DOCTOR OF PHILOSOPHY

Influencia de la superficie de juego en el rendimiento de los jugadores de fútbol y rugby

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Award date:
2020

Awarding institution:
LocalizedString(id=20612840, text={en_GB=University of Castilla-La Mancha})

UNIVERSIDAD DE CASTILLA-LA MANCHA

FACULTAD DE CIENCIAS DEL DEPORTE
DEPARTAMENTO DE ACTIVIDAD FÍSICA Y CIENCIAS DEL DEPORTE

Programa de Doctorado en Investigación Sociosanitaria
y de la Actividad Física

INFLUENCIA DE LA SUPERFICIE DE JUEGO EN EL RENDIMIENTO DE LOS JUGADORES DE FÚTBOL Y RUGBY

INFLUENCE OF SPORTS SURFACE ON SOCCER AND RUGBY PLAYERS' PERFORMANCE




Tesis Doctoral Internacional desarrollada por:

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Dra. Dª. Leonor Gallardo Guerrero
Dr. D. Javier Sánchez Sánchez

Toledo, 2018

A mi familia y amigos

Se dice que el esfuerzo y el trabajo traen sus frutos,

pero es imposible alcanzarlo sin nadie que te soporte y te apoye incondicionalmente.

Dra. Dª. Leonor Gallardo Guerrero,

Profesora Titular de la Universidad de Castilla-La mancha

en la Facultad de Ciencias del Deporte de Toledo,

Certifica:

Que el trabajo de Tesis Doctoral Internacional desarrollado por el Graduado Jorge López Fernández, titulado **INFLUENCIA DE LA SUPERFICIE DE JUEGO EN EL RENDIMIENTO DE LOS JUGADORES DE FÚTBOL Y RUGBY**, ha sido realizado bajo mi dirección. En mi opinión, reúne los requisitos para proceder a iniciar los trámites pertinentes para la Comisión de Doctorado de la Universidad de Castilla-La Mancha y su posterior defensa ante tribunal.

Y para que conste, expido la presente certificación en Toledo a 20 de diciembre de 2017

Fdo. Dra. Dª. Leonor Gallardo Guerrero

Dr. D. Javier Sánchez Sánchez,

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en la Facultad de Ciencias del Deporte de Madrid,

Certifica:

Que el trabajo de Tesis Doctoral Internacional desarrollado por el Graduado Jorge López Fernández, titulado **INFLUENCIA DE LA SUPERFICIE DE JUEGO EN EL RENDIMIENTO DE LOS JUGADORES DE FÚTBOL Y RUGBY**, ha sido realizado bajo mi dirección. En mi opinión, reúne los requisitos para proceder a iniciar los trámites pertinentes para la Comisión de Doctorado de la Universidad de Castilla-La Mancha y su posterior defensa ante tribunal.

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Fdo. Dr. D. Javier Sánchez Sánchez

AGRADECIMIENTOS [ACKNOWLEDGEMENTS]

Con estas palabras, deseo transmitir el profundo y sincero agradecimiento a todas aquellas personas que han aportado su granito de arena para que yo pudiera realizar este trabajo. En especial, debo dar las gracias a la Dra. Dª. Leonor por otorgarme la oportunidad de incorporarme a su grupo de investigación y guiarme a través de todo este proceso formativo. Espero haber respondido positivamente a las expectativas y confianza que has depositado en mí a lo largo de estos últimos cuatro años. Tampoco puedo olvidarme del Dr. D. Javier Sánchez Sánchez, sin tu supervisión y asesoramiento nunca hubiera sido capaz de completar este trabajo. Para mí ha sido un auténtico lujo teneros como mentores y aprender de vosotros el verdadero significado de las palabras “esfuerzo”, “trabajo”, “compromiso” y “éxito”.

Al Dr. D. Jorge García Unanue por sus valiosos consejos y su incalculable ayuda en todo el recorrido que supone realizar una tesis doctoral. Más que un compañero, eres un verdadero ejemplo para todos nosotros. También tengo que hacer extensible mi gratitud a mis compañeros del Grupo IGOID, Enrique Colino, Sergio Rodríguez Cañamero, Manuel León, Víctor Villacañas, Carlos Gómez González y a los Drs. D. Gustavo Paipe, Dª. Esther Ubago Guisado y D. Enrique Hernando Barrio por todo lo que he aprendido de vosotros en todo este tiempo. Gracias por vuestra aportación al desarrollo de esta tesis doctoral y por vuestra compañía a lo largo de este camino.

Al resto de compañeros y profesores que se encuentran trabajando fuera, pero cuyos consejos y apoyo ha sido fundamental en mi enriquecimiento personal, como son el caso de D. José Luis Gómez Calvo, D. Rubén Gude y los Drs. D. José Luis Felipe Hernández, D. Álvaro Fernández Luna y D. Pablo Burillo. Y, por último, con especial cariño, a mis padres y hermanos, por vuestro tiempo robado, apoyo y orgullo incondicional durante todo este tiempo; a Raquel y a los Guilaros, por toda esa atención y alegría a lo largo de esta aventura, a Carmen por ser un ejemplo a seguir y por todo el cariño que nos regalaste a todos y, a Rubén, Iván y Miguel por estar siempre a mi lado.

A todos vosotros, muchas gracias.

LISTADO DE MANUSCRITOS [LIST OF MANUSCRIPTS]

La presente Tesis Doctoral engloba un total de seis trabajos científicos. Las referencias de cada uno de los estudios que componen este documento se detallan a continuación:

1. **López-Fernández, J.**, Gallardo, L., Fernández-Luna, Á., Villacañas, V., García-Unanue, J., & Sánchez-Sánchez, J. (2017). Pitch size and Game Surface in Different Small-Sided Games. Global Indicators, Activity Profile and Acceleration of Female Soccer Players. *The Journal of Strength & Conditioning Research*. doi: 10.1519/JSC.0000000000002090. (***Publicado; Impacto 2,060; JCR; Q2; 28/81 Sports Science***).
2. **López-Fernández, J.**, Sánchez-Sánchez, J., Rodríguez-Cañamero, S., Ubago-Guisado, E., Colino, E., & Gallardo, L. (*in review*). Physiological responses, fatigue and perception of female soccer players in small-sided games with different pitch size and sport surfaces. *Biology of Sport*. (***En 2ª revisión; Impacto 1,436; JCR; Q3; 47/81 Sports Science***).
3. **López-Fernández, J.**, Sánchez-Sánchez, J., Gallardo, L., & García-Unanue, J. (2017). Metabolic power of female footballers in various small-sided games with different pitch surfaces and sizes. *Sports, 5*(24), 1-9. (***Publicado, Sin impacto***).
4. **López-Fernández, J.**, Sánchez-Sánchez, J., García-Unanue, J., Felipe, J. L.; Colino, E., & Gallardo, L. (2018). Physiological and physical responses according to the game surface in a soccer simulation protocol. *International Journal of Sports Physiology and Performance*. DOI: 10.1123/ijspp.2017-0570 (***Aceptado; Impacto 2,654; JCR; Q1; 16/81 Sports Science***).
5. **López-Fernández, J.**, García-Unanue, J., Sánchez-Sánchez, J., León, M..; Hernando, E., & Gallardo, L. (2017). Neuromuscular responses and physiological patterns during a soccer simulation protocol. Artificial turf versus natural Grass. *The Journal of Sports Medicine and Physical Fitness*. doi: 10.23736/S0022-4707.17.07768-4 (***Publicado; Impacto 1,215; JCR; Q3; 58/81 Sports Science***).
6. Ubago-Guisado, E., Rodríguez-Cañamero, S., **López-Fernández, J.**, Colino, E., Sánchez-Sánchez, J., & Gallardo, L. (2017). Muscle contractile properties on different sport surfaces using tensiomyography. *Journal of Human Sport & Exercise, 12*(1), 167-179. (***Publicado; Impacto 0,536; SJR; Q3; 76/128 Sports Science***).

