a cada uno de los tres estudios empíricos que conforman la tesis: (1) analizar la disminución en el rendimiento de carrera en la segunda mitad de los partidos cuando se considera el tiempo efectivo y las posiciones de juego; (2) analizar el rendimiento físico y técnico de los jugadores sustitutos con respecto a los que completan todo el partido o son reemplazados y examinar el rendimiento de los jugadores sustitutos en función de su posición de juego; y (3) analizar el efecto de los diferentes tipos de sustitución en el comportamiento táctico de los equipos de fútbol profesionales.

TRABAJO EMPÍRICO

Estudio 1 – Los jugadores de fútbol de élite no cubren menos distancia en la segunda mitad de los partidos cuando se consideran interrupciones del juego.

Este estudio tuvo como objetivo analizar las diferencias cuantitativas en las demandas físicas de los jugadores masculinos de fútbol de élite entre la primera y la segunda mitad de los partidos oficiales, teniendo en cuenta el tiempo efectivo de juego (la duración del juego después de restar las interrupciones del juego) y las posiciones de juego. Para ello se analizaron un total de 4,249 observaciones de partidos individuales pertenecientes a 412 jugadores de campo que competían en la liga española de primera división (LaLiga) durante la temporada 2018-2019. De acuerdo con Di Salvo et al. (2007), los jugadores se clasificaron en 5 posiciones de juego: defensas centrales, defensas laterales, mediocentros, extremos y delanteros. El rendimiento en los partidos se registró mediante un sistema de seguimiento óptico computarizado multi-cámara TRACAB (ChryronHego VID, Nueva York, NY), gestionado desde la aplicación Mediacoach (LaLiga, Madrid, España). Las variables de carrera registradas fueron la distancia total recorrida y a diferentes umbrales de velocidad: carrera a baja velocidad (0–14 $km \cdot h^{-1}$), carrera a velocidad media (14,1–21 $km \cdot h^{-1}$), carrera a alta velocidad (21,1–24 $km \cdot h^{-1}$) y esprintando (>24 $km \cdot h^{-1}$). Todas estas variables se calcularon tanto para el tiempo de juego total como para el tiempo efectivo y se normalizaron a metros recorridos por unidad de tiempo ($m \cdot min^{-1}$).

Los resultados principales de este estudio mostraron que cuando se considera el tiempo efectivo de juego no existen diferencias significativas en la distancia recorrida por los jugadores a alta velocidad (5,5 ± 2,4 frente a 5,5 ± 2,4 m·min^{-1}) y esprintando (5,3 ± 3,3 frente a 5,4 ± 3,3 m·min^{-1}) entre la primera y la segunda mitad de los partidos, a diferencia de lo observado cuando se consideró el tiempo total de juego. Sin embargo, estas diferencias en el rendimiento entre la primera y la segunda mitad dependieron de la posición de los jugadores. Mientras que los defensores laterales y extremos mantuvieron la distancia recorrida a alta velocidad y esprintando durante la segunda mitad, los defensores centrales y centrocampistas aumentaron significativamente ($p < 0.001$) la distancia recorrida a sprint durante el segundo período de los partidos. Por el contrario, los delanteros no pudieron mantener su distancia a alta velocidad (6.2 ± 2.3 vs. 5.9 ± 3.3 m·min^{-1}) y esprintando (7.0 ± 3.5 vs. 6.5 ± 3.4 m·min^{-1}) durante la segunda mitad. Estos hallazgos demostraron que el tiempo total de juego podría sobrestimar las disminuciones del rendimiento inducidas por la fatiga. Por lo tanto, el tiempo efectivo y la posición de juego deben tenerse en cuenta al interpretar el rendimiento físico de los jugadores de fútbol profesionales.

Estudio 2 – Análisis del rendimiento físico y técnico de los jugadores sustitutos en el fútbol profesional.

El objetivo de este estudio fue analizar el rendimiento físico y técnico de los jugadores sustitutos con respecto a aquellos que completaban todo el partido o eran reemplazados y también examinar el rendimiento de los sustitutos en diferentes posiciones de juego. La muestra estuvo compuesta por un total de 6,631 observaciones de partidos de 431 futbolistas profesionales que competían en la Bundesliga alemana durante la temporada 2018-2019. Estas observaciones se dividieron en tres grupos: partido completo (n = 3,807), reemplazados (n = 1,412) y sustitutos (n = 1,412). El rendimiento de los tres grupos se analizó independientemente de la posición de juego y por separado para cada posición (defensas centrales, defensas laterales, mediocentros, extremos y delanteros). Como variables dependientes se tuvieron en cuenta la distancia total recorrida por los jugadores, el número de carreras rápidas, el número de esprines, el porcentaje de posesión, la precisión en el pase y el número de contactos con el balón, pases, disparos y acciones defensivas (entradas, interceptaciones y despejes).

Con respecto a los resultados, los jugadores sustitutos mostraron mayor distancia total recorrida, número de carreras rápidas y esprines en relación con su tiempo de juego que los reemplazados y aquellos que completaban todo el partido. Las diferencias en el rendimiento técnico entre los grupos variaron en función de la posición de juego. Los sustitutos en la posición de defensa central mostraron menos posesión, toques y pases, pero un mayor número de acciones defensivas que los jugadores reemplazados y los que completaban todo el partido. Por el contrario, los jugadores sustitutos en las posiciones de centrocampista, extremo y delantero mostraron más posesión, toques y tiros que los jugadores reemplazados y los que completaban todo el partido.

Estudio 3 – El efecto de las sustituciones en el comportamiento táctico del equipo en el fútbol profesional.

En este estudio se investigó el efecto de las sustituciones de jugadores sobre el comportamiento táctico en el fútbol de alto rendimiento utilizando datos de posición. Para ello, la muestra consistió en 659 sustituciones de 234 partidos jugados en la Bundesliga alemana durante la temporada 2016-2017. Estas sustituciones se clasificaron como neutrales (n = 485), defensivas (n = 45) u ofensivas (n = 129) según los roles posicionales de los jugadores involucrados en cada sustitución. El comportamiento táctico de los equipos antes y después de cada sustitución se analizó teniendo en cuenta como variables dependientes la posición longitudinal del centroide del equipo, la distancia entre centroides de los equipos, la longitud y la amplitud del equipo, la relación entre la longitud y la amplitud de los equipos (LpW), el índice de estiramiento y el control del espacio para todo el campo y para cada tercio del mismo (defensivo, medio y ofensivo).

Los resultados de este tercer estudio evidenciaron diferencias en el efecto de las sustituciones neutrales, defensivas y ofensivas. El índice de estiramiento de los equipos fue significativamente más bajo después de las sustituciones defensivas. La relación LpW aumentó con la realización de sustituciones neutrales y ofensivas, mientras que la distancia entre centroides de los equipos disminuyó. La posición del centroide de los equipos, el control del espacio en el tercio medio y en el tercio ofensivo también fueron mayores tras la realización de sustituciones ofensivas. Estos hallazgos demostraron que las sustituciones de jugadores efectivamente modifican el comportamiento táctico de los equipos.

DISCUSIÓN GENERAL

Conclusiones

Teniendo en cuenta los hallazgos del Estudio 1, los futbolistas de élite no reducen su rendimiento físico en la segunda mitad de los partidos cuando se considera el tiempo efectivo de juego. Sin embargo, las variaciones en el rendimiento entre la primera y la segunda mitad dependen de la posición de juego. De este modo, al considerar el tiempo efectivo de juego, los delanteros parecen ser la única posición que reduce su rendimiento físico durante la segunda mitad de los partidos.

El Estudio 2 evidenció que los jugadores sustitutos pueden mejorar el rendimiento físico de los jugadores que completan todo el partido o son reemplazados, así como el rendimiento en algunas variables técnicas en función de la posición de juego. De forma más concreta, los jugadores sustitutos en la posición de defensa central mostraron un mayor número de

acciones defensivas, mientras que los centrocampistas, extremos y delanteros sustitutos mostraron más posesión, toques y tiros que los jugadores reemplazados o de partido completo.

Finalmente, en el Estudio 3 se demostró que las sustituciones de jugadores pueden modificar efectivamente el comportamiento táctico de los equipos, con diferentes efectos en función del tipo de sustitución. La realización de sustituciones ofensivas puede provocar una mayor presión defensiva y crear más oportunidades de gol debido a un mayor control del espacio en el tercio ofensivo, pero asumiendo un mayor riesgo durante la fase defensiva debido a una mayor dispersión del equipo. Por el contrario, las sustituciones defensivas pueden mejorar la efectividad defensiva a través una mayor compacidad del equipo.

Aplicaciones prácticas

Durante los partidos oficiales de fútbol, los entrenadores tienen un número limitado de sustituciones y, por lo tanto, la gestión eficiente de este recurso parece ser relevante (Rey et al., 2015). La literatura científica previa destacó el uso de las sustituciones como una estrategia eficaz para contrarrestar los efectos de la fatiga en el rendimiento físico (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2008; Reilly et al., 2008). Sin embargo, los hallazgos del Estudio 1 sugieren que solamente los delanteros reducen su rendimiento físico durante la segunda mitad de los partidos cuando se considera el tiempo efectivo de juego. En consecuencia, reemplazar los jugadores en la posición de delantero en el momento óptimo parece la estrategia más adecuada para mantener el rendimiento físico del equipo durante las segundas mitades.

Los resultados obtenidos en el Estudio 2 enfatizan la importancia de los jugadores sustitutos desde un punto de vista técnico y su posible contribución al éxito del equipo. La introducción de defensas centrales podría ser una buena estrategia cuando un equipo se encuentra por delante en el marcador, debido a su mayor rendimiento defensivo. Por el contrario, la introducción de centrocampistas, extremos o delanteros parece ser una estrategia efectiva para incrementar el rendimiento físico y técnico en estas posiciones de juego.

Desde una perspectiva táctica, los hallazgos del Estudio 3 mostraron que la realización de sustituciones ofensivas puede suponer una estrategia eficaz para revertir marcadores adversos, teniendo en cuenta sus efectos sobre el comportamiento táctico de los equipos. Por el contrario, cuando un equipo tiene un marcador favorable, hacer una sustitución defensiva puede ser útil para aumentar el éxito defensivo.

Limitaciones

Como principales limitaciones de esta tesis, debe tenerse en cuenta que estos hallazgos podrían no ser aplicables a otras ligas o competiciones debido a las diferencias en el rendimiento que pueden existir entre ellas (Dellal et al., 2011; Fernandez-Navarro et al., 2016; Yi et al., 2019). Además, en el Estudio 1 solamente se analizaron los datos de los jugadores que completaban todo el partido, por lo que es posible que algunos jugadores fuesen reemplazados debido a la disminución de su rendimiento físico durante la segunda mitad de los partidos. En el Estudio 2 no se consideró la posible influencia de variables contextuales como la ubicación del partido, la calidad de la oposición o el estado del marcador sobre el rendimiento de los jugadores. Finalmente, como principal limitación del Estudio 3 debe tenerse en cuenta que los criterios de clasificación utilizados para determinar el tipo de sustitución pueden no reflejar las intenciones ofensivas o defensivas reales de los entrenadores.

Futuras líneas de investigación

Con base en los hallazgos y limitaciones de la tesis actual, en futuras investigaciones sería interesante analizar la relación entre las disminuciones en el rendimiento de carrera y la condición física de los jugadores, así como la posible influencia de la edad sobre las variaciones en el rendimiento a lo largo de los partidos. En cuanto al análisis del rendimiento de los jugadores sustitutos, podría ser relevante considerar en futuros estudios la influencia de las variables contextuales y el tiempo efectivo de juego. A nivel táctico, los estudios futuros deberían considerar una clasificación más compleja de las sustituciones, así como las razones de los entrenadores para realizar cada sustitución. Por último, otra posible línea de investigación podría ser analizar el efecto de las sustituciones en el fútbol femenino.

I.
GENERAL INTRODUCTION

1. Performance analysis in soccer

Within the area of sports sciences, the observation and systematic analysis of the actual sports performance of an individual or a team in training or competition can be referred to as performance analysis (O'Donoghue, 2009). The main reason for undertaking performance analysis research is to develop an understanding of what is involved in sports performance (O'Donoghue et al., 2017), reducing the complexity and dynamic nature that characterizes many sports (O'Donoghue, 2009; Passos et al., 2016). Therefore, this scientific analysis of sports performance may substantially contribute to optimise the training process and competition outcomes (McGarry, 2009).

In this context, sports analysts and coaches generally use performance indicators to evaluate or compare the performance of an individual, a team, or elements of a team (Hughes & Bartlett, 2002). These performance indicators could be defined as the selection or combination of variables related to a successful performance or outcome in a specific sport (Hughes & Bartlett, 2002). For instance, Wright et al. (2012) showed that 86% of a sample of elite team sports coaches used performance indicators to assess key behaviours from matches. Moreover, 70% of the coaches surveyed were very or extremely confident that these performance indicators were related to success (Wright et al., 2012). Nevertheless, it should be taken into account that performance in soccer depends on several factors, such as technical, tactical, physical, physiological, or mental (Stølen et al., 2005).

More concretely, soccer scientific literature has extensively analysed the activity patterns and physical requirements of competition, as well as the differences between playing positions (Carling et al., 2008; Castellano et al., 2014; Sarmento et al., 2014). During elite soccer matches, outfield players typically cover a total distance (TD) of 9–12 km, of which high-intensity running (HIR; usually defined as the distance covered at a speed above 19.8 $km \cdot h^{-1}$) accounts for approximately 10% (Bradley et al., 2009; Di Salvo et al., 2007; Di Salvo et al., 2009; Mohr et al., 2003; Rampinini et al., 2007). However, these physical demands of soccer match-play depend on the playing position (Bradley et al., 2009; Di Salvo et al., 2007; Di Salvo et al., 2009). When comparing the five most common positions, research studies have shown that central midfielders (CM) and external midfielders (EM) cover greater TD than central defenders (CD), external defenders (ED), and forwards (F), being the EM those who cover the greatest distances at HIR (Bradley et al., 2009; Di Salvo et al., 2007; Di Salvo et al., 2009).

Regardless of these differences between positions, although players spend most of the match performing low-intensity activities (Bangsbo et al., 2007; Bradley et al., 2009; Stølen et al., 2005), high-intensity efforts appear to be the most decisive physical actions in soccer (Faude et al., 2012; Yang et al., 2018). In fact, Faude et al. (2012) analysed 360 goals scored in the first German league (Bundesliga), showing that 83% of these goals were preceded by at least one high-intensity action from the scorer or the player who provided the assist. Similarly, the distance covered by players at sprint has been identified as a key performance indicator of teams' success in the season (Ingebrigtsen et al., 2012; Yang et al., 2018).

Focusing on technical performance, several research studies have aimed to identify the performance indicators related to success and positive match outcomes in soccer (Castellano et al., 2012; Harrop & Nevill, 2014; Lago-Peñas et al., 2010; Lago-Peñas et al., 2011; Lepschy et al., 2020; Liu et al., 2016; Liu et al., 2015; Moura et al., 2014). Overall, the results of these studies seem to agreed that winning teams perform more total shots and shots on target than drawing and losing teams. Likewise, an increased percentage of ball possession (Castellano et al., 2012; Lago-Peñas et al., 2011; Liu et al., 2015; Moura et al., 2014) and successful passes (Harrop & Nevill, 2014; Lago-Peñas et al., 2011) were shown to have positive effects on the probability of winning a match. Apart from this information on teams' technical performance, it is also relevant to quantify the contribution of each individual player to the teams' success (Duch et al., 2010; Robertson et al., 2016). In fact, the players' technical performance indicators related to positive match outcomes of their teams vary according to the playing position (Konefał et al., 2019a; Yi et al., 2020).

However, performance in team sports depends not only on physical and technical factors, but also on the spatiotemporal relationships formed by players during matches (McGarry, 2009; Passos et al., 2016). Thus, players' positioning dynamics on the pitch has emerged as one of the key performance indicators in soccer and plays an important role in understanding the teams' tactical behaviour during the competition (Low et al., 2019; Memmert et al., 2017; Memmert & Raabe, 2018; Rein & Memmert, 2016; Sarmento et al., 2018). Considering the most recent systematic review in this field (Low et al., 2019), several variables are available to characterize collective tactical behaviour in soccer, most of them based on measures of position, distances, playing spaces, or numerical relations. Moreover, some of these variables derived from match positional data have been related to teams' match performance. For instance, an increased team compactness was associated with a lower risk of conceding shots (Moura et al., 2012), while the space controlled in the attacking third seems to be related to the probability of scoring goals and winning a match (Rein et al., 2017). In addition, the playing style during the offensive phase (Castellano et al., 2013; Duarte et al., 2013) or defensive strategy (Low et al., 2018; Low et al., 2021) adopted by soccer teams can also be characterized based on collective behaviour measures.

2. Performance changes during soccer match-play

As mentioned above, performance analysis in soccer has largely focused on the activity patterns of players during competition, which includes the analysis of the changes in performance throughout soccer match-play and the possible influence of acute physical fatigue (Carling et al., 2008; Sarmento et al., 2014; Sarmento et al., 2018).

In this regard, several research studies have shown that physical performance declines from the first half to the second half of soccer matches (Bradley et al., 2010; Bradley & Noakes, 2013; Bradley et al., 2009; Carling & Dupont, 2011; Di Salvo et al., 2007; Di Salvo et al., 2009; Mohr et al., 2003; Rampinini et al., 2007; Rampinini et al., 2009). More specifically, elite soccer players cover 2–5% less TD in the second half of matches (Bradley et al., 2010; Bradley et al., 2009; Carling & Dupont, 2011; Mohr et al., 2003; Rampinini et al., 2009), with higher decrements (3–9%) for the distance covered at HIR (Carling & Dupont, 2011; Di Salvo et al., 2009; Mohr et al., 2003; Rampinini et al., 2009). However, some studies obtained minimal differences for the distance covered at HIR (Bradley et al., 2010; Bradley et al., 2009; Di Salvo et al., 2007). Likewise, Di Salvo et al. (2007) reported a non-significant difference in the TD covered between the first and second half, although players were shown to spare energy in the second half by decreasing their distance covered at medium intensity while increasing the low-intensity distance.

Soccer scientific literature has also indicated a decline in technical performance throughout actual or simulated match-play (Carling & Dupont, 2011; Rampinini et al., 2009; Russell et al., 2011; Russell et al., 2013; Stone & Oliver, 2009). Concretely, players appear to have less involvements with the ball and perform fewer passes in the second half than in the first half of soccer matches, probably related to physical fatigue and decreased running performance (Rampinini et al., 2009; Russell et al., 2013). On the contrary, Carling & Dupont (2011) obtained non-significant differences in players' technical performance between match halves, although they did show a significant drop in technical-related involvements during the final 5 minutes of the matches. Nonetheless, research studies on simulated soccer matches seem to show clearer results. Thus, according to Stone & Oliver (2009), a 45-minute intermittent exercise protocol that replicated one-half of a match caused significant decrements in the players' ability to perform soccer-specific skills, such as dribbling and shooting. Similarly, Russell et al. (2011) demonstrated that passing and shooting ability decreased during the second half of a soccer match simulation as a consequence of exercise-induced fatigue.

Regarding tactical behaviour, previous studies have shown that team dispersion values decrease during the second half of soccer matches (Clemente et al., 2013; Coutinho et al., 2018; Moura et al., 2013). Once again, this change may be related to fatigue and the decrease in the physical capability of players to ensure an optimal spatiotemporal relationship between their teammates at any moment of the match (Clemente et al., 2013). In this regard, players are likely to reduce the distance between their teammates as playing time increases to adopt a more stable and less risky behaviour under fatigue conditions (Coutinho et al., 2018; Duarte et al., 2013). However, this decreased team dispersion also leads to less compliance with the width and length offensive principles of play (Clemente et al., 2013).

These changes in performance during the second half of soccer matches have generally been attributed to the development of acute physical fatigue (Bangsbo et al., 2007; Mohr et al., 2005; Reilly et al., 2008). In particular, fatigue towards the end of matches may be caused by a combination of peripheral factors, such as the depletion of glycogen stores in individual muscle fibres (Bangsbo et al., 2007; Bendiksen et al., 2012; Krustrup et al., 2006; Mohr et al., 2005), and central factors like a reduced central drive from the nervous system (Rampinini et al., 2011; Reilly et al., 2008). In addition, under conditions of heat stress, dehydration and associated hyperthermia could also contribute to performance impairments (Mohr et al., 2005). Moreover, due to the high cognitive demands of playing soccer, players are likely to experience mental fatigue during matches, which may also impair their physical, technical, decision-making, and tactical performance (Smith et al., 2018).

However, apart from physical and mental fatigue, the influence of self-pacing strategies and contextual factors should also be considered (Bradley & Noakes, 2013; Drust et al., 2007; Paul et al., 2015; Waldron & Highton, 2014). Therefore, changes in running performance during soccer matches could be due to players employing conscious or subconscious pacing strategies to allow physical performance to be well maintained for later stages of the match (Paul et al., 2015; Drust et al., 2007). In support, according to the results obtained by Rampinini et al. (2007), the players who covered a greater TD and distance at HIR during the first half significantly decreased these distances in the second half, while the players who covered shorter distances did not decrease their performance in the second half. Similarly, Bradley & Noakes (2013) concluded that physical performance in the second half was significantly influenced by activity performed during the first half in English Premier League soccer matches. Thus, players with high levels of activity in the first half of a match (defined as TD ≥ 70th percentile) covered 7% less TD and 12% less HIR distance in the second half, but no changes were evidenced when the levels of activity during the first half were lower (Bradley & Noakes, 2013).

As for contextual factors, several studies have recently focused on the analysis of effective playing time and its relationship with performance changes during soccer match-play (Carling & Dupont, 2011; Castellano et al., 2011; Lago-Peñas et al., 2012; Linke et al., 2018). This effective playing time could be defined as the duration of play after subtracting the amount of time in which the ball is out of play (Lago-Peñas et al., 2012). In the German Bundesliga, Siegle & Lames (2012) reported an average of 108 game interruptions per match, with a mean duration of 18 seconds. Likewise, in the FIFA World Cup 2014 there were around 109 stoppages per match, with an average duration of 23 seconds (Augste & Cordes, 2016). The most frequent reasons for stoppages appear to be throw-ins and free kicks, followed by goal kicks, corner kicks, and player substitutions (Augste & Cordes, 2016; Siegle & Lames, 2012).

Consequently, effective playing time in elite soccer matches usually accounts for 57–62% of the total playing time (Augste & Cordes, 2016; Siegle & Lames, 2012). However, this percentage of time has been shown to decrease towards the end of matches due to an increase in the duration of game interruptions (Carling & Dupont, 2011; Morgulev & Galily, 2019). In this context, game stoppages are commonly used by the leading teams as a tactical instrument to waste time, slow down the pace of the match and preserve their favourable score-line until the end of the match (Augste & Cordes, 2016; Morgulev & Galily, 2019). Specifically, Linke et al. (2018) reported a significant decline in effective playing time from 66.3% of the total playing time in the first 15 minutes to 55.9% in the final 15 minutes of matches. This fact could influence the aforementioned changes in performance from the first half to the second half of soccer matches, since players have fewer opportunities to engage in match activities as the game progresses (Carling & Dupont, 2011). Indeed, previous studies concluded that analysis of total playing time could overestimate the effects of fatigue on physical performance when compared to considering effective playing time (Lago-Peñas et al., 2012; Linke et al., 2018).

3. Player substitutions

Substitutions in soccer consist of a player entering the pitch in exchange for an existing player during a game stoppage, but the player who has been replaced can no longer participate in the match (Rey et al., 2015). During official soccer matches, teams are allowed to perform a maximum of 3 to 5 substitutions, depending on the competition (International Football Association Board, 2021). Therefore, substitutions are a limited resource for soccer coaches, a fact that emphasizes the importance of analysing its use in elite soccer (Rey et al., 2015).

In this regard, soccer coaches typically make player substitutions at half-time or during the second half of matches (Bradley et al., 2014; Del Corral et al., 2008; Gomez et al., 2016; Myers, 2012; Padrón-Cabo et al., 2018) for a wide variety of possible reasons. Current scientific literature suggests that a strategic use of substitute players towards the end of matches may counteract the effects of fatigue across the team (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2008; Reilly et al., 2008), but the main reason for substitutions is usually to modify tactics (Bradley et al., 2014; Del Corral et al., 2008; Gomez et al., 2016; Hirotsu & Wright, 2002; Reilly et al., 2008; Rey et al., 2015). Soccer coaches may also perform substitutions to replace players who have become injured (Del Corral et al., 2008), players punished with a yellow card (Ascari & Gagnepain, 2006; Del Corral et al., 2008), or underperforming players (Hills et al., 2018). Moreover, the introduction of substitute players during a match could be used as a time-wasting strategy (Bradley et al., 2014) or to give playing time to team members with less match exposure (Hills et al., 2018).

Based on the findings of a recent systematic review (Hills et al., 2018), most of the research studies regarding soccer substitutions have focused on the analysis of physical performance (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010; Liu et al., 2020; Mohr et al., 2003; Padrón-Cabo et al., 2018). Specifically, Mohr et al. (2003) reported that substitute players of an elite European team covered 25% more distance at HIR in the last 15 minutes of matches than starting players, as well as 63% more sprint distance. Likewise, English Premier League substitute players were shown to cover more TD and distance at HIR compared to the starting players who remained on the pitch after the substitution (Bradley & Noakes, 2013). Furthermore, some research studies analysed the performance of players when they were introduced as substitutes in relation to their own performance when playing whole-matches (Bradley et al., 2014; Bradley & Noakes, 2013). The results of these studies showed that players introduced as substitutes covered a greater TD and 15–21% more distance at HIR compared to the identical time period when they played the entire match (Bradley et al., 2014; Bradley & Noakes, 2013).

From a different methodological perspective, the physical performance of substituted, replaced, and whole-match players have also been analysed considering their total playing time (Bradley et al., 2014; Liu et al., 2020; Padrón-Cabo et al., 2018). In order to make this comparison, absolute match-running distances are commonly converted into relative distances per unit of time ($m \cdot min^{-1}$). Overall, substitute players have shown significantly greater running distances per minute than players who are replaced and those who play for the entire match duration (Bradley et al., 2014; Liu et al., 2020; Padrón-Cabo et al., 2018). For instance, according to the results reported by Bradley et al. (2014), substitutes covered around 10% and 27% more distance at HIR per minute than replaced and whole-match players, respectively.

Nevertheless, this higher match-running performance of substitute players seems to be modulated by playing position (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010; Padrón-Cabo et al., 2018). Despite the sample size limitations of previous studies in this field (Hills et al., 2018), substitute players in the position of CM appeared to show the greatest performance increases compared to replaced and whole-match players, especially regarding the distance covered at HIR (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010; Padrón-Cabo et al., 2018). Other factors such as the match score-line (Hills et al., 2019), the moment of pitch entry (Liu et al., 2020), or the period of the season (Padrón-Cabo et al., 2018) may also influence the physical performance of substitute players.

Regarding the technical performance of substitute players, Bradley et al. (2014) analysed the percentage of successful passes in English Premier League players, showing non-significant differences between substitute players and those who completed the entire match or were replaced. According to Hills et al. (2018), the fact that substitutes displayed similar passing accuracy to starting players is potentially important considering that substitute players cannot normally perform ball skills during their warm-up before entering the field (Hills et al., 2019). Furthermore, a case study of a team competing in the French League 1 concluded that the goals scored by substitute players in the last minutes of matches were a factor that could discriminate between a championship-winning season and less successful ones (Carling et al., 2015).

From a tactical perspective, soccer substitutions have been commonly classified as neutral, defensive, or offensive based on the field position of the players involved (Del Corral et al., 2008; Gomez et al., 2016; Rey et al., 2015). Thus, a substitution is considered neutral when a player is introduced into the same positional role as the replaced player, while offensive and defensive substitutions involve the introduction of substitute players in a more forward or backward position, respectively (Del Corral et al., 2008; Gomez et al., 2016; Rey et al., 2015).

Previous research studies in the Spanish LaLiga (Del Corral et al., 2008; Gomez et al., 2016) and the UEFA Champions League (Rey et al., 2015) showed that neutral substitutions were the most common, while offensive substitutions were more frequent than defensive ones. However, the use of each substitution strategy seems to be influenced by contextual factors such as match status. When a team is losing, coaches tend to make more offensive substitutions and earlier in the match (Del Corral et al., 2008; Gomez et al., 2016; Rey et al., 2015). In fact, the proposed decision guidelines for soccer substitutions highlighted the importance of changing tactics early to reverse losing scenarios (Myers, 2012; Rey et al., 2015). Conversely, defensive substitutions are usually made when a team is ahead and later in the match (Del Corral et al., 2008; Gomez et al., 2016; Rey et al., 2015).

According to the majority of professional soccer coaches surveyed in a recent study (Hills et al., 2020), substitutions represent an important factor in determining success and can often influence the outcome of a match. In support of these coaches' perceptions, Gomez et al. (2016) showed that the use of well-timed substitutions might improve teams' performance with regard to variables such as ball possession or goal-scoring opportunities. However, the current scientific literature is scarce regarding the impact of player substitutions on collective tactical behaviour metrics (Hills et al., 2018; Hills et al., 2020).

4. Aim of the dissertation

The general purpose of the dissertation is to analyse the changes in performance during elite soccer matches taking into account the effect of substitutions. Specifically, bearing in mind the aforementioned information, player substitutions can be an effective strategy to counteract the effects of fatigue towards the end of matches. However, to determine the playing positions most affected by fatigue, it seems necessary to analyse the physical performance of the players considering the influence of the effective playing time. Moreover, the present dissertation also aims to analyse the effect of player substitutions on physical, technical and tactical performance.

In order to accomplish this, three specific aims are proposed below, corresponding to the three empirical studies that are part of the dissertation.

Study 1 (Chapter 5) aimed to verify in a large sample of soccer players whether a decrease in match running performance occurs in the second half of matches when the effective playing time is considered and examine if these potential reductions in running performance depend on the playing positions.

Study 2 (Chapter 6) aimed to analyse the physical and technical performance of substitute players versus those who completed the entire match or were replaced and examine the performance of substitute players across different playing positions.

Study 3 (Chapter 7) aimed to analyse the effect of the different types of substitution on tactical behaviour in professional soccer teams.

II.
EMPIRICAL WORK

5. Study 1 – Elite soccer players do not cover less distance in the second half of the matches when game interruptions are considered

5.1. Abstract

This study aimed to analyse quantitative differences in the physical demands of male elite soccer players between the first and second halves during official matches, accounting for effective playing time (the duration of play after subtracting the game interruptions) and playing positions. A total of 4,249 individual match observations of 412 outfield players competing in the Spanish first division league (LaLiga) were undertaken during the 2018–2019 season, using a computerized tracking system (TRACAB, Chyronhego, New York, NY). The players were classified into 5 positional roles: CD, ED, CM, EM and F. The main results showed that in contrast to those observed when total playing time was considered, independent of playing position, there were no significant differences on high-speed running (HSR) (5.5 ± 2.4 vs. 5.5 ± 2.4 m·min^{-1}) and sprint (5.3 ± 3.3 vs. 5.4 ± 3.3 m·min^{-1}) distances between the first and second halves in professional soccer players when the effective playing time was considered. However, differences in match running performance at HSR and sprint distances between the first and second halves were dependent on players' playing position. Whereas ED and EM maintained HSR and sprint efforts during the second half, CD and CM significantly increased ($p < 0.001$) the distance covered at sprint during the second period of the match. Contrarily, F were unable to maintain their HSR (6.2 ± 2.3 vs. 5.9 ± 3.3 m·min^{-1}) and sprint (7.0 ± 3.5 vs. 6.5 ± 3.4 m·min^{-1}) match running performances during the second half. Such findings demonstrate that total playing time could overestimate fatigue-induced performance declines. Thus, effective playing time and playing position should be taken into account when interpreting the match running performance of professional soccer players.

5.2. Introduction

The match running performance of elite soccer players has been extensively studied over the past 25 years. Research portrays running performance to decline from the first half to the second half of soccer matches, particularly in the TD covered, time spent in HIR, and number of sprints (Bangsbo, 1994; Di Salvo et al., 2009; Mohr et al., 2003). The reduced distance covered in the second half could be attributed to fatigue, as studies have reported depleted muscle glycogen stores at the end of a match (Bendiksen et al., 2012; Krustrup et al., 2006), and is independent of playing position, level of competition, and sex (Mohr et al., 2004).

However, some researchers suggest that reductions in running performance in the second half could be attributed to physical or mental fatigue, pacing strategies, contextual factors, or a combination of mutually inclusive factors (Bradley & Noakes, 2013; Paul et al., 2015). The current study argues that the decline in players' match running performance during matches is non-existent or at least substantially amplified by an increase in game interruptions as the game progress.

Matches are usually composed of a series of play periods randomly interspersed with game stoppages, such as when the referee has called an infringement or the ball is off the playing field (Wallace & Norton, 2014). A study of game interruptions on elite soccer showed that there is an average of 108 interruptions per match and that matches are halted on average for 38% of the total match time (Siegle & Lames, 2012). More importantly, the duration of game interruptions increases toward the end of a match, and probably, this could have an impact on match running performance (Carling & Dupont, 2011). A recent study shows that there is a decline in effective playing time throughout a match, from 66.3% of the total playing time in the first 15 minutes to 55% in the final 15 minutes of a match (Linke et al., 2018). This may be due to the fact that leading teams during the final minutes of matches when scores are close spend almost twice more time tacking goal kicks and free kicks after offside (Morgulev & Galily, 2019). Game stoppages are used as a tactical instrument to kill time (Augste & Cordes, 2016).

The percentage of game time where the ball is in play is decreasing in modern soccer, whereas stoppage duration is increasing, and they directly impact potential work-to-recovery ratios, influence opportunities to rest, and determine the intensity with which players can compete during subsequent play periods (Glaister, 2005; Wallace & Norton, 2014). Despite this, to the best of our knowledge, only 3 studies have examined soccer-specific match running performance while considering the effective playing time (Castellano et al., 2011; Lago-Peñas et al., 2012; Linke et al., 2018). The results of these studies are inconclusive because they are based on small samples (Lago-Peñas et al., 2012; Linke et al., 2018), there was a lack of control for position-specific subdivisions of players (Castellano et al., 2011; Lago-Peñas et al., 2012; Linke et al., 2018), only matches with a narrow end result were considered for analysis (Linke et al., 2018), or only one team was analysed (Linke et al., 2018). Thus, it is clear that the consideration of the effective playing time may provide more precise information about competitive physical demands, and this can then be applied to the training context to develop drills more closely tailored to actual match requirements.

Therefore, the aims of the current study were to (a) verify in a large sample of soccer player whether a decrease in match running performance occurs in the second half of matches when the effective playing time is considered and (b) examine if these potential reductions in running performance depend on the playing positions. The research hypothesis is that professional soccer players are able to maintain their match running performance during the second half when the effective playing time is considered (Lago-Peñas et al., 2012). However, different responses could be present across playing positions (Di Salvo et al., 2007). Therefore, the data would provide relevant information on the extent to which playing positions are more or less affected by the course of a match and guide coaches on decisions concerning individualizing training strategies.

5.3. Methods

5.3.1. Experimental approach to the problem

In this cross-sectional study, physical performance data during matches from the Spanish first division league (LaLiga) from the 2018–2019 season were analysed according to match period and playing position. Data were collected only from outfield players (goalkeepers excluded) who participated in the entire match (i.e., 90 minutes). In addition, matches that included a player dismissal (red card) were excluded from the final sample.

5.3.2. Subjects

The sample comprised 4,249 individual match observations of 412 outfield players. In line with previous studies (Di Salvo et al., 2007), the players were classified into 5 positions: CD (match observations = 1,231), ED (match observations = 915), CM (match observations = 1,013), EM (match observations = 512), and F (match observations = 578). Playing position was classified manually by operators of LaLiga based on the individual technical-tactical activity on the pitch and the primary area in which this activity was performed. Players' playing position was re-categorized each game based on what they did in the field. As data used in this study were collected as part of players' routine monitoring, ethic committee approval and informed consent were not required (Winter & Maughan, 2009). In accordance with the ethical guidelines of LaLiga, this investigation does not include information that identifies soccer players (General Assembly of LaLiga, 2019).

5.3.3. Procedures

Match running performance was recorded using a multicamera computerized optical tracking system TRACAB (ChryronHego VID, New York, NY), managed from the application Mediacoach (LaLiga, Madrid, Spain) that has a sampling frequency of 25 Hz. The validity and reliability of this system for the variables used have previously been investigated (Felipe et al., 2019) and reported strong correlations ($r > 0.80$) and high intra-class correlation coefficients (>0.75) between Mediacoach multicamera tracking system and Global Positioning System. In addition, small (<0.30) to moderate (>0.60) SEs of estimate were observed in all speed categories used in this study.

Following previous research (Rey et al., 2019), match running performance was divided into the following categories: TD covered, low-speed running (LSR) distance (0–14 $km \cdot h^{-1}$), medium-speed running (MSR) distance (14.1–21 $km \cdot h^{-1}$), HSR distance (21.1–24 $km \cdot h^{-1}$), and sprinting speed running distance (>24 $km \cdot h^{-1}$), and these were collected for each player. Data were obtained from the Spanish Professional Football League (LaLiga), which authorized the use of the variables included in this investigation.

All physical performance variables were calculated for both total and effective playing time and normalized to meters per unit of time ($m \cdot min^{-1}$) (Linke et al., 2018). The total playing time was defined as the duration of the match as a whole, including injury time (Lago-Peñas et al., 2012). The effective playing time refers to the duration of play after subtracting the time taken up by stoppages, substitutions, injuries, and goals (Lago-Peñas et al., 2012).

In addition, the following situational independent variables were included match location (home or away), team quality, and match result (win, draw, or loss). Team quality was classified into 3 groups according to the criteria used by Vogelbein et al. (2014): high (teams that qualify for European competition), medium (teams that neither qualify for European competition nor descend to the second division), and low (teams that descend to the second division).

5.3.4. Statistical analyses

Results are reported as mean values and standard deviation (mean ± SD). The Kolmogorov-Smirnov and Levene's tests showed that all data were normally distributed and displayed homogeneous variance. Two-way analyses of variance (match period [first vs. second] x position [CD vs. ED vs. CM vs. EM vs. F]) were used to analyse the effects of match period and position on player activity normalized by effective playing time or total time. In the event of a difference being present, Bonferroni-adjusted post hoc tests were used to identify specific effects. In addition, effect size (ES) was calculated using Cohen's d, with the following formula: $d = (M2 - M1) / SD_{pooled}$. Cohen's d greater or equal to 0.2, 0.5, and 0.8 were considered to represent small, medium, and large differences, respectively (Cohen, 1988). Statistical significance was set at $p \leq 0.05$. All statistical analyses were conducted using IBM SPSS Statistics 21 for Macintosh (IBM Co., New York, NY).

5.4. Results

5.4.1. Effective playing time

The mean effective playing time for the whole match was 52 minutes 18 seconds ± 4 minutes 42 seconds (54.9 ± 5.2% of total time). The mean effective playing time was significantly lower ($t = 17.832$; $p < 0.001$; ES = 0.84) in the second period of the match (25 minutes 43 seconds ± 2 minutes 41 seconds, 52.5% of second period total time) than the first half (26 minutes 36 seconds ± 2 minutes 54 seconds, 57.4% of second period total time).