RESUMEN

Tradicionalmente los deportes colectivos como el fútbol y el rugby se han jugado sobre césped natural, siendo considerada esta superficie la de mayor calidad para la práctica deportiva. No obstante, entre sus principales inconvenientes destaca que requiere un alto coste de mantenimiento y, que el número de horas de uso semanales que ofrece es muy limitado. Por esa razón, el deporte amateur y de base se ha visto obligado, en muchas ocasiones, a apostar por otra tipología de pavimento como puede ser la tierra. Si analizamos el caso del fútbol en España, los terrenos de juego de tierra fueron de la mano del deporte no profesional hasta principios del siglo XXI. Momento en el que el césped artificial consiguió equiparar sus propiedades mecánicas a las del césped natural y convertirse en una alternativa de mayor calidad a la hierba natural.

Desde la aceptación del césped artificial para la práctica deportiva por la Fédération Internationale de Football Association (FIFA) y la World Rugby (WR), los campos de césped artificial se han expandido exponencialmente tanto para la práctica del fútbol, como del rugby. Entre sus principales ventajas, destaca su alto retorno económico en comparación con las superficies naturales y una mayor calidad de juego que los pavimentos de tierra. A pesar de la mejora cualitativa de estos sistemas sintéticos y de su creciente uso, muchos deportistas siguen siendo reacios a los mismos, argumentando que tienen un mayor índice de lesión, causa una mayor fatiga y afecta al desarrollo del juego. Por ello, estos sistemas de césped artificial, sin dejar de mejorar en sus prestaciones, tienen como reto el transmitir al usuario esta real equiparación con las superficies naturales, demostrando que no limitan el rendimiento deportivo ni incrementan el riesgo de sufrir una lesión.

En los últimos años ha habido un crecimiento muy elevado de los deportes de playa, incluso en zonas no costeras. Esto ha llevado a numerosos autores a estudiar cómo la superficie de arena afecta a la respuesta física y fisiológica de los deportistas. La principal particularidad de la arena es que tiene una absorción de impactos muy alta, que, a su vez, va acompañada de una mayor disipación de la energía, por lo que los deportistas se ven obligados a modificar su técnica de carrera. Así mismo, esta alta capacidad de absorción de impacto es responsable de que ante una misma tarea, los jugadores alcancen una menor velocidad pico y muestren una mayor respuesta fisiológica (mayor concentración de lactato y mayor frecuencia cardiaca pico) que sobre el resto de pavimentos deportivos. Por esta razón, varios autores destacan que la

arena de playa es una superficie óptima para la readaptación deportiva porque permite mejorar la condición física de los deportistas, sin que estos tengan que soportar unos picos de impacto muy elevados.

En la presente Tesis Doctoral, se han llevado a cabo **seis estudios** diferentes que comparan la influencia que tiene la superficie de juego sobre la respuesta física y fisiológica de los deportistas al realizar su modalidad deportiva. Los objetivos de estos estudios fueron: **1)** evaluar la influencia de la superficie de juego y las dimensiones del espacio en el perfil de movimiento de las mujeres futbolistas sub-élite durante varios juegos reducidos de cuatro jugadores por equipo; **2)** evaluar la influencia de la superficie de juego y las dimensiones del espacio en la respuesta fisiológica, la fatiga y la percepción de las jugadoras de fútbol sub-élite en diferentes juegos reducidos de cuatro jugadores por equipo; **3)** analizar las demandas de potencia metabólica de varios juegos reducidos de posesión y sin portero jugados sobre tres superficies de juego diferentes; **4)** analizar la influencia de la superficie de juego sobre la respuesta física y fisiológica de los jugadores de fútbol amateur a través de un protocolo de partido simulado; **5)** evaluar la influencia de la superficie de juego sobre los patrones fisiológicos y la respuesta muscular de los jugadores de fútbol mediante un protocolo de partido simulado que incorpora esprines repetidos y acciones no-lineales a máxima velocidad; **6)** descubrir la influencia de la arena y el césped natural sobre los parámetros musculares en jugadoras de rugby tras un test que induce a la fatiga.

La muestra de los **estudios 1, 2 y 3** estuvo compuesta por dieciséis mujeres futbolistas de la Segunda División española, con edades comprendidas entre los 17 y los 21 años (19,56 ± 1,97 años). Siguiendo las indicaciones de los entrenadores, las jugadoras se agruparon en cuatro equipos de cuatro jugadoras. Cada equipo disputó tres juegos reducidos de distinto tamaño (400 m^2; 600 m^2; y 800 m^2) sobre cada una de las tres superficies seleccionadas (césped natural, césped artificial y tierra). Los juegos reducidos se disputaron sin portero, manteniéndose los mismos enfrentamientos durante toda la prueba. Estos enfrentamientos fueron establecidos por los entrenadores para garantizar la máxima igualdad. Cada juego reducido tuvo una duración de 4 minutos y se repitió dos veces sobre cada superficie.

En el **Estudio 1**, el perfil cinemático de los jugadores (velocidad; distancia total; aceleraciones; etc.) en cada juego reducido fue registrado a través de un sistema global de posicionamiento por satélite (GPS) diseñado para la práctica deportiva (Spi Pro X, GPSports, Canberra, Australia). Además, las acciones de esprín (acciones por encima de 18 Km/h) fueron analizadas pormenorizadamente (aceleración máxima, velocidad máxima, distancia total y duración). Por su parte, en el **Estudio 2** se analizó la respuesta fisiológica de las jugadoras a través de unas bandas de monitorización de la frecuencia cardiaca (Polar Team System, Kempele, Finlandia). Los resultados de frecuencia cardiaca se obtuvieron tanto en latidos por minuto (l.p.m), como en base a la frecuencia cardiaca máxima de cada futbolista (%FC_{max}). Antes y después de cada juego reducido las jugadoras realizaron dos saltos con contramovimiento. Además, las jugadoras valoraron la calidad de la superficie a través de un cuestionario de percepción que utiliza una escala visual análoga (VAS). Por último, en el **estudio 3**, por medio de los mismos dispositivos GPS utilizados en el estudio 1, se estimó la carga metabólica (absoluta [KJ] y relativa [KJ/Kg]) que conllevó realizar cada juego reducido. Igualmente, se estimó el ratio de energía consumido por segundo (W/kg), la distancia total cubierta a más de 20 W/Kg (m) y la distancia máxima estimada si la velocidad hubiese sido constante (m).

Para los **estudios 4 y 5**, se reclutaron dieciséis futbolistas amateurs (22,17 ± 3,43 años). Los participantes completaron los primeros tres bloques de un protocolo de partido simulado sobre dos superficies diferentes (una de césped natural y otra de césped artificial) cuyas propiedades mecánicas fueron analizadas (absorción de impactos, la deformación vertical y la energía de restitución). Este protocolo fue diseñado expresamente para reproducir las demandas físicas y fisiológicas de los partidos de fútbol. En el **estudio 4**, los patrones físicos de los jugadores sobre cada superficie (tiempo de esprín, tiempo de esprines no-lineales, velocidad) fueron registrados mediante un sistema de fotocélulas (Microgate, Bolzano, Italia) y de dispositivos de GPS (HPU, GPSports, Australia). Así mismo, por medio de unas bandas de monitorización de la frecuencia cardiaca (Polar Team System, Kempele, Finlandia) se analizó la respuesta fisiológica en cada uno de los tres bloques que componen el protocolo de partido simulado. Por su parte, en el **estudio 5**, se analizó la carga fisiológica del protocolo de partido simulado a través de la monitorización de la frecuencia cardiaca. Antes y después de este test se registró el rendimiento de los deportistas en un salto con contramovimiento y la respuesta de los músculos recto femoral y bíceps femoral ante un estímulo eléctrico. Esta última prueba se realizó usando un equipo de tensiomiografía (BMC Ltd., Ljubljana, Eslovenia).

Por último, el **estudio 6** se centra en el deporte del Rugby. En este caso, quince jugadoras de rugby amateur (23,4 ± 4,42 años) realizaron un test de esprines repetidos sobre una superficie de césped natural y otra de arena. El rendimiento físico del test se obtuvo a través del sistema de fotocélulas y los equipos GPS del estudio 4; mientras que la respuesta de los músculos recto femoral y bíceps femoral ante un estímulo eléctrico antes y después de los esprines repetidos se registró mediante la prueba de tensiomiografía. Finalmente, a través del salto con contramovimiento se analizó la capacidad explosiva de las extremidades inferiores de cada participante.

Las principales conclusiones de estos estudios fueron: **1)** La respuesta física de las mujeres futbolistas es mayor sobre césped artificial que sobre tierra. En los juegos reducidos más intensos, el césped natural genera una carga externa más elevada que su homónimo el césped artificial. Además, cuando las dimensiones del espacio son demasiado grandes, la carga externa se estanca o incluso decrece. **2)** Las mujeres futbolistas consideran que el césped artificial no reduce la calidad en el juego en comparación con el césped natural, rechazando el uso de la tierra para la práctica del fútbol. La superficie natural produce una mayor carga interna en las jugadoras que el césped artificial durante la práctica del fútbol. En contraposición, las dimensiones del juego reducido pueden utilizarse para regular la intensidad de la tarea, aunque considerando que, si las dimensiones son demasiado grandes, la respuesta fisiológica decrece. **3)** Jugar sobre tierra reduce la potencia metabólica en los juegos reducidos; siendo la hierba natural la superficie más adecuada para obtener una mayor respuesta metabólica. De igual forma, si se aumenta en exceso las dimensiones de los juegos reducidos la demanda metabólica de los mismos no aumenta. **4)** La variabilidad mecánica entre el césped natural y el césped artificial no es suficientemente alta como para alterar el rendimiento en esprín y la respuesta fisiológica de los futbolistas amateur ante un mismo estímulo. No obstante, estas diferencias sí afectan ligeramente al rendimiento en los giros y cambios de dirección. **5)** La diferencia en la respuesta mecánica entre el césped artificial y la hierba natural no modifica la respuesta fisiológica y muscular de los jugadores de fútbol amateur ante un mismo estímulo. **6)** La superficie de arena produce una mayor fatiga en el recto femoral de las jugadoras de rugby que el césped natural después un test de esprines repetidos.

ABSTRACT

Collective sports like soccer and rugby have traditionally been played on natural grass which moreover is considered to be the best-quality surface for playing sports. However, this sort of surface is associated to high maintenance costs and limited hours of use. Thus, both amateur and base sports usually have to look for other surfaces. In the case of soccer, up to the XXI Century, most facilities enabled for non-professional level play opted for dirt pitches. At present, the newest artificial turf systems of third generation have achieved the mechanical properties of natural grass surfaces, becoming a real alternative either to natural grass surfaces or dirt fields.

Since the acceptance of artificial turf for sports practice by the Fédération Internationale de Football Association (FIFA) and the World Rugby (WR), artificial turf fields have expanded their presence exponentially for practising either football or rugby. The main advantage of artificial turf systems is a high economic return compared to natural surfaces, and a higher quality of play than dirt pavements. Despite the qualitative improvements of these synthetic systems and their increasing use, many athletes remain reluctant to them; arguing that they pose a higher rate of injury, greater fatigue and affects the development of the game. Therefore, artificial turf systems not only have to keep improving their performance, but they have the challenge to prove that they have achieved the same performance as natural grass surfaces, demonstrating that they do not limit the players' performance or increase the risk of suffering an injury.

On the other hand, beach sports are growing even in non-coastal areas. For that reason, several authors have started to study how sand surfaces affect the physical and physiological responses of players. Contrary to the other surfaces, sand has a very high impact reduction causing athletes to modify their running technique. Moreover, this impact reduction capacity, together with a greater capability to dissipate the energy, makes the speed of sprints much lower than in the rest of pavements. This difference in the movement kinetics results in greater metabolic demands and higher physiological responses from players (higher lactate levels in blood and greater peak heart rate). For that reason, several authors emphasize that beach sand is an optimal surface for sports rehabilitation because players can improve their fitness without facing high peaks of impact.

In the current Doctoral Thesis, there are enclosed six different studies that assess the influence of sports surface on physical and physiological responses of athletes when performing their sports modality. The objectives of these studies are: **1)** to evaluate the influence of game surface and pitch size on the movement profile in sub-elite female soccer players during small sided games of four-a-side; **2)** to evaluate the influence of game surface and pitch size on the physiological responses, fatigue and perception in sub-elite female soccer players during small sided games of four aside; **3)** to analyse the metabolic power demands of various small sided games on possession play without goal-keepers, played on three different surfaces; **4)** to analyse the influence of the game surface on amateur soccer player's physical and physiological responses using a soccer simulation protocol; **5)** to assess the influence of the game surface on physiological patterns and neuromuscular responses of soccer players during a soccer simulation protocol that incorporates repeated sprints and nonlinear actions at maximum speed; **6)** to discover the influence of sand and natural grass on muscle parameters in female rugby players after an induced fatigue test.

The sample of **studies 1, 2 and 3** was composed of sixteen female soccer players from the Spanish Second Division (19.56 ± 1.97 years old). Players were gathered into four teams of players each based on coaches' criteria. Each team played three different small-sided games of different pitch size (400 m^2; 600 m^2; 800 m^2) on the three selected surfaces (natural grass, artificial turf and dirt). The small-sided games were played without goalkeeper and both team and matches were always the same. Each small sided game lasted 4 minutes and was played twice on each surface. In **study 1**, time motion of players (speed, total distance, accelerations, etc.) on each SSGs was recorded through a global positioning system (GPS) designed for sports practising (Spi Pro X, GPSports, Canberra, Australia). Moreover, sprint actions (actions over 18 km/h) were analysed in detail (maximum acceleration, maximum speed, total distance, duration). In **study 2** a heart rate monitor was used for assessing the physiological responses of players (Polar Team System, Kempele, Finland). Outcomes of heart rate were obtained either in beats per minute (b.p.m) or based on the maximum heart rate of each player (%HR_{max}). Before and after each small-sided game, participants performed two counter-movement jumps. Also, players assessed the quality of each surface through a perception questionnaire using a visual analogue scale (VAS). Finally, in **study 3**, the metabolic load (absolute [KJ] and relative [KJ/kg]) of each small-sided game, the rate of energy consumed per second (W/kg), the total distance covered at 20 W/kg or more (m) and, the maximum distance that players could have run with the total energy consumed if they ran at a constant speed (m) were estimated using the GPS devices

The sample of the studies 4 and 5 was composed of sixteen amateur players (22.17 ± 3.43 years old). In this case players performed the first three bouts of a soccer simulation protocol on two different surfaces (natural grass and artificial turf) whose mechanical properties were assessed (impact reduction, vertical deformation and energy return). The soccer simulation protocol was designed for replicating the physical and physiological demands of soccer matches. In study 4, the physical patterns of soccer players on each surface (sprint time, non-linear sprint time, speed) were recorded through a photocell system (Microgate, Bolzano, Italy) and GPS devices (HPU, GPSports, Australia). The physiological responses were monitored by means of heart rate monitors (Polar Team System, Kempele, Finland). In **study 5**, the physiological load of the soccer simulation protocol was assessed using the heart rate monitor. The performance of players in a counter-movement jump was recorded before and after the soccer simulation protocol, as well as the response of the rectus femoris and biceps femoris to an electrical stimulus. This last test was performed by means of a tensiomyography tool (BMC Ltd., Ljubljana, Slovenia).