5.4.2. Match running performance

Descriptive statistics by match period and playing position are summarized in Table 5.1, whereas Figure 5.1 depicts the differences in percentage from the first half to the second half. Taking into account the total playing time, players, independent of playing position, covered significantly less TD ($p < 0.001$; ES = 0.78), LSR ($p < 0.001$; ES = 0.83), MSR ($p < 0.001$; ES = 0.42), HSR ($p < 0.001$; ES = 0.24), and sprint distances ($p < 0.001$; ES = 0.17) during the second period of the match compared with the first half. When effective playing time was considered, independent of playing position, players covered less TD ($p < 0.001$; ES = 0.11) and LSR ($p < 0.001$; ES = 0.39) distance during the first period of the match compared with the second period. In addition, players covered significantly greater MSR distance during the first half than the second half ($p < 0.001$; ES = 0.10). However, there were no significant differences in HSR ($p = 0.228$) and sprint ($p = 0.788$) distance between the first and second halves. No significant differences ($p > 0.05$) were found in match running performance between halves in function of match location, team quality, or match result.

5.4.3. Positional differences

Significant interactions between match period and playing position were obtained for the variables TD ($p < 0.001$), LSR ($p = 0.006$), MSR ($p < 0.001$), HSR ($p < 0.001$), and sprint ($p < 0.001$) distances according to the total playing time, as well as for TD ($p = 0.006$), LSR ($p = 0.002$), MSR ($p < 0.001$), HSR ($p = 0.001$), and sprint ($p < 0.001$) distances according to the effective playing time.

Taking into account the total playing time, CD covered significantly less TD ($p < 0.001$; ES= 1.05), LSR ($p < 0.001$; ES = 1.02), MSR ($p < 0.001$; ES = 0.62), and HSR ($p = 0.001$; ES = 0.11) distances during the second period of the match compared with the first half. When the effective playing time was considered, CD covered less TD ($p < 0.001$; ES = 0.12), LSR ($p < 0.001$; ES = 0.25), and sprint ($p < 0.001$; ES = 0.09) distances during the first period of the match compared with the second period.

Taking into account the total playing time, ED covered significantly less TD ($p < 0.001$; ES = 1.00), LSR ($p < 0.001$; ES = 0.82), MSR ($p < 0.001$; ES = 0.41), HSR ($p < 0.001$; ES = 0.27), and sprint distances ($p < 0.001$; ES = 0.24) during the second period of the match compared with the first half. When the effective playing time was considered, ED covered less TD ($p < 0.001$; ES = 0.21) and LSR ($p < 0.001$; ES = 0.28) distance during the first period of the match compared with the second period.

Taking into account the total playing time, CM covered significantly less TD ($p < 0.001$; ES = 1.06), LSR ($p < 0.001$; ES = 0.81), MSR ($p < 0.001$; ES = 0.73), and HSR ($p < 0.001$; ES = 0.26) distances during the second period of the match compared with the first half. When the effective playing time was considered, CM covered less TD ($p < 0.001$; ES = 0.10), LSR ($p < 0.001$; ES = 0.35), and sprint ($p < 0.001$; ES = 0.12) distances during the first period of the match compared with the second period. In addition, CM covered significantly greater MSR ($p < 0.001$; ES = 0.25) distance during the first half than the second half.

Taking into account the total playing time, EM covered significantly less TD ($p < 0.001$; ES = 0.82), LSR ($p < 0.001$; ES = 0.77), MSR ($p < 0.001$; ES = 0.44), HSR ($p < 0.001$; ES = 0.32), and sprint ($p < 0.001$; ES = 0.27) distances during the second period of the match compared with the first half. When the effective playing time was considered, EM covered less TD ($p < 0.001$; ES = 0.14) and LSR ($p < 0.001$; ES = 0.26) distance during the first period of the match compared with the second period. In addition, EM covered significantly greater MSR ($p = 0.012$; ES = 0.13) distance during the first half than the second half.

Taking into account the total playing time, F covered significantly less TD ($p < 0.001$; ES = 0.93), LSR ($p < 0.001$; ES = 0.81), MSR ($p < 0.001$; ES = 0.53), HSR ($p < 0.001$; ES = 0.32), and sprint ($p < 0.001$; ES = 0.35) distances during the second period of the match compared with the first half. When the effective playing time was considered, F covered less LSR ($p < 0.001$; ES = 0.25) distance during the first period of the match compared with the second period. In addition, F covered significantly greater MSR ($p < 0.001$; ES = 0.16), HSR ($p = 0.002$; ES = 0.16), and sprint ($p = 0.001$; ES = 0.12) distances during the first half compared with the second half.

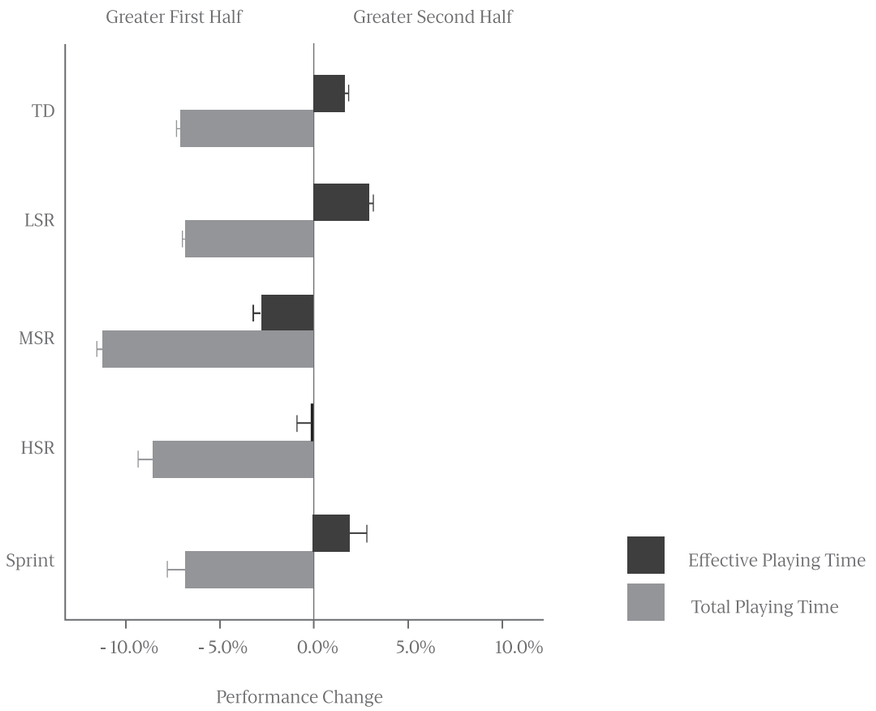

Figure 5.1. Percentage of change in physical performance between first and second half normalized by total or effective playing time. TD = Total distance; LSR = Low-speed running distance; MSR = Medium-speed running distance; HSR = High-speed running distance.

Table 5.1. Players' match activity according to match period depending on playing position, when effective or total playing time was considered.

	Independent of Position (n = 4,249)				**Central Defenders** (n = 1,231)			
	Effective playing time		Total playing time		Effective playing time		Total playing time	
	First half	Second half	First half	Second half	First half	Second half	First half	Second half
TD (m·min^{-1})	197.6 ± 24.6	200.7 ± 25.7*	112.2 ± 10.5	104.2 ± 9.8*	183.6 ± 19.9	186.9 ± 21.5*	104.3 ± 6.8	97.2 ± 7.0*
LSR (m·min^{-1})	144.4 ± 15.1	148.6 ± 16.5*	82.1 ± 5.8	77.3 ± 5.8*	142.3 ± 14.2	146.1 ± 15.5*	80.9 ± 4.8	76.1 ± 4.9*
MSR (m·min^{-1})	42.1 ± 12.1	41.0 ± 11.7*	23.9 ± 6.5	21.3 ± 5.7*	33.5 ± 7.4	32.6 ± 7.8*	19.0 ± 3.7	16.9 ± 3.6*
HSR (m·min^{-1})	5.5 ± 2.4	5.5 ± 2.4	3.1 ± 1.3	2.8 ± 1.2*	4.0 ± 1.6	4.2 ± 1.8	2.3 ± 0.9	2.2 ± 0.9#
Sprint (m·min^{-1})	5.3 ± 3.3	5.4 ± 3.3	3.0 ± 1.8	2.8 ± 1.7*	3.6 ± 1.9	4.0 ± 2.3*	2.1 ± 1.0	2.1 ± 1.2
	External defenders (n = 915)				**Central midfielders** (n = 1,013)			
	Effective playing time		Total playing time		Effective playing time		Total playing time	
	First half	Second half	First half	Second half	First half	Second half	First half	Second half
TD (m·min^{-1})	197.1 ± 19.8	201.5 ± 21.1*	111.9 ± 7.3	105.0 ± 7.3*	210.9 ± 22.3	213.9 ± 23.5*	120.1 ± 8.7	111.4 ± 7.9*
LSR (m·min^{-1})	142.5 ± 14.4	146.6 ± 14.8*	81.0 ± 5.1	76.4 ± 5.1*	149.3 ± 14.6	154.7 ± 15.4*	85.1 ± 5.7	80.6 ± 5.4*
MSR (m·min^{-1})	41.0 ± 8.2	41.3 ± 8.8	23.3 ± 4.1	21.5 ± 4.1*	52.3 ± 11.5	49.5 ± 11.1*	29.7 ± 6.0	25.7 ± 5.2*
HSR (m·min^{-1})	6.3 ± 2.1	6.5 ± 2.3	3.6 ± 1.1	3.3 ± 1.1*	5.4 ± 2.2	5.4 ± 2.3	3.1 ± 1.2	2.8 ± 1.2*
Sprint (m·min^{-1})	7.1 ± 3.1	7.0 ± 3.2	4.0 ± 1.7	3.6 ± 1.7*	3.8 ± 2.3	4.1 ± 2.6*	2.1 ± 1.3	2.1 ± 1.3
	External midfielders (n = 512)				**Forwards** (n = 578)			
	Effective playing time		Total playing time		Effective playing time		Total playing time	
	First half	Second half	First half	Second half	First half	Second half	First half	Second half
TD (m·min^{-1})	208.1 ± 23.7	211.8 ± 24.7*	118.7 ± 10.8	110.0 ± 9.7*	195.1 ± 27.5	195.4 ± 28.6	110.0 ± 10.4	101.0 ± 9.9*
LSR (m·min^{-1})	145.0 ± 15.4	150.5 ± 16.4*	82.7 ± 6.0	77.9 ± 6.0*	142.8 ± 18.9	145.2 ± 20.1*	80.5 ± 6.7	75.1 ± 6.7*
MSR (m·min^{-1})	48.1 ± 11.9	47.2 ± 11.4#	27.5 ± 6.9	24.5 ± 5.7*	39.0 ± 10.3	37.8 ± 9.9*	22.0 ± 5.3	19.5 ± 4.5*
HSR (m·min^{-1})	7.2 ± 2.4	7.0 ± 2.3	4.1 ± 1.3	3.6 ± 1.2*	6.2 ± 2.3	5.9 ± 2.3#	3.5 ± 1.3	3.0 ± 1.2*
Sprint (m·min^{-1})	7.5 ± 3.7	7.4 ± 3.8	4.3 ± 2.0	3.8 ± 1.9*	7.0 ± 3.5	6.5 ± 3.4#	3.9 ± 1.9	3.4 ± 1.7*

TD = Total distance; LSR = Low-speed running distance; MSR = Medium-speed running distance;
HSR = High-speed running distance.
*Significantly different ($p < 0.001$) from the first half. #Significantly different ($p < 0.05$) from first half.

5.5. Discussion

This study aimed to analyse quantitative differences in the physical demands of elite soccer players between the first half and second half, accounting for effective playing time and playing positions. The main findings were that (a) a significant decrement (~5%) in the effective playing time was observed during the second half of matches, (b) there were no significant differences on HSR and sprinting distances between the first half and second half in professional soccer players when the effective playing time was considered, and (c) differences in match running performance at a high-intensity between the first and second halves are dependent on players' playing position.

The average value of the effective playing time for all observed games was 52.3 ± 4.7 minutes (54.9 ± 5.2% of the total playing time) that was quite similar to those observed previously in relatively recent competitions such as in the UEFA Euro 2008 (54.4 ± 4 minutes) (Lago-Peñas et al., 2012) and World Cups 2006 (55.12 ± 2.58 minutes) and 2014 (54.10 ± 5.37 minutes) (Augste & Cordes, 2016). In addition, in line with previous evidence (~2%) (Lago-Peñas et al., 2012), a significant decline (~5%) in the effective playing time was observed during the second half of matches.

Match analysis has shown that sprint and high-intensity efforts are the most important physical actions in soccer due to the relationship with training status and their ability to discriminate between different levels of play (Bradley et al., 2009; Faude et al., 2012). These results showed, under the total playing time condition, significant decrements in all physical performance variables from the first half to the second half (ranged from 5.86 to 11.09%). Contrarily, considering the effective playing time, TD (1.52%) and LSR (2.91%) distance increased significantly from the first half to the second period, whereas the comparison of the $m \cdot min^{-1}$ covered by players at HSR and sprint in the first and second halves did not show significant differences. These effects were present in all teams, regardless of their competitive level, match location, and match result. Thus, these results seem to indicate that, regardless of the presence of fatigue during second halves, professional soccer players seem to be able to perform high-intensity efforts whenever necessary (Linke et al., 2018). This information seems to be especially important as high-intensity efforts are helpful indicators of players' physical performance in soccer and seems to support the notion that workload variations of elite players could not be only linked to fatigue but also to the strategic management of the playing time and pacing strategies (Lago-Peñas et al., 2012). However, these findings should be interpreted with caution because some players were removed if they did not complete a full match. Thus, it is reasonable to assume that some players substituted during second half leave the match when their physical performance starts to decline and they would have been unable to produce outputs similar to those described in this study by players who participated in the entire match.

A great deal of previous research on match-related fatigue in soccer showed decrements in match running performance during the second half, particularly in TD and high-intensity actions (Di Salvo et al., 2009; Mohr et al., 2003; Rampinini et al., 2009). However, these findings are partially in line with results obtained by Lago-Peñas et al. (2012) and Linke et al. (2018) in UEFA Euro 2008 and Bundesliga, respectively. Lago-Peñas et al. (2012) showed that, when the effective playing time was considered, the TD covered by players in the second half was slightly higher than that in the first period without significant differences (188.39 $m \cdot min^{-1}$ vs. 188.76 $m \cdot min^{-1}$). More recently, Linke et al. (2018) reported declines in match running performance during second halves more than twice as high when total playing time was considered compared with the effective playing time condition (24.2 vs. 10.2%). Together with results from a later study, this suggests that the effective playing time give a more representative overview of soccer players' match running performance (Castellano et al., 2011), indicating that the total playing time could overestimate fatigue-induced performance declines (Linke et al., 2018).

The physical performance during a match varies among playing positions (Bradley et al., 2009; Di Salvo et al., 2007). This study confirms, for the first time, that differences in match running performance at high intensity between first and second halves are dependent on players' playing position, when the effective playing time is considered. Whereas external players (i.e., ED and EM) maintained high-intensity efforts (HRS and sprint) during the second half, CD and CM significantly increased the distance covered at sprint during the second period of the match. Contrarily, F were unable to maintain their high-intensity match running performance during the second half, undergoing significant reductions in HSR and sprint distance compared with the first period of the match. Although it is hard for these findings to be put into perspective with the literature, as no other study has investigated this issue, present results could be attributed to a combination of factors including fatigue, lower level of aerobic power than other playing positions (Iaia et al., 2009; Marcos et al., 2018; Tønnessen et al., 2013), or the possibility of players adopting pacing strategies (Paul et al., 2015). In addition, from a decision-making perspective these results are not surprising and may be partially behind the coaches' practices during soccer substitutions, as F are one of the most frequent replaced players (Lorenzo-Martínez et al., 2020; Rey et al., 2015) and offset the effects of fatigue in tired players one of the primary motivations underlying decisions to use substitutions (Hills et al., 2020).

Concerning the limitations of the current study, some aspects should be highlighted: (a) A main limitation of this article was the absence of fitness level data obtained by a regular soccer test. Hence, future research is required to analyse the relationship between the decline of physical match performance during second halves and physical fitness; (b) Only starting players were included in the analysis. Some of the substituted players probably left the game because of physical performance declines. Future studies should address this limitation; and (c) Previous evidence showed that physical performance of soccer players may be affected by their age. Thus, this variable should be considered in further studies.

5.6. Conclusions

This study showed that professional soccer players do not reduce their running distance performance in the second half of the matches when game interruptions are considered. Therefore, the effective playing time should be taken into account when interpreting the match running performance of professional soccer players. In addition, this study demonstrated for the first time that variations on the match running performance from the first half to the second half are dependent on players' playing position, when the effective playing time is considered.

These findings, although necessary to be taken with caution due to the complex and unpredictable nature of soccer, may have a great deal of practical implications and may help coaches and strength and conditioning specialist to better understand match running performance variations according to playing positions. To achieve a comprehensive analysis of the real physical demands of official soccer matches, practitioners should take into account the effective playing time, as variations on the workload of the players could not only be linked to fatigue. In this context, F were the only position that reduces their physical performance (HSR and sprint distance) during the second half of the matches. Consequently, it is recommended that fitness coaches consider designing individualized soccer specific training programs (i.e., high-intensity interval training and repeated sprint ability training) for F to compensate physical fitness deficits that may contribute to running performance decrements during second halves. In addition, coaches should be aware that maintaining team physical performance during second halves could require replacing F at an optimal time.

6. Study 2 – Analysis of physical and technical performance of substitute players in professional soccer

6.1. Abstract

Current soccer scientific literature is scarce with regards to examining the technical performance of substitute players. Therefore, this study aimed to analyse the physical and technical performance of substitute players versus those who completed the entire match or were replaced and also examine the performance of substitutes across different playing positions. The sample was composed of 6,631 match observations from 431 professional soccer players competing in the German Bundesliga during the season 2018–2019. These observations were divided into three groups: entire match (n = 3,807), replaced (n = 1,412), and substitutes (n = 1,412). Linear mixed models were adjusted to compare the performance of the three groups independently of playing position and separately for each position (CD, ED, CM, EM, and F). Regarding the results, substitute players showed higher TD covered (ES = 0.99–1.06), number of fast runs (ES = 0.83–0.91), and number of sprints (ES = 0.60–0.64) relative to playing time than replaced and entire match players. The differences in technical performance between groups varied according to playing position. Substitute CD showed less possession (ES = 0.39–0.41), touches (ES = 0.47–0.57), and passes (ES = 0.54–0.59), but higher defensive performance (ES = 0.51–0.54) than replaced and entire match players. Substitutes CM, EM and F displayed more possession (ES = 0.22–0.47), touches (ES = 0.27–0.37), and shots (ES = 0.22–0.28) than replaced and entire match players. In conclusion, this study has shown that substitutes are able to improve the performance of the players who completed the entire match or were replaced in both physical and some technical variables depending on playing position.

6.2. Introduction

Soccer coaches have a limited amount of resources to change the course of a match (Rey et al., 2015). Consequently, an efficient management of substitutions could contribute to sustaining or reverting the score-line of a match (Carling et al., 2015; Myers, 2012; Rey et al., 2015). Generally, soccer coaches seem to have similar patterns of substitution, with small differences in timing between competitions (Del Corral et al., 2008; Gomez et al., 2016; Myers, 2012; Rey et al., 2015). However, there are a wide variety of reasons to make substitutions, such as to modify tactical behaviours (Hirotsu & Wright, 2002), counteract fatigue (Bradley et al., 2014), restructure the team after a dismissal, replace players punished with a yellow card (Ascari & Gagnepain, 2006), and replace injured or underperforming players (Hills et al., 2018). Soccer coaches could also make substitutions to provide playing time to individuals with less match exposure and prevent the accumulation of fatigue among other team members (Hills et al., 2018) or to waste time with a player's introduction (Bradley et al., 2014).

Several studies have investigated the match physical performance of soccer substitute players (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010; Hills et al., 2019; Padrón-Cabo et al., 2018). Overall, substitutes have shown higher running performance relative to playing time than the players who were replaced and those who completed the entire match (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010; Padrón-Cabo et al., 2018). It has been also shown that several variables such as playing position (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010; Padrón-Cabo et al., 2018), match score-line (Hills et al., 2019), and the period of the season (Padrón-Cabo et al., 2018) may each influence the physical performance of substitutes.