Finally, **study 6** is focused on rugby. In this case, fifteen female amateur players (23.4 ± 4.42 years old) performed a repeated sprint test on a natural grass surface and a sand surface. The physical performance of the test was collected through the photocell system and GPS devices used in the study 4; while the muscular responses of biceps femoris and rectus femoris to an electrical stimulus either before or after the repeated sprint test were recorded through the tensiomyography test. Lastly, the explosive capacity of participants' lower body was assessed through a counter-movement jump.

The main conclusions of these studies are that **1)** the physical response of female soccer players is higher on artificial turf than ground. In the most intense small sided games, natural grass provides greater external load than artificial turf. Moreover, when the dimensions of the space are too large, the external load stagnates or even decreases. **2)** Female soccer players consider that artificial turf does not reduce the quality of the game compared to natural grass, rejecting the use of dirt for playing soccer. The natural surfaces produce a greater internal load in the players than artificial turf during soccer practice. In contrast, pitch size can be used for controlling the intensity of the small-sided games, as bigger pitches entail higher physiological responses. However, if the pitch size increases too much the physiological responses decrease. **3)** Playing on dirt reduces the metabolic power of small-sided games; being natural grass the most suitable surface for obtaining the highest metabolic response. Likewise, if pitch sizes increase too much the metabolic demands of the small-sided games do not improve. **4)** The mechanical variability between natural grass and artificial turf is not high enough to affect the physical and physiological performance of amateur football players to the same stimulus. However, these differences do slightly affect the performance in turns and changes in direction. **5)** The mechanical response of artificial grass differs from that of natural grass. However, the physiological and muscular responses of amateur soccer players to the same stimulus are not affected by such mechanical variability. **6)** Sand surfaces produces greater fatigue in the rectus femoris of the rugby players than the natural grass after a repeated sprint test.

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ÍNDICE DE ABREVIATURAS [LIST OF ABBREVIATIONS]

AA: Atleta Artificial.

AAA o Triple A: Atleta Artificial Avanzado.

AENOR: Asociación Española de Normalización y Certificación.

AI: Absorción de impactos.

ANOVA: Análisis de la varianza.

CEN: Comité Europeo de Normalización.

CMJ: Salto con contramovimiento.

Dm: Máximo desplazamiento radial del vientre muscular.

DV: Deformación Vertical.

ER: Energía de Restitución.

ES: Tamaño del efecto.

FC: Frecuencia cardiaca.

FC_{max}: Frecuencia cardiaca máxima.

FC_{pico}: Frecuencia cardiaca pico.

FC_{media}: Frecuencia cardiaca media.

FIFA: Fédération Internationale de Football Association.

GPS: Sistema de posicionamiento global.

IC: Intervalo de confianza.

DE: Desviación estándar.

RSA: Test de esprines repetidos.

RSA_{mejor}: Mejor tiempo de esprín del RSA.

RSA_{media}: Tiempo medio de los esprines del RSA.

RSA_{TT}: Tiempo total del RSA.

RT: Tracción Rotacional.

SSG: Juego reducido.

SSP: Protocolo de partido simulado.

TMG: Tensiomiografia.

Tc: Tiempo de contracción.

Td: Tiempo de reacción.

Tr: Tiempo de relajación.

Ts: Tiempo que se mantiene la contracción.

UEFA: Union of European Football Associations.

VAS: Escala visual análoga.

V_{max}: Pico de velocidad máxima.

V_{media}: Velocidad media.

WR: World Rugby.

%Dec: Porcentaje de decrecimiento.

%Dif: Diferencia entre el mejor y peor esprín del RSA.

* Abbreviations in English language are shown in the scientific papers included in the present doctoral thesis

Capítulo 1

INTRODUCCIÓN [INTRODUCTION]

1.1. Superficies deportivas en el fútbol y en el rugby

1.1.1. Introducción

La práctica de la actividad física es algo inherente al ser humano, que ha ido evolucionando a lo largo de historia hasta convertirse en muchos de los deportes que conocemos hoy en día. Aunque cada modalidad deportiva tiene sus propias particularidades, todas ellas coinciden en que deben realizarse en un entorno especifico, en un momento concreto y bajo unas reglas comunes (Burillo, 2009). En el caso del fútbol o del rugby, este entorno está limitado por un terreno de juego específico, cuyo tamaño y características están previamente establecidos. Estos terrenos se conocen por el nombre de superficies deportivas o pavimentos deportivos y están diseñados específicamente para cubrir las demandas del deporte principal que se va a llevar a cabo sobre ellos (Dixon, Fleming, James, & Carré, 2015).

En el ámbito de las ciencias del deporte, un pavimento óptimo para la práctica deportiva es aquél que permite al deportista realizar sus mejores habilidades sin incrementar el riesgo de sufrir una lesión como consecuencia de su interacción con dicha superficie (Stiles, James, Dixon, & Guisasola, 2009). Por eso, el reto actual de la industria de las superficies deportivas es cumplir con las demandas requeridas para la práctica deportiva, dentro de las expectativas de sus usuarios y de su presupuesto. Esto incluye tanto la construcción de las mismas, como su mantenimiento.

Como vemos, la elección de un pavimento u otro para la práctica deportiva no es una decisión baladí. De hecho, en casi todos los casos, supone una inversión muy importante, por lo que la supervivencia de la instalación deportiva donde se integra dicho pavimento, así como su utilidad a largo plazo, dependen de dicha elección (Burillo et al., 2010). En el caso del fútbol, principalmente se han utilizado tres pavimentos, el césped natural, el césped artificial y la tierra, mientras que, en el rugby, se han utilizado fundamentalmente las dos primeras. Por otra parte, a pesar de no ser una superficie adecuada para la práctica del fútbol o del rugby, la arena de playa está cada vez más ligada a estos dos deportes, habiéndose desarrollado una modalidad deportiva de fútbol y otra de rugby exclusivamente para este pavimento: fútbol playa y rugby playa.

1.1.2. Superficies de césped natural

El césped natural deportivo, puede definirse como aquella superficie o terreno deportivo que posee una cubierta de hierba natural (Burillo, 2009); siendo la superficie original para deportes como el fútbol o el rugby. La principal particularidad de este pavimento es que es el único terreno de juego que está formado por seres vivos, lo que hace que mantenerlo en óptimas condiciones para la práctica deportiva a lo largo plazo sea muy complejo y generalmente costoso (Felipe, 2011).

En los primeros años de desarrollo del fútbol o el rugby, esta superficie estaba formada por el propio pasto presente en las praderas inglesas, que se cortaba a determinada altura para permitir la práctica deportiva (Dixon et al., 2015). Hoy en día las superficies de césped natural se construyen específicamente para la práctica deportiva (Burillo, 2009), utilizando una estructura compuesta de varias capas. De arriba (más superficial) a abajo (meno superficial) esta estructura se suele componer de: la hierba natural, la capa de enraizamiento o subbase, otras capas intermedias de arena y/o grava y el subsuelo (Figura 1), que suele tener integrado la red de drenaje o de riego (Burillo, 2009; Dixon et al., 2015).