Nevertheless, the current scientific literature is scarce about the technical performance of substitute players. This information could be relevant taking into account that technical performance is considered an essential factor for match success in professional soccer (Castellano et al., 2012; Konefal et al., 2019a; Lago- Peñas et al., 2011; Liu et al., 2016; Yi et al., 2020). It has been shown that winning teams perform more shots, have more ball possession, and better passing accuracy in comparison with drawing and losing teams (Castellano et al., 2012; Lago-Peñas et al., 2011; Liu et al., 2016). In addition, players' technical performance across all playing positions has been also related to match outcome (Konefal et al., 2019a; Yi et al., 2020). However, to the best of our knowledge, only one previous study has attempted to analyse the technical performance in English Premier League substitute players (Bradley et al., 2014). Their results revealed no differences in the percentage of successful passes between substitutes, players who were replaced, and those who completed the entire match. Nonetheless, there is some controversy regarding whether technical skills decline across the match due to the effects of fatigue (Carling & Dupont, 2011; Rampinini et al., 2009). Indeed, a recent systematic review established that mental fatigue could cause a reduction in performance in decision-making and soccer-specific skills (Smith et al., 2018).

Consequently, bearing in mind the abovementioned considerations and limitations, it is necessary to examine a broader range of technical performance indicators in substitute players and their contribution to team success (Hills et al., 2018). Likewise, in previous studies, the sample size was considered limited in order to analyse the effects of playing position in substitute players (Hills et al., 2018). Hence, a large-scale analysis with multiple observations over a season could provide more comprehensive information about substitute players' performance. Therefore, the aims of this study were to (a) analyse the physical and technical performance of substitute players versus those who completed the entire match or were replaced and (b) examine the performance of substitute players across different playing positions. Based on the most recent systematic reviews (Hills et al., 2018; Smith et al., 2018), the research hypothesis is that substitute players, independently of position, would display higher relative physical and technical performance in comparison with replaced and entire match players.

6.3. Methods

6.3.1. Participants

The sample was composed of 6,631 individual observations from 431 professional soccer players competing in the German Bundesliga during the season 2018–2019. According to previous studies (Bradley et al., 2014; Padrón-Cabo et al., 2018), observations were collected from players who completed the entire match (n = 3,807), were replaced (n = 1,412), and substitutes (n = 1,412). In order to reduce the effect of injuries, the observations from substitutions that took place in the first half were not included (Del Corral et al., 2008; Myers, 2012), as well as the substitutions in stoppage time, i.e., later than 90th minute. The observations belonging to matches with a player dismissal were also excluded (Myers, 2012) due to the effect of dismissals on performance (Lago-Peñas et al., 2016). To ensure players' and teams' confidentiality, all data were anonymized in accordance with the principles of the Declaration of Helsinki. Ethical approval for this study was granted by the ethical committee of the German Sport University Cologne.

6.3.2. Variables and procedures

Match physical performance was examined considering the variables TD covered, number of fast runs, and number of sprints. The variable fast runs can be defined as the number of running activities in which players' speed is higher than 18 $km \cdot h^{-1}$ for at least 1 second, while sprints are the number of running activities above the speed threshold of 22.7 $km \cdot h^{-1}$ during at least 1 second (Hoppe et al., 2015; Link & de Lorenzo, 2016). These data were recorded using TRACAB multiple-camera computerized tracking system, and they are provided on the official website of Bundesliga (www.bundesliga.com). The validity and reliability of the TRACAB video tracking system have been analysed recently (Linke et al., 2018).

For the analysis of technical performance, according to previous studies (Lago-Peñas et al., 2016; Liu et al., 2016, 2013), the following variables were considered: possession, touches, passes, passing accuracy, shots, and defence. The operational definitions of these variables are shown in Table 6.1.

Table 6.1. Definitions for the technical variables considered in the study.

Possession	The duration when a player takes over the ball as a proportion of total duration when the ball was in play.
Touches	A sum of all events where a player touches the ball.
Pass	An intentional played ball from one player to another.
Passing Accuracy	The percentage of attempted passes that successfully found a teammate.
Shot	An attempt to score a goal, made with any (legal) part of the body, either on or off target.
Defence	Sum of the tackles, interceptions and clearances.
Tackle	Act of gaining possession from an opposition player who is in possession of the ball.
Interception	A player intercepts a pass with some movement or reading of the play.
Clearance	Attempt made by a player to get the ball out of the danger zone, when there is pressure from opponents on him.

All these technical data for each individual observation were collected manually from the public-accessed website of OPTA Sportsdata Company (www.whoscored.com). The tracking system used by this company has been assessed to have an acceptable inter-operator reliability, showing intra-class correlation coefficients ranged from 0.88 to 1.00 (Liu et al., 2013). Data related to playing time for each player observation were also obtained from the same website (www.whoscored.com). Absolute values for the variables TD, fast runs, sprints, touches, passes, shots, and defence were converted into relative values per unit of time ($n \cdot min^{-1}$). Additionally, in order to assess the participation of each player within his team, touches data were also converted into a percentage over team total touches (touches ratio) according to the procedures proposed by Robertson et al. (2016).

According to previous studies, all players were classified as CD, ED, CM, EM, and F (Bradley et al., 2014; Bradley & Noakes, 2013; Padrón-Cabo et al., 2018). This classification was done based on the playing position in each game according to the data available on OPTA website.

6.3.3. Statistical analyses

All analyses were conducted using the statistical software R version 3.5.2 (R Core Team, 2018). The descriptive results for each variable are presented as mean ± SD. Linear mixed models were adjusted using the R package lme4 (Bates et al., 2015) to analyse the differences between the performance of substitute, replaced, and entire match players (fixed factor). Player identity, team, and match were modelled as random effects to account for the repeated measurements. All these analyses were performed for the whole data and then separately for each playing position. The assumptions of homogeneity and normal distribution of the residuals were verified for each model, without revealing specific problems. Pair-wise comparisons between groups were conducted via Bonferroni post-hoc test, using Cohens' d to calculate ES. According to Cohen (1988), these effects were classified as trivial ($d < 0.2$), small ($0.2 \leq d < 0.5$), medium ($0.5 \leq d < 0.8$), and large ($d \geq 0.8$). For all analyses, the significance value was set at $p < 0.05$.

6.4. Results

Table 6.2 displays the differences in match performance of substitute players in comparison with those who completed the entire match or were replaced. Independently of playing position, the substitutes showed higher relative TD covered ($p < 0.001$; ES = 0.99–1.06, large), number of sprints ($p < 0.001$; ES = 0.60–0.64, medium), and fast runs ($p < 0.001$; ES = 0.83–0.91, large) than the players who were replaced or completed the entire match. Substitute players also showed significantly ($p < 0.001$) higher possession (ES = 0.33, small), touches (ES = 0.25, small), touches ratio (ES = 0.47, small), shots (ES = 0.29, small), and defence (ES = 0.24, small) in comparison with the players who were replaced as well as higher touches ratio ($p < 0.001$; ES = 0.28, small) and shots ($p < 0.001$; ES = 0.29, small) than the players who completed the entire match. Trivial differences (ES <0.20) were obtained between the players who were replaced and those who completed the entire match for the variables TD covered, number of sprints, fast runs, possession, touches, touches ratio, and passes. Both replaced and substitute players showed worse passing accuracy (ES = 0.12–0.16, trivial) in comparison with the players who complete the entire match.

Furthermore, the results given in Table 6.2 are also presented depending on field position. For all playing positions, the substitutes showed significantly higher ($p < 0.001$) TD covered (ES = 0.77–1.22, medium to large), sprints (ES = 0.39–0.80, small to large), and fast runs (ES = 0.45–0.97, small to large) relative to playing time than replaced and entire match players, except for sprints between substitute and replaced CD. Regarding technical performance, substitute CD showed less possession ($p < 0.05$; ES = 0.41–0.39, small), touches ($p < 0.001$; ES = 0.47–0.57, small and medium), touches ratio ($p < 0.05$; ES = 0.28–0.41, small), and passes ($p < 0.001$; ES = 0.54–0.59, medium) relative to playing time than the players who completed the entire match or were replaced but higher number of defence actions per minute ($p < 0.01$; ES = 0.54–0.51, medium). Substitute ED exhibited higher possession than those who were replaced ($p = 0.023$; ES = 0.41, small) or completed the entire match ($p < 0.001$; ES = 0.49, small), with also more touches ratio in comparison with the ED who completed the entire match ($p = 0.003$; ES = 0.42, small), but worse passing accuracy ($p = 0.005$; ES = 0.39, small).

In the position of CM, substitutes showed higher possession ($p < 0.001$; ES = 0.30–0.47, small), touches ($p < 0.001$; ES = 0.27–0.37, small), touches ratio ($p < 0.001$; ES = 0.33–0.55, small and medium), shots ($p < 0.01$; ES = 0.27–0.22, small), and defence relative to playing time ($p < 0.05$; ES = 0.17–0.31, trivial to small) than entire match and replaced players. Substitute EM

showed higher possession (p = 0.009; ES = 0.22, small), touches ratio (p = 0.001; ES = 0.27, small), and shots relative (p = 0.005; ES = 0.23, small) in comparison with the players who complete the entire match and also higher possession (p < 0.001; ES = 0.43, small), touches (p < 0.001; ES = 0.35, small), touches ratio (p < 0.001; ES = 0.59, medium), shots (p = 0.002; ES = 0.28, small), and defence (p = 0.015; ES = 0.23, small) than replaced wide midfielders. Substitute F exhibited higher possession (p < 0.001; ES = 0.30–0.41, small), touches (p < 0.001; ES = 0.30–0.37, small), touches ratio (p < 0.001; ES = 0.45–0.48, small), shots (p < 0.001; ES = 0.22–0.28, small), and defence actions per minute (p < 0.05; ES = 0.17–0.20, trivial and small) than entire match and replaced F.

Table 6.2. Match performance of substitute players in comparison with those who completed the entire match or were replaced (Mean ± SD).

	Independent of Position			Central Defender			External Defender		
	Entire Match (n=3807)	Replaced (n=1412)	Substitute (n=1412)	Entire Match (n=1124)	Replaced (n=72)	Substitute (n=93)	Entire Match (n=709)	Replaced (n=107)	Substitute (n=70)
Time Played (min)	94.44 ± 1.82	72.39 ± 12.64	21.98 ± 12.61	94.41 ± 1.80	61.56 ± 13.42	20.98 ± 14.06	94.50 ± 1.79	71.27 ± 14.50	21.17 ± 14.19
TD (m·min^{-1})	118.51 ± 9.26$^{\#‡}$	120.53 ± 9.03*‡	129.35 ± 18.42$^{*\#}$	109.27 ± 6.89‡	111.02 ± 8.20‡	117.39 ± 16.71$^{*\#}$	117.03 ± 6.70‡	117.85 ± 8.48‡	124.34 ± 16.43$^{*\#}$
Fast Runs (n·min^{-1})	0.72 ± 0.18$^{\#‡}$	0.76 ± 0.18*‡	0.90 ± 0.35$^{*\#}$	0.49 ± 0.11$^{\#‡}$	0.53 ± 0.13*‡	0.58 ± 0.28$^{*\#}$	0.71 ± 0.13$^{\#‡}$	0.74 ± 0.13*‡	0.84 ± 0.33$^{*\#}$
Sprints (n·min^{-1})	0.23 ± 0.09$^{\#‡}$	0.24 ± 0.09*‡	0.30 ± 0.17$^{*\#}$	0.15 ± 0.06‡	0.16 ± 0.06	0.17 ± 0.12*	0.25 ± 0.07$^{\#‡}$	0.27 ± 0.07*‡	0.31 ± 0.19$^{*\#}$
Possession (%)	4.44 ± 2.03$^{\#‡}$	4.17 ± 1.81*‡	4.75 ± 2.75$^{*\#}$	5.88 ± 2.24‡	5.83 ± 2.34‡	4.99 ± 3.65$^{*\#}$	4.72 ± 1.63‡	4.90 ± 1.60‡	5.56 ± 3.53$^{*\#}$
Touches (n·min^{-1})	0.64 ± 0.23$^{\#‡}$	0.61 ± 0.22*‡	0.66 ± 0.31$^{*\#}$	0.74 ± 0.24‡	0.76 ± 0.27‡	0.63 ± 0.36$^{*\#}$	0.73 ± 0.20	0.77 ± 0.20	0.78 ± 0.39
Touches Ratio (%)	9.08 ± 2.37$^{\#‡}$	8.70 ± 2.47*‡	9.86 ± 3.98$^{*\#}$	10.40 ± 2.17‡	10.67 ± 2.13‡	9.75 ± 4.54$^{*\#}$	10.64 ± 1.74‡	10.86 ± 1.92	11.49 ± 4.09*
Passes (n·min^{-1})	0.44 ± 0.23$^{\#}$	0.42 ± 0.20*	0.43 ± 0.27	0.60 ± 0.25‡	0.61 ± 0.27‡	0.48 ± 0.37$^{*\#}$	0.45 ± 0.19	0.47 ± 0.18	0.48 ± 0.32
Passing Accuracy (%)	77.70 ± 11.07$^{\#‡}$	75.98 ± 12.36*	75.18 ± 23.55*	83.14 ± 9.25	81.58 ± 9.08	81.16 ± 24.08	76.66 ± 10.18‡	75.14 ± 10.86	71.96 ± 26.91*
Shots (n·min^{-1})	0.01 ± 0.01‡	0.01 ± 0.02‡	0.02 ± 0.04$^{*\#}$	0.01 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.01 ± 0.01‡	0.01 ± 0.01	0.00 ± 0.01*
Defence (n·min^{-1})	0.05 ± 0.04‡	0.05 ± 0.03‡	0.06 ± 0.07$^{*\#}$	0.08 ± 0.04‡	0.08 ± 0.04‡	0.10 ± 0.10$^{*\#}$	0.06 ± 0.03	0.06 ± 0.04	0.07 ± 0.08
	Central Midfielder			**External Midfielder**			**Forward**		
	Entire Match (n=1007)	Replaced (n=472)	Substitute (n=389)	Entire Match (n=433)	Replaced (n=267)	Substitute (n=311)	Entire Match (n=534)	Replaced (n=494)	Substitute (n=549)
Time Played (min)	94.47 ± 1.80	72.56 ± 12.61	21.79 ± 13.00	94.44 ± 1.86	73.61 ± 11.80	21.98 ± 12.03	94.40 ± 1.89	73.38 ± 11.83	22.39 ± 12.19
TD (m·min^{-1})	124.46 ± 7.39$^{\#‡}$	126.10 ± 7.52*‡	134.81 ± 16.28$^{*\#}$	120.56 ± 6.95$^{\#‡}$	122.78 ± 7.39*‡	131.74 ± 16.87$^{*\#}$	120.10 ± 8.57‡	121.67 ± 8.84‡	130.61 ± 19.88$^{*\#}$
Fast Runs (n·min^{-1})	0.76 ± 0.17$^{\#‡}$	0.79 ± 0.19*‡	0.95 ± 0.33$^{*\#}$	0.81 ± 0.12$^{\#‡}$	0.85 ± 0.15*‡	0.99 ± 0.29$^{*\#}$	0.82 ± 0.16‡	0.84 ± 0.16‡	1.00 ± 0.36$^{*\#}$
Sprints (n·min^{-1})	0.21 ± 0.08‡	0.22 ± 0.08‡	0.28 ± 0.17$^{*\#}$	0.29 ± 0.08‡	0.29 ± 0.08‡	0.35 ± 0.17$^{*\#}$	0.28 ± 0.08‡	0.29 ± 0.08‡	0.34 ± 0.17$^{*\#}$
Possession (%)	4.82 ± 1.81$^{\#‡}$	4.53 ± 1.81*‡	5.42 ± 2.92$^{*\#}$	3.92 ± 1.33‡	3.62 ± 1.47‡	4.32 ± 2.53$^{*\#}$	2.99 ± 1.25‡	2.90 ± 1.10‡	3.43 ± 1.90$^{*\#}$
Touches (n·min^{-1})	0.66 ± 0.21‡	0.64 ± 0.21‡	0.72 ± 0.32$^{*\#}$	0.61 ± 0.17	0.58 ± 0.19‡	0.65 ± 0.31$^{\#}$	0.48 ± 0.15‡	0.48 ± 0.14‡	0.54 ± 0.24$^{*\#}$
Touches Ratio (%)	9.51 ± 2.00$^{\#‡}$	9.06 ± 2.26*‡	10.33 ± 3.60$^{*\#}$	8.91 ± 2.13$^{\#‡}$	8.11 ± 2.07*‡	9.69 ± 3.86$^{*\#}$	6.94 ± 1.94‡	6.97 ± 1.84‡	8.21 ± 3.76$^{*\#}$
Passes (n·min^{-1})	0.48 ± 0.20	0.46 ± 0.20‡	0.50 ± 0.30$^{\#}$	0.36 ± 0.13	0.35 ± 0.16	0.36 ± 0.24	0.29 ± 0.13	0.29 ± 0.11‡	0.31 ± 0.17$^{\#}$
Passing Accuracy (%)	79.08 ± 9.93‡	77.71 ± 10.98	77.04 ± 20.77*	72.85 ± 11.31	73.92 ± 12.78	74.02 ± 23.32	72.56 ± 11.69	71.58 ± 12.72	71.35 ± 24.53
Shots (n·min^{-1})	0.01 ± 0.01‡	0.01 ± 0.02‡	0.02 ± 0.03$^{*\#}$	0.02 ± 0.02‡	0.02 ± 0.02‡	0.03 ± 0.04$^{*\#}$	0.03 ± 0.02‡	0.03 ± 0.02‡	0.04 ± 0.05$^{*\#}$
Defence (n·min^{-1})	0.05 ± 0.03‡	0.04 ± 0.03‡	0.06 ± 0.08$^{*\#}$	0.04 ± 0.03	0.03 ± 0.02‡	0.04 ± 0.06$^{\#}$	0.02 ± 0.02‡	0.02 ± 0.02‡	0.03 ± 0.05$^{*\#}$

*Significant difference (p < 0.05) with Entire; $^{\#}$Significant difference (p < 0.05) with Replaced;
‡Significant difference (p < 0.05) with Substitute. TD = total distance.

6.5. Discussion

The main aim of this study was to analyse the physical and technical performance of substitute players versus those who completed the entire match or were replaced. The results obtained have shown that substitute players performed better in some technical variables such as possession, touches, shots, and defence in comparison with the players who completed the entire match or were replaced. To our knowledge, this is the first study that analysed several technical performance indicators in substitute players, as previous studies have pointed out the need for information about this topic (Bradley et al., 2014; Hills et al., 2018). The results related to physical performance have also shown that substitute players displayed in all playing positions higher TD covered, number of fast runs, and sprints relative to playing time than the players who were replaced or completed the entire match. These findings are in agreement with previous studies as the higher work rate of substitute players was well established in the scientific literature (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010; Padrón-Cabo et al., 2018). Nevertheless, this study added information about a competition that had not been analysed yet, namely the German Bundesliga. In this sense, bearing in mind the cultural differences in physical and technical aspects of match-play that could exist between leagues and playing positions (Dellal et al., 2011; Yi et al., 2019), the results obtained in this study provide relevant information about substitute players' performance for Bundesliga coaches.

Focusing on technical performance, the research literature has demonstrated that some technical variables, such as ball possession, passing accuracy, and shots, could accurately discriminate between successful and unsuccessful teams (Castellano et al., 2012; Lago-Peñas et al., 2011; Liu et al., 2016). Despite their importance, little attention has been given to examining the technical activities in substitute players (Bradley et al., 2014; Hills et al., 2018). Bradley et al. (2014) analysed the percentage of successful passes in English Premier League players, obtaining no differences between those who completed the entire match, were replaced, or substitutes. Similarly, the results obtained in the present study have shown only trivial differences in passing accuracy between entire match, replaced, and substitute players. More generally, Rampinini et al. (2009) determined that the total number of short passes, successful passes, and involvements with the ball decreases between the first and second half of soccer matches, probably as a consequence of players' fatigue. In this sense, the substitutions appear to be a good strategy to counteract this decline in technical performance since the substitute players showed more possession, touches, shots, and defence actions per minute in comparison with the players who were replaced and those who completed the entire match. However, it should be noted that substitutes displayed slightly worse passing accuracy, maybe due to riskier pass attempts and the influence of match status in the moment of pitch-entry (Gomez et al., 2016).

Nevertheless, the results independently of position could be influenced by the patterns of substitutions, as in accordance with previous studies (Bradley et al., 2014; Del Corral et al., 2008; Gomez et al., 2016; Padrón-Cabo et al., 2018), more substitutions were made in offensive positions, i.e., CM, EM and F. Moreover, the physical and technical performance seems to vary according to positional role (Bradley et al., 2014; Konefal et al., 2019b). For these reasons, the differences in the performance of substitute, replaced, and entire match players should be discussed specifically for each playing position. Thus, the substitute CD analysed in this study have shown more defensive actions per minute, but less possession, touches, and passes in comparison with the defenders who were replaced or completed the entire match. Usually, soccer coaches tend to introduce defensive players when their team is ahead (Myers, 2012; Rey et al., 2015). This fact could explain the results obtained since teams have less ball possession and should perform more defensive actions when they are winning (Bradley et al., 2013; Lago, 2009). However, it should be noted that the players introduced in the role of ED did not show significantly higher defensive performance than replaced or entire match ED.

On the contrary, when a team is losing, coaches introduce more offensive players in the match (Myers, 2012; Rey et al., 2015). This strategy has been suggested to increase team's ball possession (Gomez et al., 2016) or team's chances of creating scoring opportunities (Bradley et al., 2014; Gomez et al., 2016). Accordingly, the results of this study have shown that CM, EM, and F entering the match as substitutes were able to display more possession, touches, and shots in comparison with the players who were replaced or completed the entire match. These findings emphasize the importance of substitute players from a technical point of view and their possible contribution to team success. In this sense, previous scientific literature has related the number of touches and shots performed by midfielders and attackers with match success (Konefal et al., 2019a; Yi et al., 2020). Likewise, Carling et al. (2015) highlighted the role of substitutes as a factor to the team's season success due to the numbers of goals scored by these players in the last minutes of matches. Furthermore, substitutes in midfield and attack positions also showed higher defensive performance in comparison with the players who were replaced. This fact is related to more tackles and interceptions in offensive positions and could be relevant considering the importance of ball recoveries for team success (Lago-Ballesteros et al., 2012; Vogelbein et al., 2014).

In addition, to our knowledge, this is the first study in soccer which includes a variable relating the technical performance of players and teams, namely touches ratio. This variable provides information about which percentage of team total touches are made by each player (Robertson et al., 2016). According to the results obtained, the substitute players participated more within his team, i.e., greater touches ratio, in comparison with those who were replaced or completed the entire match, especially in midfield and attack positions. This approach to quantify the relative contributions of individual players in soccer teams could be applied

in future studies to a broader range of technical variables. Conversely, there are some study limitations which should be taken into account. The descriptive results of performance of substitutes have evidenced large standard deviations, which could be explained by some variables not included in this study. In this sense, it would be interesting to analyse the influence of situational variables, such as match location, quality of opposition, and match status (Lago, 2009), on substitute players' performance since only one previous study has analysed the effect of the score-line on the physical performance of substitutes (Hills et al., 2019). Additionally, bearing in mind the sample size limitations of previous scientific literature (Hills et al., 2018), future studies analysing larger datasets from multiple seasons or a different competition are also warranted.

6.6. Conclusions

This study has shown that substitutes are able to improve the performance of the players who completed the entire match or were replaced in both physical and some technical variables depending on playing position. More specifically, substitute players showed higher TD covered, number of fast runs, and number of sprints relative to playing time than replaced and entire match players. The differences in technical performance of substitute, replaced, and entire match players varied according to the playing positions. Substitutes in the position of CD showed less involvements with the ball but higher defensive performance, while the substitute players in the positions of CM, EM, and F showed more possession, touches, and shots than replaced or entire match players.

Even though technical performance is considered an essential factor for success in soccer, previous scientific literature was scarce about examining the technical performance of substitute players in comparison with those who were replaced or completed the entire match. This information could be relevant for soccer coaches, as the results obtained in this study emphasize the importance of substitute players from a technical point of view and their possible contribution to team success. Nevertheless, coaches should take into account the differences in substitutes' performance according to their playing position. The introduction of CD could be a good strategy when a team is ahead since substitutes in this field position have shown that they are able to perform many defensive actions per minute. Moreover, when a player is showing signs of fatigue or is underperforming or simply the team is losing, the introduction of substitute players in midfield or attack positions could be another effective strategy, as substitutes in these positions were able to display higher physical and technical performance in comparison with replaced or entire match players.

7. Study 3 – The effect of substitutions on team tactical behaviour in professional soccer

7.1. Abstract

Player substitutions are one of the main options for the coach to change tactical behaviour of his team. The present study therefore investigates the effect of player substitutions on tactical behaviour in high-performance soccer using positional data. The sample consisted of 659 substitutions from 234 matches played in the German Bundesliga during the season 2016–2017. Substitutions were classified either as neutral (n = 485), defensive (n = 45), or offensive (n = 129) according to the player's roles. The teams' tactical behaviour before and after each substitution was analysed using team centroid, inter-team centroid distance, team length and width, length per width (LpW) ratio, stretch index, and space control for the whole pitch and for each third as the dependent variables. The results of linear mixed model analysis showed different effects for neutral, defensive, and offensive substitutions. Teams displayed significantly lower stretch index after defensive substitutions. LpW ratio increased with neutral and offensive substitutions, while inter-team distance decreased. The position of the team centroid, space control in the middle third and in the attacking third were also greater following an offensive substitution. These findings demonstrate that player substitutions effectively change tactical behaviour of teams. Soccer coaches should perform more offensive substitutions to elicit a higher defensive pressure and improve goal-scoring opportunities, especially due to greater space control in the attacking third. In contrast, defensive substitutions can be used to increase defensive efectiveness through increases in team compactness.

7.2. Introduction

The analysis of substitutions is an emerging research topic in high-performance soccer, but only limited scientific literature has been published so far (Hills et al., 2018). Most of the research studies in this field have been focused on changes in physiological parameters due to player substitutions (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010; Liu et al., 2020; Padrón-Cabo et al., 2018). Current evidence suggests that substitute players display greater physical performance in comparison to the replaced players or those who play for the entire match duration (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010; Liu et al., 2020; Padrón-Cabo et al., 2018). Consequently, the introduction of substitute players into a match supposes an effective strategy to reduce the effects of fatigue across a team (Bradley et al., 2014; Hills et al., 2018).

However, several studies have suggested that the main reason to make a substitution during a soccer match is to modify a teams' tactical behaviour (Bradley et al., 2014; Del Corral et al., 2008; Gomez et al., 2016; Rey et al., 2015). Accordingly, previous scientific literature has classified the soccer substitutions from a tactical approach in neutral, defensive, or offensive changes (Del Corral et al., 2008; Gomez et al., 2016; Rey et al., 2015). Current results

in the Spanish LaLiga (Del Corral et al., 2008; Gomez et al., 2016) and in the UEFA Champions League (Rey et al., 2015) suggest that coaches tend to make more offensive substitutions earlier in the match when their team is losing, while the defensive substitutions are made later in the match when a team is leading. Regarding team performance, the introduction of more offensive players in a match has been shown to improve team's scoring opportunities (Gomez et al., 2016). Nevertheless, there is a lack of scientific literature analysing the substitutions from a tactical perspective and more research is warranted (Hills et al., 2018).

Current approach to analyse tactical behaviours in soccer is increasingly based on match positional data using a big data approach (Low et al., 2019; Memmert et al., 2017; Memmert & Raabe, 2018; Rein & Memmert, 2016). In this regard, several studies have analyzed the relation of tactical variables based on positional data with teams' match performance or playing style (Castellano et al., 2013; Castellano & Casamichana, 2015; Duarte et al., 2013; Frencken et al., 2012; Low et al., 2018; Moura et al., 2012; Rein et al., 2017). These studies suggest that greater values of team length are related with a more direct playing style during the attack (Castellano et al., 2013; Duarte et al., 2013), while possession play seems to be related with greater team width (Castellano & Casamichana, 2015; Duarte et al., 2013). Conversely, increased team compactness was associated with defensive play (Castellano et al., 2013), as teams are more likely to concede shots when they are not compacted enough (Moura et al., 2012). Other studies have analysed the distance between the centroid of the teams, showing that smaller inter-team distance is related to higher defensive pressure (Frencken et al., 2012; Low et al., 2018), or higher attacking pressure to create more goal-scoring opportunities (Frencken et al., 2012). More recently, Rein et al. (2017) have related the space control in the attacking third with the number of goals scored and the probability of winning a game. Thus, several variables are available to characterize tactical performance in high-performance soccer teams.

Furthermore, there is some evidence to suggest that team tactical performance and playing style during a soccer match change after player substitutions (Gomez et al., 2016). Accordingly, changes in team tactical performance should lead to changes in the tactical variables presented above. Nevertheless, to the best of our knowledge, no study has analysed the effect of substitutions using variables derived from soccer positional data which provides a much more in-depth insight into team performance compared to eventing data (Rein & Memmert, 2016). Therefore, bearing in mind the aforementioned considerations, the aim of this study was to analyse the effect of the different types of substitution on tactical behaviour in professional soccer teams. Based on previous scientific literature that has analysed substitutions (Del Corral et al., 2008; Gomez et al., 2016; Rey et al., 2015) or some tactical variables in soccer (Castellano et al., 2013; Frencken et al., 2012; Rein et al., 2017), the research hypothesis is that neutral, defensive, and offensive substitutions would have different effects on tactical behaviour. More specifically, defensive substitutions are expected to increase team compactness and space control in defensive third, while offensive substitutions should increase space control in attacking third and decrease inter-team distance.

7.3. Methods

7.3.1. Sample

This study analysed 659 substitutions from 234 matches played in the German Bundesliga during the season 2016–2017. The raw data consisted of the (x,y) position of each player and the ball. Match positional data were recorded using a semi-automatic optical tracking system (VISTRACK, by Impire Corp., Germany) with a sampling frequency of 25 Hz. The validity and reliability of this tracking system have been described previously (Siegle et al., 2013). From these raw positional data, the time segments for before and after each substitution were extracted. At least 5 minutes of match-play without other substitutions or goals were required before and after (Mohr et al., 2003). Substitutions involving two or more players simultaneously were excluded from the analysis (Gomez et al., 2016). Additionally, in order to avoid confounding factors, the substitutions belonging to matches with a player dismissal and those due to players' injuries were also excluded from the sample (Del Corral et al., 2008). Ethical approval for this study was granted by the ethical committee of the German Sport University Cologne.

7.3.2. Variables and procedures

According to previous studies, the substitutions were classified as neutral, defensive or offensive (Del Corral et al., 2008; Rey et al., 2015). This classification was done considering the playing position of the players involved in each substitution. Thus, a substitution was considered neutral when both players had the same positional role (defender, midfielder or F), while if the substitute played in a more forward or backward position than the player who was replaced, the substitution was considered offensive or defensive, respectively (Del Corral et al., 2008; Rey et al., 2015). Playing positions were determined based on players' different activity on the pitch and the primary area in which this activity was carried out according to each match positional data (Konefal et al., 2019; Di Salvo et al., 2007).

In addition, the following contextual variables were recorded for each substitution: match location, recorded as playing home or away (Lago, 2009), the difference in season final ranking between the two competing teams (Lago, 2009), and match status, i.e. losing by two goals or more, losing by one goal, drawing, winning by one goal, or winning by two goals or more (Fernandez-Navarro et al., 2018). The match positional data corresponding to each substitution were processed to obtain the datasets before and after. This procedure took into account other substitutions or goals scored by any of the two teams as cutting points. All sequences where the ball was not in play were excluded (Clemente et al., 2013). Subsequently, the following tactical variables were calculated for the team performing the substitution: team centroid longitudinal position (x) with respect to the centre point of

the pitch (Frencken et al., 2011), inter-team centroid distance (Frencken et al., 2012), team length and width (Frencken et al., 2011), length per width (LpW) ratio (Folgado et al., 2014), and stretch index (Bourbousson et al., 2010; Duarte et al., 2013). All variables were calculated using the 10 outfield players whilst excluding the goalkeeper (Duarte et al., 2013; Frencken et al., 2011).

Additionally, space control using Voronoi diagrams was calculated and expressed as the percentage of pitch space controlled for the team that performs each substitution (Fonseca et al., 2012; Rein et al., 2017). This space controlled was obtained for the whole pitch and for three regions of interest: defensive third, middle third and attacking third (Lago, 2009). Following previous studies, all endpoints were determined for (1) the whole datasets and separately for the time (2) in ball possession and (3) out of ball possession (Clemente et al., 2013; Duarte et al., 2012; Moura et al., 2012). All computations were performed using dedicated routines implemented in Python version 3.7 (Van Rossum & Drake, 2009). Each substitution positional data sub-sample was analysed independently. The final data set served to the statistical analysis included for each substitution the match information already described above and the mean values for the tactical variables before and after the substitution.

7.3.3. Statistical analysis

All subsequent statistical analyses were conducted using the statistical software R version 3.5.2 (R Core Team, 2018). The descriptive results for each variable before and after the substitutions are presented as mean ± SD. Linear mixed models were adjusted using the R package lme4 (Bates et al., 2015) in order to analyse the differences between the performance before and after the substitutions (moment) according to the type of substitution (neutral, defensive, or offensive). The contextual variables match location, ranking difference, and match status were also fitted as fixed effects. Match, team, and substitution identity were modelled as random effects to account for the repeated measurements. Then, for all the dependent variables (y), the following model structure was adjusted:

$$y = \text{Moment} \cdot \text{Type of Substitution} + \text{Match Status} + \text{Ranking Difference} + \text{Location} + (1|\text{Match}) + (1|\text{Team}) + (1|\text{Substitution ID})$$

The assumptions of homogeneity and normal distribution of the residuals were verified for each model, without revealing specific problems. Pair-wise comparisons for the interaction between the variables moment and type of substitution were conducted via Bonferroni post-hoc test using the R package emmeans (Lenth et al., 2019). ES were calculated using Cohens' d (Cohen, 1988) and classified as trivial ($d < 0.2$), small ($0.2 \leq d < 0.5$), medium ($0.5 \leq d < 0.8$), or large ($d \geq 0.8$). For all analysis, the significance value was set at $p < 0.05$.

7.4. Results

Table 7.1 shows the distribution of type of substitution according to match status. The majority of defensive substitutions were performed when teams were winning by 1 goal (44.4%), while most offensive substitutions occurred when losing by 1 goal (48.1%). Neutral substitutions were performed mainly in drawing match situations (36.1%).

Table 7.1. Type of substitution according match status.

	Defensive		Neutral		Offensive	
	n	%	n	%	n	%
Winning by ≥ 2 goals	10	33.3	62	12.8	0	0.0
Winning by 1 goal	20	44.4	102	21.0	2	1.5
Drawing	15	33.3	175	36.1	40	31.0
Losing by 1 goal	0	0.0	96	19.8	62	48.1
Losing by ≥ 2 goals	0	0.0	50	10.3	25	19.4

Table 7.2 displays the differences in tactical performance before and after the substitutions. Team width ($p = 0.043$; ES = 0.43, small) and stretch index ($p = 0.001$; ES = 0.69, medium) decreased significantly after defensive substitutions. Neutral substitutions showed significantly declines in inter-team distance ($p = 0.002$; ES = 0.20, small), team width ($p < 0.001$; ES = 0.30, small), and stretch index ($p = 0.011$; ES = 0.16, trivial), while LpW ratio ($p < 0.001$; ES = 0.30, small) and space control in attacking third ($p = 0.007$; ES = 0.17, trivial) increase significantly after these neutral substitutions. Offensive substitutions decreased significantly inter-team distance ($p < 0.001$; ES = 0.58, medium) and team width ($p = 0.024$; ES = 0.28, small), but increased the position of team centroid ($p = 0.002$; ES = 0.38, small), team length ($p < 0.001$; ES = 0.53, medium), LpW ratio ($p < 0.001$; ES = 0.60, medium), space control ($p = 0.004$; ES = 0.36, small), space control in the middle third ($p = 0.013$; ES = 0.31, small), and space control in the attacking third ($p < 0.001$; ES = 0.72, medium).

Table 7.2. Differences in tactical performance before and after the substitutions (Mean ± SD).

	Defensive (n = 45)			**Neutral** (n = 485)			**Offensive** (n = 129)		
	Before	After	Δ	Before	After	Δ	Before	After	Δ
Team Centroid	-6.92 ± 6.69	-7.91 ± 7.09	-0.99	-3.89 ± 6.58	-3.62 ± 7.14	0.27	-1.31 ± 6.14	0.52 ± 6.90	1.83*
Inter-team Distance	6.44 ± 0.65	6.63 ± 0.72	0.20	6.49 ± 0.64	6.39 ± 0.77	-0.10*	6.61 ± 0.67	6.33 ± 0.70	-0.28*
Team Length	32.88 ± 2.67	32.45 ± 3.90	-0.43	33.23 ± 2.74	33.42 ± 2.97	0.19	33.81 ± 2.31	34.76 ± 2.26	0.94*
Team Width	38.66 ± 3.61	37.69 ± 3.82	-0.97#	40.03 ± 4.03	39.34 ± 4.28	-0.68*	41.24 ± 4.27	40.60 ± 3.95	-0.64#
LpW Ratio	0.89 ± 0.09	0.90 ± 0.13	0.01	0.87 ± 0.09	0.89 ± 0.10	0.02*	0.87 ± 0.09	0.91 ± 0.10	0.04*
Stretch Index	15.17 ± 1.33	14.68 ± 1.38	-0.50*	15.53 ± 1.23	15.41 ± 1.30	-0.12#	15.82 ± 1.20	16.02 ± 1.02	0.19#
Space Control	45.86 ± 7.37	44.67 ± 8.06	-1.19	49.08 ± 7.26	49.21 ± 7.96	0.13	51.79 ± 6.93	53.59 ± 7.50	1.80*
Defensive Third	80.99 ± 7.84	79.87 ± 8.36	-1.11	84.37 ± 6.83	83.78 ± 7.47	-0.59	87.23 ± 6.33	87.26 ± 6.13	0.03
Middle Third	44.82 ± 9.74	43.02 ± 10.84	-1.81	48.77 ± 9.82	48.97 ± 10.54	0.20	52.43 ± 9.34	54.50 ± 9.97	2.08#
Attacking Third	11.79 ± 5.70	11.13 ± 6.36	-0.66	14.09 ± 6.20	14.88 ± 7.04	0.79*	15.71 ± 6.25	18.99 ± 7.38	3.28*

Significant difference ($p < 0.05$) between Before and After. * Significant difference ($p < 0.01$) between Before and After.

The differences between the effect of defensive, neutral, and offensive substitutions are depicted in Figure 7.1. The effect of defensive substitutions was significantly different from neutral substitutions for the variables inter-team distance ($p = 0.006$, ES = 0.43, small) and stretch index ($p = 0.017$; ES = 0.37, small). Offensive substitutions showed significantly different effects in comparison with neutral substitutions for the variables team centroid ($p = 0.021$; ES = 0.23, small), inter-team distance ($p = 0.007$; ES = 0.27, small), team length ($p = 0.003$; ES = 0.30, small), LpW ratio ($p = 0.036$; ES = 0.21, small), stretch index ($p = 0.002$; ES = 0.31, small), space control ($p = 0.017$; ES = 0.24, small), space control in middle third ($p = 0.045$; ES = 0.20, small), and space control in attacking third ($p < 0.001$; ES = 0.39, small). The effect of offensive substitutions was significantly different from defensive substitutions for the variables team centroid ($p = 0.017$; ES = 0.41, small), inter-team distance ($p < 0.001$; ES = 0.70, medium), team length ($p = 0.002$; ES = 0.54, medium), stretch index ($p < 0.001$; ES = 0.68, medium), space control ($p = 0.014$; ES = 0.43, small), space control in the middle third ($p = 0.018$; ES = 0.41, small), and in the attacking third ($p < 0.001$; ES = 0.61, medium). No significant differences between defensive, neutral, or offensive substitutions were found for the variables team width and space control in the defensive third.