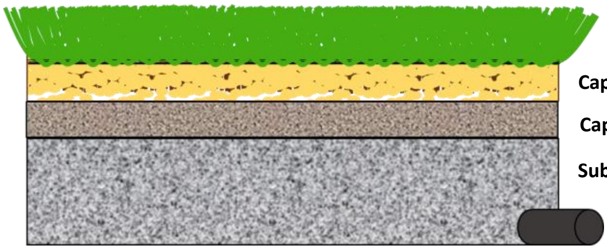


Figura 1. Estructura de una superficie de césped natural

Al ser la hierba natural una planta viva, la velocidad de regeneración de esta superficie depende tanto de la capacidad de la planta para crecer y renovar sus hojas, como para reparar y restaurar la capa de enraizamiento. Al mismo tiempo, esta capa de enraizamiento tiene que ser capaz de proveer a la planta de los nutrientes necesarios para su desarrollo y soportar las fuerzas aplicadas por los deportistas durante el juego. Por esta razón, estos dos componentes no se pueden considerar como sistemas aislados, sino que integran una única estructura o sistema (Dixon et al., 2015). De hecho, la calidad de este sistema está directamente relacionado con la capacidad de desgaste de la superficie; ya que juega un papel fundamental tanto en el crecimiento de la planta como en el desarrollo del sistema radicular de la misma (Burillo, 2009; James, 2011).

Desde un punto de vista de la funcionalidad deportiva, este sistema es el encargado de dotar a la superficie de una buena funcionalidad mecánica en términos de absorción de impactos (dureza), recuperación elástica, agarre (tracción) y fricción (Burillo, 2009; Dixon et al., 2015). El excelente balance entre la interacción superficie-balón y superficie-jugador ofrecido por estas superficies, ha hecho que sus propiedades mecánicas se utilicen como punto de referencia para el resto de pavimentos utilizados tanto en fútbol, como en rugby (FIFA, 2015a; Sánchez-Sánchez, 2014). Sin embargo, es preciso señalar que no todos los campos de césped natural poseen el mismo comportamiento mecánico (Caple, James, & Bartlett, 2012; Guisasola, James, Llewellyn, Stiles, & Dixon, 2009; Guisasola, James, Stiles, & Dixon, 2010), ni están en condiciones óptimas para ser utilizados en actividades deportivas (Burillo, 2009).

En este sentido, la altura de la planta juega un papel fundamental en la absorción de impactos de la superficie, en la fricción de la misma tanto con el balón, como con los deportistas y, en la uniformidad del terreno de juego (Dixon et al., 2015). En el fútbol, por ejemplo, la hierba natural se corta entre los 20 mm y los 35 mm para que la pelota ruede con mayor velocidad, mientras que, en el rugby, se opta por una mayor altura (entre 35 mm y 50 mm) porque aumenta la absorción de impactos y proporciona al deportista una mayor protección ante las caídas (Dixon et al., 2015; James, 2011). Por otra parte, los materiales que conforman la capa de enraizamiento y su interacción con la propia planta también tienen un efecto directo en las propiedades mecánicas de la superficie (tracción) y en su calidad (resistencia a la rotura) (Dixon et al., 2015). Por estas razones, a la hora de construir un pavimento de césped natural, se deben tener en cuenta tanto las propiedades agrónomas que lo conforman, como las propiedades que afectan a su mantenimiento y al uso deportivo (Burillo, 2009).

Tradicionalmente, los terrenos de juego de césped natural han estado relacionados con problemas como falta de uniformidad, excesivo nivel de encharcamiento a consecuencia de la lluvia, incapacidad para regenerar las plantas que lo conforman o, con un desgaste excesivo de la superficie (Dixon et al., 2015; Stiles et al., 2009). En los últimos veinte años, la industria del césped natural ha desarrollado nuevos componentes estructurales y nuevas variedades de plantas que permiten un mejor rendimiento biológico del césped natural y, por lo tanto, una mayor capacidad para adaptarse a los requerimientos de cada entorno (Burillo et al., 2010;

Guisasola et al., 2010). Estos avances se han producido tanto en la construcción y drenaje de la estructura que conforma el césped natural, como en las particularidades de los vegetales empleados. Consiguiendo superficies más resistentes, pero sin incrementar el riesgo de lesión (Dixon et al., 2015; James, 2011; Stiles et al., 2009). De esta forma, las principales particularidades de estos nuevos pavimentos son que poseen una mayor resistencia a la rotura (que mejora la tracción de los deportistas) y que son más duros y resistentes (Stiles et al., 2009).

A pesar de estas mejoras y de su continua evolución, las superficies de césped natural siguen teniendo los dos inconvenientes principales: su baja capacidad para resistir el desgaste ocasionado por la práctica deportiva y, sus altos costes de mantenimiento, especialmente en aquellas zonas con temperaturas extremas (Burillo, 2009). Estos dos factores hacen que el uso de la superficie se vea limitado a unas pocas horas a la semana, pues de lo contrario, su capacidad para regenerarse y recuperar su estado inicial se vería seriamente dañada (Burillo, 2009; Dixon et al., 2015; James, 2011). Motivo por el que muchos clubes deportivos y entidades públicas están optando por superficies más asequibles, que además permiten un mayor número de horas de uso (Felipe, 2011).

1.1.3. Superficies de tierra

Los campos de tierra surgieron a medida que el fútbol se fue expandiendo por aquellas regiones cuya climatología dificulta la existencia de praderas uniformes de pasto natural o la construcción de este tipo de superficies. Así, en países como España, los campos de tierra han ido de la mano en el desarrollo y crecimiento del fútbol desde sus orígenes. Siendo, además, la superficie más utilizada en el deporte no profesional hasta principios del Siglo XXI (Burillo, 2009).

Con la aparición de las competiciones nacionales, el fútbol regional sufrió un rápido desarrollo, creciendo exponencialmente la demanda de terrenos de juego para el fútbol (Burillo, 2009). En este punto, los campos de tierra cobraron una especial relevancia, debido a que no requieren de una alta inversión en el proyecto de ejecución, ni tienen unos costes de mantenimiento tan elevados como en las superficies de césped natural (Felipe, 2011). Además, debido a la dureza de estas superficies, el número de horas de uso a la semana es mucho más elevado, permitiendo un mayor retorno de la inversión y por lo tanto un mayor equilibrio económico de las instalaciones deportivas. Por esa razón, los campos de césped natural quedaron relegados a las categorías profesionales y semiprofesionales (Burillo, 2009; Burillo, Barajas, Gallardo, & Garcia Tascón, 2011).

Tradicionalmente, los pavimentos de tierra están construidos de grava y areniscas compactadas, teniendo dos capas principales, la capa superior y la subbase (Figura 2). La capa superior normalmente está constituida por una mezcla de arena de sílice y tierra con un tamaño inferior a 1 mm. Sin embargo, en zonas como Andalucía, ha sido frecuente el uso del albero (arena más fina), porque posee unas mejores propiedades que la tierra convencional (Felipe, 2011). Por su parte, la subbase está generalmente constituida por una zahorra de grava que puede ser tanto natural como artificial (Burillo, 2009).

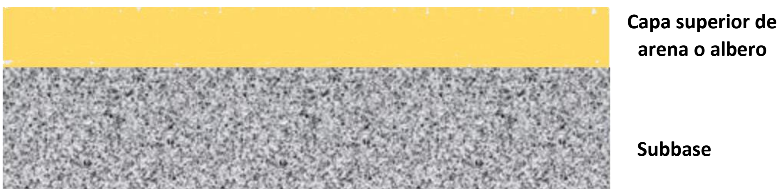


Figura 2. Estructura de una superficie de tierra

Debido a las características de los campos de tierra, estos necesitan una cierta humedad para no perder su elasticidad. De ahí que la subbase deba contar con un drenaje moderado. En consecuencia, uno de los principales inconvenientes de los campos de tierra es la formación de charcos y barrizales (Burillo, 2009). Así mismo, la dureza de esta superficie y su alta resistencia a la fricción hace que estos terrenos de juego estén asociados con numerosas heridas en la piel, tanto por impacto como por abrasión (Felipe, 2011).