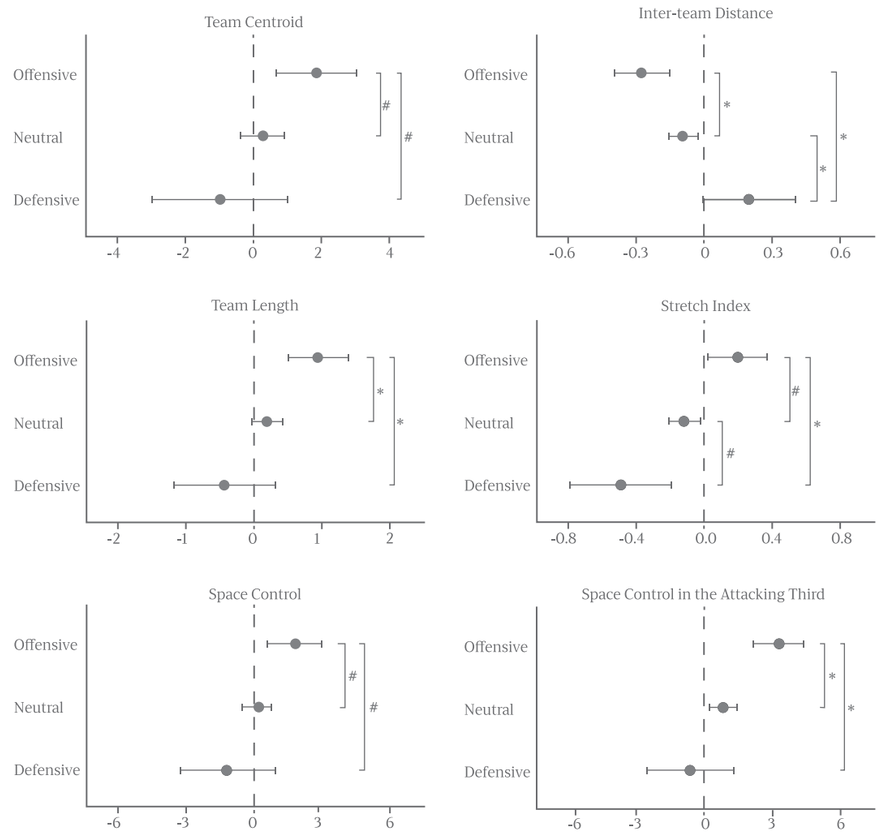

Figure 7.1. Differences between the effect of defensive, neutral and offensive substitutions. #Significant difference ($p < 0.05$). *Significant difference ($p < 0.01$).

The effect of defensive, neutral, and offensive substitutions on tactical performance with ball possession and without ball possession are shown in Tables 7.3 and 7.4, respectively. In contrast with the overall results, team length with ball possession decreased significantly after defensive substitutions ($p = 0.016$; ES = 0.51, medium), whereas this variable increased after offensive substitutions ($p = 0.006$; ES = 0.34, small). Thus, the effect of defensive and offensive substitutions was significantly different ($p < 0.001$; ES = 0.60, medium). Team length without ball possession showed significantly greater values after neutral ($p = 0.023$; ES = 0.15, trivial) and offensive ($p < 0.001$; ES = 0.60, medium) substitutions. Small differences were observed for offensive substitutions in comparison with defensive ($p = 0.045$; ES = 0.32, small) and neutral ($p = 0.001$; ES = 0.35, small) substitutions for this variable. The effects of substitutions on stretch index differed according to ball possession state. Stretch index with ball possession decreased after defensive ($p < 0.001$; ES = 0.96, large) and neutral ($p < 0.001$; ES = 0.26, small) substitutions. Differences between defensive substitutions with respect to neutral ($p = 0.002$; ES = 0.49, small) and offensive ($p < 0.001$; ES = 0.73, medium) substitutions were monitored for this variable, and also differences between neutral and offensive substitutions ($p = 0.020$; ES = 0.23, small). Stretch index without ball possession increased significantly after offensive substitutions ($p < 0.001$; ES = 0.50, medium), in contrast with the effect of neutral ($p < 0.001$; ES = 0.38, small) and defensive ($p = 0.002$; ES = 0.54, medium) substitutions.

Table 7.3. Effect of defensive, neutral, and offensive substitutions on tactical performance with ball possession (Mean ± SD).

	Defensive (n = 45)			Neutral (n = 485)			Offensive (n = 129)		
	Before	After	Δ	Before	After	Δ	Before	After	Δ
Team Centroid	-4.60 ± 7.96	-5.53 ± 7.85	-0.93^{O}	-1.64 ± 6.63	-1.21 ± 7.18	0.43^{O}	0.80 ± 5.69	2.88 ± 6.47	2.08^{*,D,N}
Inter-team Distance	6.36 ± 0.82	6.57 ± 0.77	0.21^{O,N}	6.44 ± 0.76	6.34 ± 0.89	-0.10^{*,D}	6.58 ± 0.77	6.32 ± 0.81	-0.26^{*,D}
Team Length	34.55 ± 2.71	33.65 ± 3.05	-0.90$^{\#,O,N}$	34.45 ± 2.39	34.45 ± 2.66	0.00^{D,O}	34.66 ± 1.97	35.27 ± 1.87	0.61^{*,D,N}
Team Width	41.10 ± 4.83	39.20 ± 5.42	-1.90*	42.95 ± 5.42	41.96 ± 5.75	-0.99*	44.80 ± 5.34	43.76 ± 5.02	-1.03*
LpW Ratio	0.89 ± 0.10	0.91 ± 0.13	0.02	0.85 ± 0.10	0.87 ± 0.11	0.02*	0.82 ± 0.10	0.86 ± 0.11	0.03*
Stretch Index	16.02 ± 1.65	15.18 ± 1.65	-0.84^{*,O,N}	16.38 ± 1.53	16.15 ± 1.62	-0.23^{*,D,O}	16.71 ± 1.38	16.77 ± 1.18	0.06^{D,N}
Space Control	49.43 ± 8.46	47.89 ± 8.68	-1.55^{O}	52.47 ± 7.16	52.65 ± 7.85	0.17^{O}	54.95 ± 6.10	56.75 ± 6.87	1.81^{*,D,N}
Defensive Third	83.06 ± 9.74	81.71 ± 9.45	-1.35	86.77 ± 7.22	86.17 ± 7.87	-0.60	89.79 ± 5.72	89.81 ± 5.85	0.01
Middle Third	50.45 ± 10.62	48.13 ± 10.61	-2.31^{O}	53.75 ± 9.49	54.14 ± 10.21	0.39	57.07 ± 8.24	59.23 ± 9.02	2.16$^{\#,D}$
Attacking Third	14.80 ± 6.29	13.82 ± 6.29	-0.98^{O}	16.90 ± 6.27	17.64 ± 7.06	0.74$^{\#,O}$	17.97 ± 6.07	21.22 ± 7.18	3.25^{*,D,N}

$^{\#}$ Significant difference ($p < 0.05$) between Before and After. * Significant difference ($p < 0.01$) between Before and After. ^{D} Significant difference ($p < 0.05$) with defensive substitutions. ^{N} Significant difference ($p < 0.05$) with neutral substitutions. ^{O} Significant difference ($p < 0.05$) with offensive substitutions.

Table 7.4. Effect of defensive, neutral, and offensive substitutions on tactical performance without ball possession (Mean ± SD).

	Defensive (n = 45)			Neutral (n = 485)			Offensive (n = 129)		
	Before	After	Δ	Before	After	Δ	Before	After	Δ
Team Centroid	-9.17 ± 6.13	-10.14 ± 6.09	-0.97	-6.01 ± 6.50	-5.91 ± 7.10	0.10	-3.48 ± 6.65	-2.09 ± 7.47	1.39$^{\#}$
Inter-team Distance	6.46 ± 0.69	6.63 ± 0.83	0.18^{O,N}	6.47 ± 0.75	6.38 ± 0.85	-0.09^{*,D,O}	6.54 ± 0.77	6.25 ± 0.77	-0.29^{*,D,N}
Team Length	31.62 ± 2.94	31.85 ± 5.19	0.23^{O}	32.39 ± 3.28	32.72 ± 3.49	0.32$^{\#,O}$	33.15 ± 3.10	34.49 ± 3.02	1.34^{*,D,N}
Team Width	35.87 ± 2.23	35.48 ± 2.31	-0.39	36.43 ± 2.63	36.04 ± 2.76	-0.39*	36.42 ± 2.65	36.06 ± 2.26	-0.37
LpW Ratio	0.91 ± 0.10	0.93 ± 0.18	0.02	0.92 ± 0.12	0.94 ± 0.12	0.02^{*,O}	0.94 ± 0.11	0.99 ± 0.11	0.05^{*,N}
Stretch Index	14.29 ± 0.90	14.12 ± 1.06	-0.17^{O}	14.61 ± 0.92	14.58 ± 0.95	-0.02^{O}	14.70 ± 0.95	15.03 ± 0.85	0.33^{*,D,N}
Space Control	42.60 ± 6.53	41.71 ± 6.88	-0.89^{O}	45.80 ± 6.83	45.94 ± 7.61	0.14^{O}	48.47 ± 7.35	50.05 ± 7.91	1.58$^{\#,D,N}$
Defensive Third	78.68 ± 7.17	77.79 ± 7.48	-0.89	81.74 ± 6.52	81.25 ± 7.23	-0.48	84.24 ± 6.71	84.07 ± 6.35	-0.16
Middle Third	39.97 ± 9.00	38.26 ± 9.02	-1.71^{O}	44.02 ± 9.28	44.08 ± 9.97	0.05	47.57 ± 9.93	49.28 ± 10.72	1.71$^{\#,D}$
Attacking Third	9.17 ± 5.37	9.09 ± 6.77	-0.08^{O}	11.63 ± 6.21	12.48 ± 7.22	0.85^{*,O}	13.60 ± 6.90	16.80 ± 7.90	3.20^{*,D,N}

$^{\#}$ Significant difference ($p < 0.05$) between Before and After. * Significant difference ($p < 0.01$) between Before and After. ^{D} Significant difference ($p < 0.05$) with defensive substitutions. ^{N} Significant difference ($p < 0.05$) with neutral substitutions. ^{O} Significant difference ($p < 0.05$) with offensive substitutions.

7.5. Discussion

This study aimed to analyse the effect of defensive, neutral, and offensive substitutions on tactical behaviour in professional soccer teams. To the authors' knowledge, this is the first study that analysed the soccer substitutions using tactical variables based on match positional data, since a recent systematic review has pointed out the need of information about this topic (Hills et al., 2018). The main finding of this study was that teams' tactical behaviour can be modified by player substitutions. Likewise, as it was stated in the research hypothesis, different effects were obtained for defensive, neutral, and offensive substitutions, in particular for the variables team centroid, inter-team distance, team length, stretch index, and space control in the attacking third.

With respect to the team centroid, offensive substitutions significantly modified the team position on the pitch, by shifting the team centroid to a more advanced position, closer to opponent's goal. Moreover, as it was stated in the research hypothesis, inter-team centroid distance also decreased after an offensive substitution. According to previous findings, a more advanced position and less inter-team distance during the defensive phase is related to a higher pressure (Frencken et al., 2012; Low et al., 2018). This defensive strategy has been linked with success in elite soccer as a more advanced defensive pressure allows ball recoveries in more advantageous pitch positions (Almeida et al., 2014; Lago-Ballesteros et al., 2012). These same effects were also observed with ball possession and might be related to greater attacking pressure to create more goal-scoring opportunities (Frencken et al., 2012). Likewise, after performing an offensive substitution, teams significantly increase the percentage of pitch space controlled, especially in the attacking third, where this effect was larger. Greater space control near to the opponent's goal has been associated with an increased number of goals scored and probability of winning a game (Rein et al., 2017). Therefore, considering that, in agreement with previous studies (Del Corral et al., 2008; Rey et al., 2015), offensive substitutions are commonly made by teams when losing, this substitution type appears to be a good strategy to revert the score-line. Furthermore, previous studies have shown that the introduction of more offensive players improves the scoring opportunities of a team (Gomez et al., 2016).

The effects of neutral substitutions on inter-team distance and space control were similar to the effects of offensive substitutions, but smaller in magnitude. This suggests that substituting a player with the same playing position slightly increases defensive pressure and offensive performance, based on the smaller inter-team distance and greater space control in the attacking third displayed by teams after neutral substitutions (Frencken et al., 2012; Low et al., 2018; Rein et al., 2017). These small changes in tactical behaviour could be due to the less fatigue and better physical performance of substitute players. Previous research has shown that substitutes are able to perform at a better physiological performance level due to lack of fatigue (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2010; Liu et al., 2020; Padrón-Cabo et al., 2018). Accordingly, as some team formations are more physiological taxing (Carling, 2011), the substitutions might allow the team to reinstate these formations. Furthermore, the effects of defensive and offensive substitutions were also significantly different for the variables team centroid, inter-team distance, and space control. These results are in agreement with the research hypothesis and underline the association between the type of substitution and match status (Del Corral et al., 2008; Rey et al., 2015). Previous studies have demonstrated that soccer coaches tend to make defensive substitutions when their team is winning (Del Corral et al., 2008; Rey et al., 2015). Consequently, the introduction of a more defensive player was hypothesized to increase space control near the own goal and reduce the probability of concede scoring opportunities (Rein et al., 2017). However, this effect was not observed for defensive substitutions. Teams displayed less space control in defensive third after this type of changes, even though it was observed a tendency to keep players closer to their own goal, i.e. lower team centroid position.

Regarding team dispersion variables, the results indicated significant differences between defensive, neutral and offensive substitutions, especially for team length and stretch index. More specifically, after performing an offensive substitution, teams displayed significantly greater values of length and LpW ratio during ball possession. These effects have been suggested to indicate a more direct approach to attack the opponent goal (Castellano et al., 2013; Duarte et al., 2013; Folgado et al., 2014), which could be a more effective strategy to create scoring opportunities and score quickly when losing (Fernandez-Navarro et al., 2019; Lago-Ballesteros et al., 2012). Nonetheless, the effect of offensive substitutions on team dispersion variables was larger without ball possession. Teams' length and stretch index increased significantly after offensive substitutions. This less team compactness during defensive phase is a riskier tactical behaviour (Coutinho et al., 2018) and has been suggested to increase the possibilities of conceding a goal (Moura et al., 2012). In contrast, the stretch index values were smaller after defensive substitutions, that is, teams' player arrangements seem to be more compacted after this type of substitutions in order to increase their defensive success (Castellano et al., 2013; Moura et al., 2012). These effects of substitutions are in agreement with those obtained by Batista et al. (2019), whose study compared the effect of offensive and defensive coach's instructions during soccer small-sided games.

However, independently of the type of substitution, team width showed small decreases during the time period after the substitution, especially when in ball possession. Previous studies have shown that team dispersion decrease during the second half of soccer matches due to players' fatigue (Clemente et al., 2013; Coutinho et al., 2018; Moura et al., 2013). Therefore, as playing time increases, it is more difficult for teams to occupy the pitch width properly during the offensive phase (Clemente et al., 2013), a fact that decreases the effectiveness of possession play (Castellano & Casamichana, 2015; Duarte et al., 2013; Merlin

et al., 2020). Nevertheless, the present results do not provide a clear picture of which type of substitution can be useful in order to increase team width in ball possession. Following previous scientific literature, the introduction of substitute players in wide positions could be suggested to counteract the effect of fatigue on team width (Bradley et al., 2014; Padrón-Cabo et al., 2018), but more research is needed.

Finally, there are some study limitations which have to be taken into account. As only post-priori data were used, offensive or defensive intentions of soccer coaches were not available and the only classification criteria were the introduction of players in a more forward or backward position (Rey et al., 2015). However, neutral substitutions could have had different purposes depending on technical and tactical capabilities of the players involved (Rey et al., 2015). In this respect, the results of the present study provide a first approach to assess the effects of substitutions on tactical behaviour using positional data. Future studies should consider a more comprehensive classification of substitutions, and/or try to take into account the coaches' reasons to make particular substitutions (Hills et al., 2018). This approach could be especially interesting because substitutions usually aimed to respond to match situations or oppositions' team tactics (Gomez et al., 2016; Rein & Memmert, 2016).

Moreover, the use of Voronoi diagrams to assess space control has some limitations, as players' running velocity and acceleration are not taken into account. However, previous studies have demonstrated that the Voronoi approach is a suitable approximation of space control (Fonseca et al., 2012). Likewise, as the same procedure was applied to both teams, this can be seen as systematic error which affects total magnitude but not the relationships. More complex approaches have been recently introduced to take running velocity into account (Brefeld et al., 2019; Fernandez & Bornn, 2018). Nonetheless, these approaches are computationally complex and information regarding their actual improvements in realistic situations is lacking at present. In addition, future studies could analyse the effect of substitutions on some additional tactical variables related to teams' performance, such as intra-team movement synchronization (Folgado et al., 2018).

7.6. Conclusions

This study showed that teams' tactical behaviour can be modified by performing player substitutions. However, different effects were obtained for neutral, defensive, and offensive substitutions. The present findings suggest that soccer coaches should perform offensive substitutions in order to elicit a higher defensive pressure and create more goal-scoring opportunities with a more direct approach to opponent goal. Consequently, such a substitution strategy can be useful to revert adverse score-lines, but assuming a higher risk during the defensive phase, i.e. higher team dispersion. On contrary, a defensive substitution increases defensive success through increases in team compactness

III.
GENERAL DISCUSSION

8. Conclusions

The current dissertation aimed to analyse the changes in performance during elite soccer matches taking into account the effect of substitutions. Specifically, Study 1 analysed the declines in physical performance of elite soccer players from the first half to the second half, accounting for effective playing time and playing positions, while Study 2 and Study 3 analysed the effect of player substitutions on physical, technical, and tactical performance.

According to the main findings of Study 1, elite soccer players do not reduce their physical performance in the second half of the matches when effective playing time is considered. However, variations in running performance from the first half to the second half depend on playing position. Therefore, when considering effective playing time, F was the only position that reduced their physical performance (HSR and sprint distance) during the second half of the matches.

Study 2 evidenced that substitutes are able to improve the physical performance of players who complete the entire match or are replaced. Specifically, the substitute players showed higher TD covered, number of fast runs, and number of sprints relative to playing time than the replaced and whole-match players. In terms of technical performance, the differences between substitute, replaced, and whole-match players varied according to playing positions. The substitute CD showed less involvements with the ball but higher defensive performance, while the substitute CM, EM, and F showed more possession, touches, and shots than replaced or whole-match players.

Finally, the results obtained in Study 3 demonstrated that player substitutions can effectively modify the tactical behaviour of teams. However, different effects were obtained for neutral, defensive, and offensive substitutions. In this regard, performing offensive substitutions can elicit a higher defensive pressure and create more goal-scoring opportunities, but assuming a higher risk during the defensive phase due to higher team dispersion. On the contrary, defensive substitutions appear to increase defensive effectiveness through increases in team compactness.

9. Practical applications

During official soccer matches, coaches have a limited number of substitutions and therefore, efficient management of this resource seems to be relevant (Rey et al., 2015). In fact, based on the coaches' perceptions (Hills et al., 2020), player substitutions represent an important factor in determining success and can often influence the outcome of a match.

Previous soccer scientific literature highlighted the use of player substitutions as an effective strategy to counteract the effects of fatigue on players' physical performance (Bradley et al., 2014; Bradley & Noakes, 2013; Carling et al., 2008; Reilly et al., 2008). However, the findings of Study 1 suggest that the decrease in the players' match running performance from the first to the second half can be overestimated due to the increase in game interruptions towards the end of matches. Therefore, to achieve a comprehensive analysis of the physical demands of official soccer matches, coaches and strength and conditioning specialists should consider the effective playing time, as variations in the running performance of the players could not only be linked to fatigue.

Regardless of the possible presence of fatigue during the second half of matches, elite soccer players analysed in Study 1 were shown to maintain their HSR and sprint performance when effective playing time was considered. Nonetheless, soccer coaches should be aware that F players did reduce their running performance (HSR and sprint distance) during the second half of the matches. Consequently, maintaining team physical performance during second halves could require replacing F at an optimal time. Moreover, fitness coaches should consider designing individualized soccer-specific training programs for F to compensate for physical fitness deficits that may contribute to running performance decrements during second halves.

The results obtained in Study 2 emphasize the importance of substitute players from a technical point of view and their possible contribution to team success. Nevertheless, soccer coaches should take into account the differences in the performance of substitute players according to their playing position. The introduction of CD could be a good strategy when a team is ahead, as substitutes in this field position have shown that they are capable to perform many defensive actions per minute. Moreover, when a player is showing signs of fatigue or is underperforming or simply when the team is losing, the introduction of substitute players in the positions of CM, EM, or F could be another effective strategy, as substitutes entering the match in these positions were able to display higher physical and technical performance in comparison with replaced and whole-match players.

From a tactical perspective, Study 3 evidenced the differences between the effects of neutral, defensive, and offensive substitutions. Based on these findings, soccer coaches should perform offensive substitutions in order to elicit a higher defensive pressure and create more goal-scoring opportunities with a more direct approach to the opponent's goal. Consequently, these type of substitutions are commonly made by teams when losing and appear to be a good strategy to revert adverse score-lines. However, coaches should be aware that after performing an offensive substitution, there may be a higher team dispersion during the defensive phase, which is a riskier tactical behaviour and could increase the possibilities of conceding a goal. Conversely, when a team has a favourable score-line, making a defensive substitution can be useful to increase defensive success, since this substitution strategy seems to increase team compactness.

10. Limitations

Concerning the limitations of this dissertation, some aspects should be taken into account. The current results were obtained by analysing data from the German Bundesliga (Study 1) and Spanish LaLiga (Study 2 and Study 3). Consequently, the findings of this dissertation may not be applicable to other leagues or competitions due to the differences in physical, technical, and tactical performance that could exist between them (Dellal et al., 2011; Fernandez-Navarro et al., 2016; Yi et al., 2019). Likewise, differences between leagues have also been proven in terms of the duration of game interruptions (Zhao & Zhang, 2021).

In Study 1, only data from players who completed the entire match were included in the analysis. Therefore, the findings presented in this research should be interpreted with caution because some players may have been replaced during the second half due to decreased running performance. In addition, players' physical performance could be affected by other factors not analysed in the study, such as their fitness level or age.

Regarding the limitations of Study 2, unlike the other studies included in this dissertation, the possible influence of situational variables such as the match location, the quality of the opposition, and the match status on players' performance was not considered. Furthermore, the performance of the substitute, replaced, and whole-match players were only analysed in relation to their total playing time. However, analysis of the substitutes' performance compared to the players who remained on the pitch after the substitution would provide more relevant information, especially considering the transient changes in the effective playing time throughout matches.

Finally, the main limitation of Study 3 is that the intentions of soccer coaches to perform each substitution were not available, and the only classification criterion for the type of substitution was the introduction of players in a more forward or backward position. In addition, the limitations of the variables used to analyse the teams' tactical behaviour should also be noted, especially in the case of space control using Voronoi diagrams.

11. Future lines of research

Based on the findings and limitations of the current dissertation, some suggestions can be made for future research. In relation to Study 1, it would be interesting to analyse the relationship between the decreases in running performance throughout soccer matches and players' physical fitness according to regular soccer tests. Future studies should also analyse the changes in the technical performance of players from the first half to the second half of matches accounting for the effective playing time and playing positions.

Moreover, previous scientific literature has evidenced age-related changes in elite soccer players' physical and technical performance (Sal de Rellán-Guerra et al., 2019; Rey et al., 2019). Consequently, future studies analysing the relation between players' age and the changes in performance throughout the matches could also be warranted considering the lack of information on this topic.

With regard to the analysis of substitute players' performance, it would also be relevant to consider in future studies the possible influence of the situational variables and the effective playing time. Indeed, player substitutions are commonly made during the second half of matches, when effective playing time has been shown to decrease. Therefore, the differences between the performance of substitute players compared to those who were replaced or completed the entire match could be underestimated with the current methodological approach followed in Study 2.

The findings of Study 3 provide a first insight into the effects of substitutions on teams' tactical behaviour. However, future studies should consider a more comprehensive classification of the type of substitutions, as well as the coaches' reasons for making each substitution. Specifically, mixed-methods case studies integrating quantitative data on player and team performance and qualitative data based on coaches' perceptions and reasons would add more relevant information on this topic.

Finally, another possible line of research could be to analyse the effect of player substitutions in women's soccer. Currently, only one study (Vescovi & Favero, 2014) appears to have examined the physical performance of substitutes in female college soccer players. Nevertheless, bearing in mind the existing gender differences in technical and tactical performance in soccer (Garnica-Caparrós & Memmert, 2021; Tenga et al., 2015), some findings of this dissertation could have limited applicability to women's soccer.

IV.
REFERENCES

Almeida, C. H., Ferreira, A. P., & Volossovitch, A. (2014). Effects of match location, match status and quality of opposition on regaining possession in UEFA Champions League. *Journal of Human Kinetics, 41* (1), 203–214. https://doi.org/10.2478/hukin-2014-0048

Ascari, G., & Gagnepain, P. (2006). Spanish football. *Journal of Sports Economics, 7* (1), 76–89. https://doi.org/10.1177/1527002505282869

Augste, C., & Cordes, O. (2016) Game stoppages as a tactical means in soccer – A comparison of the FIFA World Cups TM 2006 and 2014. *International Journal of Performance Analysis in Sport*, *16* (3), 1053–1064. https://doi.org/10.1080/24748668.2016.11868947

Bangsbo, J. (1994). The physiology of soccer with special reference to intense intermittent exercise. *Acta Physiologica Scandinavica. Supplementum*, *619*, 1–155.

Bangsbo, J., Iaia, F. M., & Krustrup, P. (2007). Metabolic response and fatigue in soccer. International *Journal of Sports Physiology and Performance*, *2* (2), 111–127. https://doi.org/10.1123/ijspp.2.2.111

Bates, D., Mächler, M., Bolker, B. M, & Walker, S. C. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67* (1), 1–48. https://doi.org/10.18637/jss.v067.i01

Batista, J., Goncalves, B., Sampaio, J., Castro, J., Abade, E., & Travassos, B. (2019). The influence of coaches' instruction on technical actions, t*actical* behaviour, and external workload in football small-sided games. *Montenegrin Journal of Sports Science and Medicine, 8* (1), 29–36. https://doi.org/10.26773/mjssm.190305

Bendiksen, M., Bischoff, R., Randers, M. B., Mohr, M., Rollo, I., Suetta, C., Bangsbo, J., & Krustrup, P. (2012). The Copenhagen Soccer Test: Physiological response and fatigue development. *Medicine and Science in Sports and Exercise*, *44* (8), 1595–1603. https://doi.org/10.1249/MSS.0b013e31824cc23b

Bourbousson, J., Sève, C., & McGarry, T. (2010). Space-time coordination dynamics in basketball: Part 2. The interaction between the two teams. *Journal of Sports Sciences, 28* (3), 349–358. https://doi.org/10.1080/02640410903503640

Bradley, P. S., Di Mascio, M., Peart, D., Olsen, P., & Sheldon, B. (2010). High-intensity activity profiles of elite soccer players at different performance levels. *Journal of Strength and Conditioning Research*, *24* (9), 2343–2351. https://doi.org/10.1519/JSC.0b013e3181aeb1b3

Bradley, P. S., Lago-Peñas, C., & Rey, E. (2014). Evaluation of the match performances of substitution players in elite soccer. *International Journal of Sports Physiology and Performance, 9* (3), 415–424. https://doi.org/10.1123/ijspp.2013-0304

Bradley, P. S., Lago-Peñas, C., Rey, E., & Gomez-Diaz, A. (2013). The effect of high and low percentage ball possession on physical and technical profiles in English FA Premier League soccer matches. *Journal of Sports Sciences, 31* (12), 1261–1270. https://doi.org/10.1080/02640414.2013.786185

Bradley, P. S., & Noakes, T. D. (2013). Match running performance fluctuations in elite soccer: Indicative of fatigue, pacing or situational influences?. *Journal of Sports Sciences, 31* (15), 1627–1638. https://doi.org/10.1080/02640414.2013.796062

Bradley, P. S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., & Krustrup, P. (2009). High-intensity running in English FA Premier League soccer matches. *Journal of Sports Sciences, 27* (2), 159–168. https://doi.org/10.1080/02640410802512775

Brefeld, U., Lasek, J., & Mair, S. (2019). Probabilistic movement models and zones of control. *Machine Learning, 108* (1), 127–147. https://doi.org/10.1007/s10994-018-5725-1

Carling, C. (2011). Influence of opposition team formation on physical and skill-related performance in a professional soccer team. *European Journal of Sport Science, 11* (3), 155–164. https://doi.org/10.1080/17461391.2010.499972

Carling, C., Bloomfield, J., Nelsen, L., & Reilly, T. (2008). The role of motion analysis in elite soccer: Contemporary performance measurement techniques and work rate data. *Sports Medicine, 38* (10), 839–862. https://doi.org/10.2165/00007256-200838100-00004

Carling, C., & Dupont, G. (2011). Are declines in physical performance associated with a reduction in skill-related performance during professional soccer match-play?. *Journal of Sports Sciences, 29* (1), 63–71. https://doi.org/10.1080/02640414.2010.521945

Carling, C., Espié, V., Le Gall, F., Bloomfield, J., & Jullien, H. (2010). Work-rate of substitutes in elite soccer: A preliminary study. *Journal of Science and Medicine in Sport, 13* (2), 253–255. https://doi.org/10.1016/j.jsams.2009.02.012

Carling, C., Le Gall, F., McCall, A., Nédélec, M., & Dupont, G. (2015). Squad management, injury and match performance in a professional soccer team over a championship-winning season. *European Journal of Sport Science, 15* (7), 573–582. https://doi.org/10.1080/17461391.2014.955885

Castellano, J., Álvarez, D., Figueira, B., Coutinho, D., & Sampaio, J. (2013). Identifying the effects from the quality of opposition in a football team positioning strategy. International *Journal of Performance Analysis in Sport, 13* (3), 822–832. https://doi.org/10.1080/24748668.2013.11868691

Castellano, J., Alvarez-Pastor, D., & Bradley, P. S. (2014). Evaluation of research using computerised tracking systems (Amisco and Prozone) to analyse physical performance in elite soccer: A systematic review. *Sports Medicine, 44* (5), 701–712. https://doi.org/10.1007/s40279-014-0144-3

Castellano, J., Blanco-Villaseñor, A., & Álvarez, D. (2011). Contextual variables and time-motion analysis in soccer. *International Journal of Sports Medicine, 32* (6), 415–421. https://doi.org/10.1055/s-0031-1271771

Castellano, J., & Casamichana, D. (2015). What are the differences between first and second divisions of Spanish football teams? *International Journal of Performance Analysis in Sport, 15* (1), 135–146. https://doi.org/10.1080/24748668.2015.11868782

Castellano, J., Casamichana, D., & Lago, C. (2012). The use of match statistics that discriminate between successful and unsuccessful soccer teams. *Journal of Human Kinetics, 31* (1), 137–147. https://doi.org/10.2478/v10078-012-0015-7

Clemente, F. M., Couceiro, S. M., Martins, F. M. L., Mendes, R., & Figueiredo, A. J. (2013). Measuring collective behaviour in football teams: Inspecting the impact of each half of the match on ball possession. *International Journal of Performance Analysis in Sport, 13* (3), 678–689. https://doi.org/10.1080/24748668.2013.11868680

Cohen, J. (1988). *Statistical power analysis for the behavioural sciences* (2nd ed). Lawrence Erlbaum.

Coutinho, D., Gonçalves, B., Wong, D. P., Travassos, B., Coutts, A. J., & Sampaio, J. (2018). Exploring the effects of mental and muscular fatigue in soccer players' performance. *Human Movement Science, 58*, 287–296. https://doi.org/10.1016/j.humov.2018.03.004

Del Corral, J., Barros, C. P., & Prieto-Rodriguez, J. (2008). The determinants of soccer player substitutions: A survival analysis of the Spanish soccer league. *Journal of Sports Economics, 9* (2), 160–172. https://doi.org/10.1177/1527002507308309

Dellal, A., Chamari, K., Wong, D. P., Ahmaidi, S., Keller, D., Barros, R., Bisciotti, G. N., & Carling, C. (2011). Comparison of physical and technical performance in European soccer match-play: FA Premier League and La Liga. *European Journal of Sport Science, 11* (1), 51–59. https://doi.org/10.1080/17461391.2010.481334

Di Salvo, V., Baron, R., Tschan, H., Calderon Montero, F. J., Bachl, N., & Pigozzi, F. (2007). Performance characteristics according to playing position in elite soccer. *International Journal of Sports Medicine, 28* (3), 222–227. https://doi.org/10.1055/s-2006-924294

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., & Drust, B. (2009). Analysis of high intensity activity in Premier League soccer. *International Journal of Sports Medicine, 30* (3), 205–212. https://doi.org/10.1055/s-0028-1105950

Drust, B., Atkinson, G., & Reilly, T. (2007). Future perspectives in the evaluation of the physiological demands of soccer. *Sports Medicine, 37* (9), 783–805. https://doi.org/10.2165/00007256-200737090-00003

Duarte, R., Araújo, D., Folgado, H., Esteves, P., Marques, P., & Davids, K. (2013). Capturing complex, non-linear team behaviours during competitive football performance. *Journal of Systems Science and Complexity, 26* (1), 62–72. https://doi.org/10.1007/s11424-013-2290-3

Duarte, R., Araújo, D., Freire, L., Folgado, H., Fernandes, O., & Davids, K. (2012). Intra-and inter-group coordination patterns reveal collective behaviour of football players near the scoring zone. *Human Movement Science, 31* (6), 1639–1651. https://doi.org/10.1016/j.humov.2012.03.001

Duch, J., Waitzman, J. S., & Amaral, L. A. (2010). Quantifying the performance of individual players in a team activity. *PloS One, 5* (6), e10937. https://doi.org/10.1371/journal.pone.0010937

Faude, O., Koch, T., & Meyer, T. (2012). Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences, 30* (7), 625–631. https://doi.org/10.1080/02640414.2012.665940

Felipe, J. L., Garcia-Unanue, J., Viejo-Romero, D., Navandar, A., & Sánchez-Sánchez, J. (2019). Validation of a video-based performance analysis system (Mediacoach®) to analyze the physical demands during matches in LaLiga. *Sensors, 19* (19), 4113. https://doi.org/10.3390/s19194113

Fernandez, J., & Bornn, L. (2018). *Wide open spaces: A statistical technique for measuring space creation in professional soccer* [Paper presentation]. 12th Annual MIT Sloan Sports Analytics Conference, Boston, MA, USA.

Fernandez-Navarro, J., Fradua, L., Zubillaga, A., Ford, P. R., & McRobert, A. P. (2016). Attacking and defensive styles of play in soccer: analysis of Spanish and English elite teams. *Journal of Sports Sciences, 34* (24), 2195–2204. https://doi.org/10.1080/02640414.2016.1169309

Fernandez-Navarro, J., Fradua, L., Zubillaga, A., & McRobert, A. P. (2018). Influence of contextual variables on styles of play in soccer. *International Journal of Performance Analysis in Sport, 18* (3), 423–436. https://doi.org/10.1080/24748668.2018.1479925

Fernandez-Navarro, J., Fradua, L., Zubillaga, A., & McRobert, A. P. (2019). Evaluating the effectiveness of styles of play in elite soccer. *International Journal of Sports Science & Coaching, 14* (4), 514–527. https://doi.org/10.1177/1747954119855361

Folgado, H., Duarte, R., Marques, P., Gonçalves, B., & Sampaio, J. (2018). Exploring how movement synchronization is related to match outcome in elite professional football. *Science and Medicine in Football, 2* (2), 101–107. https://doi.org/10.1080/24733938.2018.1431399

Folgado, H., Lemmink, K. A., Frencken, W., & Sampaio, J. (2014). Length, width and centroid distance as measures of teams tactical performance in youth football. *European Journal of Sport Science, 14* (sup1), S487–S492. https://doi.org/10.1080/17461391.2012.730060

Fonseca, S., Milho, J., Travassos, B., & Araújo, D. (2012). Spatial dynamics of team sports exposed by Voronoi diagrams. *Human Movement Science, 31* (6), 1652–1659. https://doi.org/10.1016/j.humov.2012.04.006

Frencken, W., Lemmink, K., Delleman, N., & Visscher, C. (2011). Oscillations of centroid position and surface area of soccer teams in small-sided games. *European Journal of Sport Science, 11* (4), 215–223. https://doi.org/10.1080/17461391.2010.499967

Frencken, W., Poel, H. D., Visscher, C., & Lemmink, K. (2012). Variability of inter-team distances associated with match events in elite-standard soccer. *Journal of Sports Sciences, 30* (12), 1207–1213. https://doi.org/10.1080/02640414.2012.703783

Garnica-Caparrós, M., & Memmert, D. (2021). Understanding gender differences in professional European football through machine learning interpretability and match actions data. *Scientific Reports, 11* (1), 10805. https://doi.org/10.1038/s41598-021-90264-w

General Assembly of LaLiga. (2019). *Code of ethics*. https://www.laliga.com/transparencia/cumplimiento/politicas

Glaister, M. (2005). Multiple sprint work: Physiological responses, mechanisms of fatigue and the influence of aerobic fitness. *Sports Medicine, 35* (9), 757–777. https://doi.org/10.2165/00007256-200535090-00003

Gomez, M. A., Lago-Peñas, C., & Owen, L. A. (2016). The influence of substitutions on elite soccer teams' performance. International Journal of Performance Analysis in *Sport, 16* (2), 553–568. https://doi.org/10.1080/24748668.2016.11868908

Harrop, K., & Nevill, A. (2014). Performance indicators that predict success in an English professional League One soccer team. *International Journal of Performance Analysis in Sport, 14* (3), 907–920. http://dx.doi.org/10.1080/24748668.2014.11868767

Hills, S. P., Barrett, S., Feltbower, R. G., Barwood, M. J., Radcliffe, J. N., Cooke, C. B., Kilduff, L. P., Cook, C. J., & Russell, M. (2019). A match-day analysis of the movement profiles of substitutes from a professional soccer club before and after pitch-entry. *PloS One, 14* (1), e0211563. https://doi.org/10.1371/journal.pone.0211563

Hills, S. P., Barwood, M. J., Radcliffe, J. N., Cooke, C. B., Kilduff, L. P., Cook, C. J., & Russell, M. (2018). Profiling the responses of soccer substitutes: A review of current literature. *Sports Medicine, 48* (10), 2255–2269. https://doi.org/10.1007/s40279-018-0962-9

Hills, S. P., Radcliffe, J. N., Barwood, M. J., Arent, S. M., Cooke, C. B., & Russell, M. (2020). Practitioner perceptions regarding the practices of soccer substitutes. *PloS One, 15* (2), e0228790. https://doi.org/10.1371/journal.pone.0228790

Hirotsu, N., & Wright, M. (2002). Using a Markov process model of an association football match to determine the optimal timing of substitution and tactical decisions. J*ournal of the Operational Research Society, 53* (1), 88–96.