Actualmente, aunque los campos de tierra siguen estando permitidos para la práctica del fútbol en competiciones amateur, están siendo sustituidos por los pavimentos de césped artificial de tercera generación (Burillo, 2009). Esto se debe principalmente al gran esfuerzo que está realizando la FIFA por incrementar la calidad de los terrenos de juego usados en el fútbol semiprofesional y amateur (FIFA, 2015a). Aun así, los campos de tierra siguen siendo predominantes en los países con menos recursos económicos. Con el objetivo de potenciar la creación de campos de fútbol de mayor calidad, la FIFA cuenta con un programa de apoyo a las federaciones con menos recursos, apostando claramente por el césped artificial como medio donde desarrollar el fútbol moderno (Felipe et al., 2013; McNitt, 2005; Sánchez-Sánchez, 2014).

1.1.4. Superficies de césped artificial

El césped artificial surgió en los años 60 en Estados Unidos como sustituto de la hierba natural (Burillo, 2009). Las primeras versiones de ese pavimento estaban fabricadas con fibras de nylon fibrilado cuya altura oscilaba entre los 10 y 12 mm (Fleming, 2011). El alto riesgo de sufrir lesiones por abrasión de la piel asociados a estas fibras hizo que otras empresas optasen por un material de polipropileno (Burillo, 2009; Dixon et al., 2015). Estos dos productos se instalaban con una base elástica inferior y fueron denominados como césped artificial de primera generación (Figura 3), utilizándose actualmente para la práctica del Hockey.

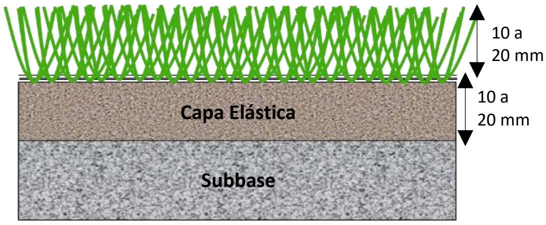


Figura 3. Césped artificial de 1ª generación

El césped de segunda generación apareció a finales de los años 70 con el objetivo de mejorar las prestaciones del césped de la generación anterior. En este caso, la superficie presenta una menor cantidad de fibras de polipropileno, con costuras más separadas. Su principal diferencia con el césped de primera generación es que la altura de fibra se incrementa hasta los 30 mm. Incorporando un relleno de arena entre las fibras (Burillo, 2009; Stiles et al., 2009). Este incremento en la altura de la fibra hizo que no siempre se incluyera una capa elástica de entre 20 y 40 mm encima de la subbase (Figura 4). Aunque esta superficie llegó a ser utilizada en estadios de la primera división inglesa (Sánchez-Sánchez, 2014), seguía siendo muy abrasiva para la piel y modificaba los patrones de juego. Por lo que los organismos internacionales como la Fédération Internationale de Football Association (FIFA) y la Union of European Football Associations (UEFA) optaron por prohibirlos para el uso deportivo de alto nivel (Burillo, 2009; Stiles et al., 2009).

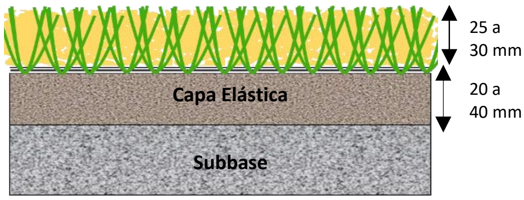


Figura 4. Césped artificial de 2ª generación

Con la incorporación de partículas de caucho triturado, surgió el denominado césped de 3ª generación. Este pavimento ha ido evolucionando desde finales del siglo XX hasta la actualidad, con el objetivo de ofrecer una calidad de juego y seguridad similares a la hierba natural (Green Floor & Moure, 2004). Al utilizarse fibras de polietilenos lubricados con una altura de pelo de entre 50 y 70 mm y con una menor densidad de puntadas, el riesgo de abrasión se ha reducido considerablemente. Además, esta mayor altura de fibra, unido a la utilización de un relleno formado por arena y caucho entre las mismas (Dixon et al., 2015; Fleming, 2012), mejora la absorción de impactos y ofrece un comportamiento mecánico muy parecido al de la hierba natural (Dixon et al., 2015; Fleming, 2012) (Figura 5).

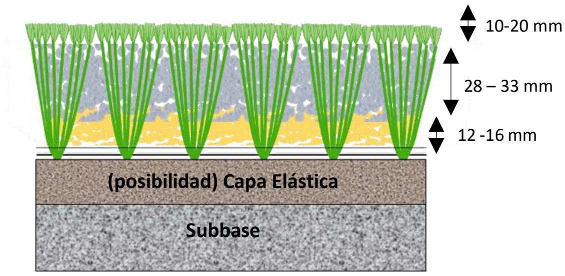


Figura 5. Césped artificial de 3ª generación

Este salto cualitativo del césped artificial de tercera generación ha conseguido superar los principales obstáculos asociados a los sistemas sintéticos; obteniéndose unas ratios de seguridad similares a los pavimentos formados por hierba natural (Ekstrand, Hägglund, & Fuller, 2011; Meyers, 2016). De hecho, aunque parecen existir unas ligeras diferencias en el juego asociadas a estos pavimentos artificiales (Andersson, Ekblom, & Krustrup, 2008), los últimos estudios comparativos muestran una funcionalidad deportiva similar al césped natural (Hughes et al., 2013; Nédélec et al., 2013; Stone et al., 2014).

Al igual que con las otras generaciones de césped artificial, tradicionalmente los usuarios han percibido el césped de tercera generación como un pavimento de peor calidad que el césped natural (Andersson et al., 2008). No obstante, la evolución continua de estos sistemas y una mayor familiarización con ellos ha incrementado la satisfacción con estas superficies, equiparándolas con su homónimo el césped natural (Burillo, Gallardo, Felipe, & Gallardo, 2014). Entre los beneficios estratégicos del césped artificial, destaca el ahorro de los costes de mantenimiento y el aumento de la rentabilidad derivado de una mayor cantidad de horas de uso (Claudio, 2008; ESTO, 2012; Felipe, 2011), causando que estos pavimentos se hayan implantados de manera masiva en todo el mundo, aunque con mayor importancia en aquellos países con una climatología adversa para el desarrollo de las superficies de hierba natural (Burillo et al., 2014; Kordi, Hemmati, Heidarian, & Ziaee, 2011).

En la actualidad, la industria de césped artificial tiene como reto mejorar las prestaciones de la hierba natural y reducir las elevadas temperaturas que alcanzan los sistemas sintéticos, llegando a ser hasta 20º superior a la de su competidor (Petrass, Twomey, & Harvey, 2014; Villacañas, Sánchez-Sánchez, García-Unanue, López, & Gallardo, 2017). A través de combinar distintos tipos de fibra y mezclar los dos componentes de relleno (caucho y arena), se está buscando una mayor estabilidad, elasticidad y energía de restitución, junto con una mejora de la recuperación del aplastamiento de las fibras (Burillo et al., 2010). Estas mejoras han llevado a varios autores y marcas comercializadoras a hablar del césped artificial de cuarta generación (Fleming, 2011; Williams, Hume, & Kara, 2011). Sin embargo, la falta de evidencia en la mejora cualitativa de estos nuevos sistemas hace que sea inadecuado utilizar esta denominación en la actualidad (Sánchez-Sánchez, 2014). El cambio generacional en las superficies artificiales podrá darse si los desarrollos tecnológicos tanto en las fibras como en el relleno y capa elástica consiguen solucionar las limitaciones del pavimento de césped artificial de tercera generación actual (Fleming, 2011).