Hoppe, M. W., Slomka, M., Baumgart, C., Weber, H., & Freiwald, J. (2015). Match running performance and success across a season in German Bundesliga soccer teams. *International Journal of Sports Medicine, 36* (7), 563–566. https://doi.org/10.1055/s-0034-1398578

Hughes, M. D., & Bartlett, R. M. (2002). The use of performance indicators in performance analysis. *Journal of Sports Sciences, 20* (10), 739–754. https://doi.org/10.1080/026404102320675602

Iaia, F. M., Rampinini, E., & Bangsbo, J. (2009). High-intensity training in football. *International Journal of Sports Physiology and Performance, 4* (3), 291–306. https://doi.org/10.1123/ijspp.4.3.291

International Football Association Board. (2021). *Laws of the game*.https://downloads.theifab.com/downloads/laws-of-the-game-2021-22?l=en

Ingebrigtsen, J., Bendiksen, M., Randers, M. B., Castagna, C., Krustrup, P., & Holtermann, A. (2012). Yo-Yo IR2 testing of elite and sub-elite soccer players: Performance, heart rate response and correlations to other interval tests. *Journal of Sports Sciences, 30* (13), 1337–1345. https://doi.org/10.1080/02640414.2012.711484

Konefał, M., Chmura, P., Zając, T., Chmura, J., Kowalczuk, E., & Andrzejewski, M. (2019a). Evolution of technical activity in various playing positions, in relation to match outcomes in professional soccer. *Biology of Sport, 36* (2), 181–189. https://doi.org/10.5114/biolsport.2019.83958

Konefał, M., Chmura, P., Zając, T., Chmura, J., Kowalczuk, E., & Andrzejewski, M. (2019b). A new approach to the analysis of pitch-positions in professional soccer. *Journal of Human Kinetics, 66* (1), 143–153. https://doi.org/10.2478/hukin-2018-0067

Krustrup, P., Mohr, M., Steensberg, A., Bencke, J., Kjaer, M., & Bangsbo, J. (2006). Muscle and blood metabolites during a soccer game: Implications for sprint performance. *Medicine and Science in Sports and Exercise, 38* (6), 1165–1174. https://doi.org/10.1249/01.mss.0000222845.89262.cd

Lago, C. (2009). The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *Journal of Sports Sciences, 27* (13), 1463–1469. https://doi.org/10.1080/02640410903131681

Lago-Ballesteros, J., Lago-Peñas, C., & Rey, E. (2012). The effect of playing tactics and situational variables on achieving score-box possessions in a professional soccer team. *Journal of Sports Sciences, 30* (14), 1455–1461. https://doi.org/10.1080/02640414.2012.712715

Lago-Peñas, C., Gómez-Ruano, M. Á., Owen, A. L., & Sampaio, J. (2016). The effects of a player dismissal on competitive technical match performance. *International Journal of Performance Analysis in Sport, 16* (3), 792–800. https://doi.org/10.1080/24748668.2016.11868928

Lago-Peñas, C., Lago-Ballesteros, J., Dellal, A., & Gómez, M. (2010). Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league. *Journal of Sports Science & Medicine, 9* (2), 288–293.

Lago-Peñas, C., Lago-Ballesteros, J., & Rey, E. (2011). Differences in performance indicators between winning and losing teams in the UEFA Champions League. *Journal of Human Kinetics, 27* (1), 135–146. https://doi.org/10.2478/v10078-011-0011-3

Lago-Peñas, C., Rey, E., & Lago-Ballesteros, J. (2012). The influence of effective playing time on physical demands of elite soccer players. *The Open Sports Science Journal, 5* (1), 188–192.

Lenth, R., Singmann, H., Love, J., Buerkner, P., & Hervé, M. (2019). Estimated marginal means, aka least-squares means (version 1.3.5) [Computer software]. https://cran.r-project.org/package=emmeans

Lepschy, H., Wäsche, H., & Woll, A. (2020) Success factors in football: An analysis of the German Bundesliga. *International Journal of Performance Analysis in Sport, 20* (2), 150–164. https://doi.org/10.1080/24748668.2020.1726157

Link, D., & de Lorenzo, M. F. (2016). Seasonal pacing – Match importance affects activity in professional soccer. *PloS One, 11* (6), e0157127. https://doi.org/10.1371/journal.pone.0157127

Linke, D., Link, D., Weber, H., & Lames, M. (2018). Decline in match running performance in football is affected by an increase in game interruptions. *Journal of Sports Science and Medicine, 17 (*4), 662–667.

Liu, H., Gomez, M. Á., Lago-Peñas, C., & Sampaio, J. (2015). Match statistics related to winning in the group stage of 2014 Brazil FIFA World Cup. *Journal of Sports Sciences, 33* (12), 1205–1213. https://doi.org/10.1080/02640414.2015.1022578

Liu, H., Hopkins, W., Gómez, M. A., & Molinuevo, S. J. (2013). Inter-operator reliability of live football match statistics from OPTA Sportsdata. *International Journal of Performance Analysis in Sport, 13* (3), 803–821. https://doi.org/10.1080/24748668.2013.11868690

Liu, H., Hopkins, W. G., & Gómez, M. A. (2016). Modelling relationships between match events and match outcome in elite football. *European Journal of Sport Science, 16* (5), 516–525. https://doi.org/10.1080/17461391.2015.1042527

Liu, H., Wang, L., Huang, G., Zhang, H., & Mao, W. (2020). Activity profiles of full-match and substitution players in the 2018 FIFA World Cup. *European Journal of Sport Science, 20* (5), 599–605. https://doi.org/10.1080/17461391.2019.1659420

Low, B., Boas, G. V., Meyer, L., Lizaso, E., Hoitz, F., Leite, N., & Gonçalves, B. (2018). Exploring the effects of deep-defending vs high-press on footballers' tactical behaviour, physical and physiological performance: A pilot study. Motriz: *Revista de Educação Física, 24* (2), e1019171. https://doi.org/10.1590/s1980-6574201800020009

Low, B., Coutinho, D., Gonçalves, B., Rein, R., Memmert, D., & Sampaio, J. (2019). A systematic review of collective tactical behaviours in football using positional data. *Sports Medicine, 50* (2), 343–385. https://doi.org/10.1007/s40279-019-01194-7

Low, B., Rein, R., Raabe, D., Schwab, S., & Memmert, D. (2021). The porous high-press? An experimental approach investigating tactical behaviours from two pressing strategies in football. *Journal of Sports Sciences,* 1–12. Advance online publication. https://doi.org/10.1080/02640414.2021.1925424

Mackenzie, R., & Cushion, C. (2013). Performance analysis in football: A critical review and implications for future research. *Journal of Sports Sciences, 31* (6), 639–676. https://doi.org/10.1080/02640414.2012.746720

Marcos, M. A., Koulla, P. M., & Anthos, Z. I. (2018). Preseason maximal aerobic power in professional soccer players among different divisions. *Journal of Strength and Conditioning Research, 32* (2), 356–363. https://doi.org/10.1519/JSC.0000000000001810

McGarry, T. (2009). Applied and theoretical perspectives of performance analysis in sport: Scientific issues and challenges. *International Journal of Performance Analysis in Sport, 9* (1), 128–140. http://dx.doi.org/10.1080/24748668.2009.11868469

Memmert, D., Lemmink, K., & Sampaio, J. (2017). Current approaches to tactical performance analyses in soccer using position data. *Sports Medicine, 47* (1), 1–10. https://doi.org/10.1007/s40279-016-0562-5

Memmert, D., & Raabe, D. (2018). *Data analytics in football: Positional data collection, modelling and analysis.* Routledge. https://doi.org/10.4324/9781351210164

Merlin, M., Cunha, S. A., Moura, F. A., Torres, R. D. S., Gonçalves, B., & Sampaio, J. (2020). Exploring the determinants of success in different clusters of ball possession sequences in soccer. *Research in Sports Medicine, 28* (3), 339–350. https://doi.org/10.1080/15438627.2020.1716228

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of Sports Sciences, 21* (7), 519–528. https://doi.org/10.1080/0264041031000071182

Mohr, M., Krustrup, P., & Bangsbo, J. (2005). Fatigue in soccer: A brief review. *Journal of Sports Sciences, 23* (6), 593–599. https://doi.org/10.1080/02640410400021286

Mohr, M., Krustrup, P., Nybo, L., Nielsen, J. J., & Bangsbo, J. (2004). Muscle temperature and sprint performance during soccer matches – Beneficial effect of re-warm-up at half-time. *Scandinavian Journal of Medicine & Science in Sports, 14* (3), 156–162. https://doi.org/10.1111/j.1600-0838.2004.00349.x

Morgulev, E., & Galily, Y. (2019). Analysis of time-wasting in English Premier League football matches: Evidence for unethical behavior in final minutes of close contests. *Journal of Behavioral and Experimental Economics, 81*, 1–8. https://doi.org/10.1016/j.socec.2019.05.003

Moura, F. A., Martins, L. E. B., Anido, R. D. O., De Barros, R. M. L., & Cunha, S. A. (2012). Quantitative analysis of Brazilian football players' organisation on the pitch. *Sports Biomechanics, 11* (1), 85–96. https://doi.org/10.1080/14763141.2011.637123

Moura, F. A., Martins, L. E. B., Anido, R. O., Ruffino, P. R. C., Barros, R. M. L., & Cunha, S. A. (2013). A spectral analysis of team dynamics and tactics in Brazilian football. *Journal of Sports Sciences, 31* (14), 1568–1577. https://doi.org/10.1080/02640414.2013.789920

Moura, F. A., Martins, L. E. B., & Cunha, S. A. (2014). Analysis of football game-related statistics using multivariate techniques. *Journal of Sports Sciences, 32* (20), 1881–1887. https://doi.org/10.1080/02640414.2013.853130

Myers, B. R. (2012). A proposed decision rule for the timing of soccer substitutions. *Journal of Quantitative Analysis in Sports, 8* (1), 1–22. https://doi.org/10.1515/1559-0410.1349

O'Donoghue, P. (2009). *Research methods for sports performance analysis.* Routledge. https://doi.org/10.4324/9780203878309

O'Donoghue, P., Holmes, L., & Robinson, G. (2017). *Doing a research project in sport performance analysis.* Routledge. https://doi.org/10.4324/9781315619132

Padrón-Cabo, A., Rey, E., Vidal, B., & García-Nuñez, J. (2018). Work-rate analysis of substitute players in professional soccer: Analysis of seasonal variations. *Journal of Human Kinetics, 65* (1), 165–174. https://doi.org/10.2478/hukin-2018-0025

Passos, P., Araújo, D., & Volossocitch, A. (2016). *Performance analysis in team sports.* Routledge. https://doi.org/10.4324/9781315739687

Paul, D. J., Bradley, P. S., & Nassis, G. P. (2015). Factors affecting match running performance of elite soccer players: Shedding some light on the complexity. *International Journal of Sports Physiology and Performance, 10* (4), 516–519. https://doi.org/10.1123/IJSPP.2015-0029

R Core Team (2018). R: *A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Rampinini, E., Bosio, A., Ferraresi, I., Petruolo, A., Morelli, A., & Sassi, A. (2011). Match-related fatigue in soccer players. *Medicine and Science in Sports and Exercise, 43* (11), 2161–2170. https://doi.org/10.1249/MSS.0b013e31821e9c5c

Rampinini, E., Coutts, A. J., Castagna, C., Sassi, R., & Impellizzeri, F. M. (2007). Variation in top level soccer match performance. *International Journal of Sports Medicine, 28* (12), 1018–1024. https://doi.org/10.1055/s-2007-965158

Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisløff, U. (2009). Technical performance during soccer matches of the Italian Serie A league: Effect of fatigue and competitive level. *Journal of Science and Medicine in Sport, 12* (1), 227–233. https://doi.org/10.1016/j.jsams.2007.10.002

Reilly, T., Drust, B., & Clarke, N. (2008). Muscle fatigue during football match-play. *Sports Medicine, 38* (5), 357–367. https://doi.org/10.2165/00007256-200838050-00001

Rein, R., & Memmert, D. (2016). Big data and tactical analysis in elite soccer: Future challenges and opportunities for sports science. *SpringerPlus, 5,* 1410. https://doi.org/10.1186/s40064-016-3108-2

Rein, R., Raabe, D., & Memmert, D. (2017). "Which pass is better?" Novel approaches to assess passing effectiveness in elite soccer. *Human Movement Science, 55*, 172–181. https://doi.org/10.1016/j.humov.2017.07.010

Rey, E., Costa, P. B., Corredoira, F. J., & Sal de Rellán Guerra, A. (2019). Effects of age on physical match performance in professional soccer players. *Journal of Strength and Conditioning Research,* 1–6. Advance online publication. https://doi.org/10.1519/JSC.0000000000003244

Rey, E., Lago-Ballesteros, J., & Padrón-Cabo, A. (2015). Timing and tactical analysis of player substitutions in the UEFA Champions League. *International Journal of Performance Analysis in Sport, 15* (3), 840–850. https://doi.org/10.1080/24748668.2015.11868835

Robertson, S., Gupta, R., & McIntosh, S. (2016). A method to assess the influence of individual player performance distribution on match outcome in team sports. *Journal of Sports Sciences, 34* (19), 1893–1900. https://doi.org/10.1080/02640414.2016.1142106

Russell, M., Benton, D., & Kingsley, M. (2011). The effects of fatigue on soccer skills performed during a soccer match simulation. I*nternational Journal of Sports Physiology and Performance, 6* (2), 221–233. https://doi.org/10.1123/ijspp.6.2.221

Russell, M., Rees, G., & Kingsley, M. I. C. (2013). Technical demands of soccer match play in the English championship. *Journal of Strength and Conditioning Research, 27* (10), 2869–2873. https://doi.org/10.1519/JSC.0b013e318280cc13

Sal de Rellán-Guerra, A., Rey, E., Kalén, A., & Lago-Peñas, C. (2019). Age-related physical and technical match performance changes in elite soccer players. *Scandinavian Journal of Medicine & Science in Sports, 29* (9), 1421–1427. https://doi.org/10.1111/sms.13463

Sarmento, H., Clemente, F. M., Araújo, D., Davids, K., McRobert, A., & Figueiredo, A. (2018). What performance analysts need to know about research trends in association football (2012–2016): A systematic review. *Sports Medicine, 48* (4), 799–836. https://doi.org/10.1007/s40279-017-0836-6

Sarmento, H., Marcelino, R., Anguera, M. T., Campaniço, J., Matos, N., & Leitão, J. C. (2014). Match analysis in football: A systematic review. *Journal of Sports Sciences, 32* (20), 1831–1843. https://doi.org/10.1080/02640414.2014.898852

Siegle, M., & Lames, M. (2012). Game interruptions in elite soccer. *Journal of Sports Sciences, 30* (7), 619–624. https://doi.org/10.1080/02640414.2012.667877

Siegle, M., Stevens, T., & Lames, M. (2013). Design of an accuracy study for position detection in football. *Journal of Sports Sciences, 31* (2), 166–172. https://doi.org/10.1080/02640414.2012.723131

Smith, M. R., Thompson, C., Marcora, S. M., Skorski, S., Meyer, T., & Coutts, A. J. (2018). Mental fatigue and soccer: Current knowledge and future directions. *Sports Medicine, 48* (7), 1525–1532. https://doi.org/10.1007/s40279-018-0908-2

Stølen, T., Chamari, K., Castagna, C., & Wisløff, U. (2005). Physiology of soccer: An update. *Sports Medicine, 35 (*6), 501–536. https://doi.org/10.2165/00007256-200535060-00004

Stone, K. J., & Oliver, J. L. (2009). The effect of 45 minutes of soccer-specific exercise on the performance of soccer skills. *International Journal of Sports Physiology and Performance, 4* (2), 163–175. https://doi.org/10.1123/ijspp.4.2.163

Tenga, A., Zubillaga, A., Caro, O., & Fradua, L. (2015). Explorative study on patterns of game structure in male and female matches from elite Spanish soccer, *International Journal of Performance Analysis in Sport, 15* (1), 411–423. https://doi.org/10.1080/24748668.2015.11868802

Tønnessen, E., Hem, E., Leirstein, S., Haugen, T., & Seiler, S. (2013). Maximal aerobic power characteristics of male professional soccer players, 1989–2012. *International Journal of Sports Physiology and Performance, 8* (3), 323–329. https://doi.org/10.1123/ijspp.8.3.323

Van Rossum, G., & Drake, F. L. (2009). Python 3 reference manual. CreateSpace.

Vescovi, J. D., & Favero, T. G. (2014). Motion characteristics of women's college soccer matches: Female Athletes in Motion (FAiM) study. I*nternational Journal of Sports Physiology and Performance, 9* (3), 405–414. https://doi.org/10.1123/IJSPP.2013-0526

Vogelbein, M., Nopp, S., & Hökelmann, A. (2014). Defensive transition in soccer – Are prompt possession regains a measure of success? A quantitative analysis of German Fußball-Bundesliga 2010/2011. *Journal of Sports Sciences, 32* (11), 1076–1083. https://doi.org/10.1080/02640414.2013.879671

Waldron, M., & Highton, J. (2014). Fatigue and pacing in high-intensity intermittent team sport: An update. *Sports Medicine, 44* (12), 1645–1658. https://doi.org/10.1007/s40279-014-0230-6

Wallace, J. L., & Norton, K. I. (2014). Evolution of World Cup soccer final games 1966–2010: Game structure, speed and play patterns. *Journal of Science and Medicine in Sport, 17* (2), 223–228. https://doi.org/10.1016/j.jsams.2013.03.016

Winter, E. M., & Maughan, R. J. (2009). Requirements for ethics approvals. *Journal of Sports Sciences, 27* (10), 985. https://doi.org/10.1080/02640410903178344

Wright, C., Atkins, S., & Jones, B. (2012). An analysis of elite coaches' engagement with performance analysis services (match, notational analysis and technique analysis). *International Journal of Performance Analysis in Sport, 12* (2), 436–451. http://dx.doi.org/10.1080/24748668.2012.11868609

Yang, G., Leicht, A. S., Lago, C., & Gómez, M. Á. (2018). Key team physical and technical performance indicators indicative of team quality in the soccer Chinese super league. *Research in Sports Medicine, 26* (2), 158–167. https://doi.org/10.1080/15438627.2018.1431539

Yi, Q., Gómez-Ruano, M. Á., Liu, H., Zhang, S., Gao, B., Wunderlich, F., & Memmert, D. (2020). Evaluation of the technical performance of football players in the UEFA Champions League. *International Journal of Environmental Research and Public Health, 17* (2), 604. https://doi.org/10.3390/ijerph17020604

Yi, Q., Groom, R., Dai, C., Liu, H., & Gómez-Ruano, M. Á. (2019). Differences in technical performance of players from 'The Big Five' European football leagues in the UEFA Champions League. *Frontiers in Psychology, 10,* 2738. https://doi.org/10.3389/fpsyg.2019.02738

Zhao, Y. & Zhang, H. (2021). Investigating the inter-country variations in game interruptions across the Big-5 European football leagues. *International Journal of Performance Analysis in Sport, 21* (1), 180–196.https://doi.org/10.1080/24748668.2020.1865688

V.
ANNEXES

A. Study 1

Rey, E., Kalén, A., Lorenzo-Martínez, M., López-Del Campo, R., Nevado-Garrosa, F., & Lago-Peñas, C. (2020). Elite Soccer Players do Not Cover Less Distance in the Second Half of the Matches When Game Interruptions Are Considered. *Journal of Strength and Conditioning Research.* Advance online publication.
https://doi.org/10.1519/JSC.0000000000003935

B. Study 2

Lorenzo-Martínez, M., Padrón-Cabo, A., Rey, E., & Memmert, D. (2020). Analysis of Physical and Technical Performance of Substitute Players in Professional Soccer. *Research Quarterly for Exercise and Sport.* Advance online publication.
https://doi.org/10.1080/02701367.2020.1755414

C. Study 3

Lorenzo-Martínez, M., Rein, R., Garnica-Caparrós, M., Memmert, D., & Rey, E. (2020). The Effect of Substitutions on Team Tactical Behavior in Professional Soccer. *Research Quarterly for Exercise and Sport.* Advance online publication.
https://doi.org/10.1080/02701367.2020.1828563