La principal crítica realizada a los sistemas artificiales a lo largo de su historia ha sido su falta de capacidad para reproducir las propiedades mecánicas de la hierba natural (Burillo, Gallardo, Felipe, & Gallardo, 2012). Con la aparición del césped artificial de tercera generación, estas diferencias se han reducido progresivamente hasta alcanzar actualmente un comportamiento parejo al de las superficies naturales (Sánchez-Sánchez, 2014). Esto ha hecho que las diferentes federaciones internacionales, la FIFA en fútbol y World Rugby (WR) en rugby, no sólo lo hayan aceptado para la práctica del fútbol y del rugby respectivamente, sino que están promoviendo su uso a todos los niveles (Burillo et al., 2010; Stiles et al., 2009). Así, si ponemos como ejemplo el fútbol, el césped artificial ha sido utilizado satisfactoriamente en competiciones de máximo nivel, como son el mundial de fútbol femenino o la Champions League (Felipe, Burillo, Fernández-Luna, & García-Unanue, 2016).

A pesar de este éxito, la evidencia científica demuestra la existencia de una gran variabilidad en la respuesta mecánica entre los pavimentos artificiales (Sánchez-Sánchez et al., 2014b; Villacañas et al., 2017), de forma que no todos ellos cumplen los requisitos mínimos para ser considerados aptos para la práctica deportiva (Burillo et al., 2014; Sánchez-Sánchez, Felipe, Burillo, del Corral, & Gallardo, 2014a). Por eso, con el objetivo de garantizar un comportamiento de estos pavimentos más homogéneo, cada modalidad deportiva cuenta con sus propias certificaciones y homologaciones que buscan adaptar las propiedades mecánicas del césped artificial a las demandas y necesidades de sus deportistas (Burillo et al., 2014; FIFA, 2015a; Sánchez-Sánchez et al., 2014a; WR, 2016).

1.1.5. Superficies de arena de playa

A pesar de que la arena de playa no se utiliza ni en el fútbol ni en el rugby, la alta demanda de los deportes modernos ha llevado a varios autores a explorar la superficie de arena de playa como métodos de preparación que permitan controlar la carga del entrenamiento (Binnie, Dawson, Pinnington, Landers, & Peeling, 2014; Pinnington, Lloyd, Besier, & Dawson, 2005). Esto es principalmente debido a que esta superficie cuenta con una mayor capacidad para amortiguar los impactos que las anteriormente mencionadas gracias a que la arena que forma la capa superior está muy descompactada (Binnie et al., 2014; Burillo, 2009).

Hoy en día, los campos de arena de playa suelen ser construidos para la realización de modalidades deportivas específicas, como pueden ser fútbol playa o rugby playa. La gran mayoría de ellos se encuentra en las zonas costeras, porque se reducen los gastos de construcción. Sin embargo, cada vez existen más instalaciones que los incorporan a sus servicios deportivos (Martins & Gas, 2014; Rafoss & Troelsen, 2010). Normalmente, los campos de arena están formados por una subbase de tierra natural sobre la que se deposita la capa superior de arena de sílice. Esta capa superior está formada por granos de arena fina no compactados que se tamizan para reducir su aspereza (Figura 6). Esta capa debe contar como mínimo con 40 cm de profundidad, no pudiendo albergar guijarros ni otros elementos peligrosos (FIFA, 2015c).

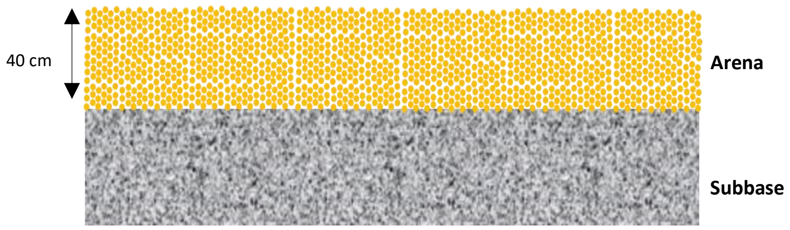


Figura 6. Estructura de un campo de arena de playa

Como se ha mencionado anteriormente, la principal característica de la arena de playa es su alta absorción de impactos. Esta respuesta mecánica está relacionada con un descenso en las fuerzas de impacto que experimenta el atleta durante la práctica deportiva, pudiendo reducir tanto el dolor muscular tardío (DOMS), como el daño muscular (Impellizzeri et al., 2008; Miyama & Nosaka, 2004). Este hecho hace que diversos autores consideren que la arena puede ser beneficiosa en la reparación muscular y en los procesos de adaptación (Barnett, 2006; Binnie et al., 2014). Por otro lado, la baja compactación de las partículas de arena hace que los jugadores tengan una menor estabilidad durante la práctica deportiva (Cressey, West, Tiberio, Kraemer, &

Maresh, 2007; Pinnington et al., 2005). Este hecho, unido a la alta absorción de impactos de la arena, parece modificar la técnica de carrera de los deportistas (Binnie et al., 2014), haciendo que los músculos de la pierna se activen de forma distinta (Miyama & Nosaka, 2004).

Diversos autores han encontrado que la práctica deportiva sobre arena causa un mayor gasto energético, una mayor frecuencia cardiaca y una mayor concentración de lactato que otros pavimentos con una menor absorción de impactos, como son la hierba natural o el césped artificial (Brito, Krustrup, & Rebelo, 2012; Impellizzeri et al., 2008). Estos resultados parecen sugerir que entrenar sobre arena permite reducir el tiempo requerido para obtener las adaptaciones fisiológicas deseadas (Binnie et al., 2014). No obstante, son necesarios más estudios para poder establecer una causa-efecto. Además, aunque entrenar en arena parece aumentar la fuerza del tren inferior, no está claro si puede tener un efecto negativo sobre las acciones explosivas de los deportistas (Impellizzeri et al., 2008).

1.2. Comportamiento mecánico de los pavimentos deportivos

1.2.1. Evaluación de la función deportiva

A la hora de valorar si un pavimento está en condiciones para la práctica deportiva, es preciso analizar todas aquellas propiedades que tienen un efecto directo en el riesgo de sufrir una lesión, además de facilitar un correcto rendimiento del deportista y un adecuado comportamiento tanto en el bote, como en la rodadura del balón (Rosa, Sanchis, Alcántara, & Zamora, 2008; Rosa, Sanchís, Alcántara, & Zamora, 2007). Esto se conoce como el análisis de la función deportiva, que es el estudio de la interacción superficie-jugador y superficie-balón a través de las propiedades mecánicas del pavimento (Burillo et al., 2010; Rosa et al., 2008).

Estas propiedades mecánicas se analizan por medio de diferentes equipos mecánicos (Sánchez-Sánchez et al., 2014a), comparando los resultados con los valores que han demostrado ser adecuados para garantizar un nivel de riesgo y de rendimiento durante el juego aceptables (Burillo et al., 2010; Rosa et al., 2008). Hoy en día se sabe que las propiedades mecánicas o la respuesta mecánica de una superficie vienen determinada por los componentes de soporte que integran sus diferentes capas y por los materiales empleados en la construcción de los mismos (Sánchez-Sánchez, 2014). Diversos estudios no sólo han demostrado que las propiedades mecánicas varían de un pavimento a otro, incluso dentro de la misma tipología, sino que a lo largo del tiempo estas propiedades también van variando (Sánchez-Sánchez et al., 2014a). Por consiguiente, una misma tipología de superficie deportiva no puede ser considerada como un grupo homogéneo (Caple et al., 2012; McGhie & Ettema, 2013; Sánchez-Sánchez et al., 2014a), salvo que se controlen y se analicen sus propiedades mecánicas.

El estudio de las propiedades mecánicas de los pavimentos deportivos se realiza a través de dos modalidades de pruebas, las pruebas de laboratorio y las pruebas *in situ*. Las pruebas de laboratorio son las más complejas y más exhaustivas. En ellas se estipulan las características que deben cumplir los diferentes componentes estructurales para poder ser incorporados al pavimento. A través de estas pruebas de verificación, se comprueba que el producto que va a ser instalado posee unas propiedades mecánicas óptimas para la modalidad deportiva principal que se va a realizar sobre el mismo (Burillo et al., 2012). Por su parte, las pruebas *in situ* tienen como principal objetivo certificar que las propiedades mecánicas del producto final no se han visto deterioradas durante la instalación y, por lo tanto, el pavimento está listo para su uso (Burillo et al., 2014; FIFA, 2015a; WR, 2016). En otras palabras, su principal función es garantizar que la interacción superficie-jugador y superficie-balón es adecuada para la práctica deportiva.

En España, los principales organismos que establecen los criterios para certificar las propiedades mecánicas de los sistemas de césped artificial *in situ* son: la Asociación Española de Normalización y Certificación (AENOR), el organismo legalmente responsable del desarrollo y difusión de las normas técnicas en España, que está bajo la supervisión del Comité Europeo de Normalización (European Committee for Standardization; CEN) y, las federaciones internacionales, en este caso la FIFA y la WR. Aunque sendas organizaciones utilizan criterios similares, existen ligeras variaciones entre los estándares marcados por cada organización y para cada modalidad deportiva (Burillo et al., 2012; FIFA, 2015b; Sánchez-Sánchez et al., 2014a; WR, 2016).

1.2.2. Propiedades mecánicas bajo la modalidad de prueba *in situ*

1.2.2.1. Absorción de impactos

La absorción de impactos (AI) es la capacidad del pavimento para absorber y disipar parte de la energía generada por un impacto como consecuencia de la carrera, los saltos o las caídas (Rosa et al., 2008; Rosa et al., 2007). Esta propiedad ha sido altamente estudiada debido a que las propiedades de las superficies deportivas juegan un papel determinante en las aceleraciones de impacto máximo experimentadas por los atletas (Zanetti, Bignardi, Franceschini, & Audenino, 2013). Se ha comprobado que las superficies blandas (alto nivel de absorción de impactos) disipan una mayor cantidad de energía que las superficies rígidas o duras cuyas fuerzas de reacción ante un impacto son mucho más elevadas (McGhie & Ettema, 2013).

Desde el punto de vista de la prevención de lesiones, las superficies más duras están relacionadas con un mayor número de lesiones por sobrecarga, ya que los atletas se ven repetidamente sometidos a picos de fuerza más elevados durante la práctica deportiva (Ford et al., 2006; Hreljac, 2004). Así, una excesiva rigidez del pavimento deportivo incrementa el riesgo de sufrir una lesión. Por otro lado, si analizamos la influencia de la absorción de impactos en el rendimiento deportivo, nos encontramos que las superficies más rígidas reducen el tiempo de esprín de los deportistas (Sánchez-Sánchez et al., 2014b); mientras que las más blandas aumentan el nivel de fatiga (Sánchez-Sánchez et al., 2016). Por consiguiente, el reto de los pavimentos deportivos es ser capaz de garantizar una buena funcionalidad deportiva, sin incrementar el riesgo de sufrir una lesión (Sánchez-Sánchez, 2014).

El método principal para conocer la absorción de impactos de un pavimento deportivo se establece mediante un sistema que simula el impacto que ejerce el talón del deportista en el pavimento durante la carrera. Para ello, existen dos equipos distintos, el Atleta Artificial (AA) que se utiliza para certificar campos bajo la normativa UNE EN de AENOR (Figura 7) (AENOR, 2014) y el Atleta Artificial Avanzado (AAA o Triple A) que es utilizado en la acreditación de campos por la FIFA y por la WR (Figura 8) (FIFA, 2015a; WR, 2016).

Bajo la normativa UNE EN 14808:2014/AC (AENOR, 2014), el AA registra la absorción de impactos al dejar caer, desde una altura de 55mm (±0,25 mm), una masa de 20 Kg que utiliza un muelle con una rigidez controlada. Cuando dicha masa impacta en el suelo, la máxima fuerza aplicada se recoge a través de un sensor de fuerza (resultados en %), proporcionándonos resultados con una resolución del 0,01%. Para ello, se utiliza la siguiente fórmula

$$\%AI = [1-(F_t / F_{ref})] \cdot 100$$

donde %AI es la absorción de impactos en %; la F_t es la máxima fuerza medida sobre la superficie deportiva y la F_{ref} es la fuerza de referencia del hormigón. En este caso, la F_{ref} debe calcularse previamente a los test sobre las superficies deportiva. Para ello, se realiza esta prueba sobre una superficie de hormigón (Colino et al., 2017)

Figura 7. Atleta Artificial (Imagen de Deltec®)

Para la certificación en base a los criterios de la FIFA o la WR, se utiliza el Atleta Artificial Avanzado. La principal diferencia entre este equipo con el Atleta Artificial es que no calcula la fuerza máxima a través de un sensor de fuerza, sino que lo estima por medio de una célula de carga calibrada previamente (FIFA, 2015a; WR, 2016). Para ello utiliza la siguiente fórmula

$$\%AI = [1- (F_{max} / F_{ref})] \cdot 100$$

donde %AI es la absorción de impactos en %; F_{ref} es la fuerza de referencia que se establece en 6760N (valor teórico calculado para el horminón); y F_{max} es la fuerza máxima medida en la superficie deportiva que se estima por medio de la fórmula $F_{max} = m \cdot g \cdot G_{max} + m \cdot g$ (m es la masa incluido el muelle en Kg; g es la aceleración de la gravedad [9.81 m/s^2]; y G_{max} es el pico de aceleración durante el impacto expresado en g [1g = 9.81 m/s^2] (Colino et al., 2017; FIFA, 2015a)

Figura 8. Atleta Artificial Avanzado (Imagen de Deltec®)

1.2.2.2. Deformación vertical

La deformación vertical (DV), muestra cuanto se deforma un pavimento tras un impacto. Este parámetro se relaciona con la estabilidad, ya que es el responsable de las pérdidas de equilibrio laterales en los deportistas (Alcántara, Gámez, Rosa, & Sanchís, 2007). Aunque la deformación vertical contribuye a la amortiguación de los impactos, un exceso de la misma puede ocasionar movimientos articulares inesperados, produciendo lesiones de tipo articular (Sánchez-Sánchez, 2014). Así mismo, puede afectar a la experiencia deportiva al causar un bote de balón irregular (Burillo et al., 2010).

Al igual que en el caso anterior, la certificación de la superficie por la normativa UNE EN 14809:2015 requiere del uso del Atleta Artificial (AENOR, 2014). Para ello, desde una altura de 125 mm (±0,25 mm), se deja caer una masa de 20 Kg sobre un muelle blando, y por medio de unos sensores de desplazamiento sobre el pie del Atleta Artificial (Figura 9) se registra la deformación de la superficie (Sánchez-Sánchez et al., 2014a). Este parámetro se obtiene a través de la fórmula

$$DV = (1500 / F_{max}) D_{max}$$

donde F_{max} es el valor del pico de fuerza en N y el D_{max} es la deformación máxima registrada por los sensores de desplazamiento.

Figura 9. Sensores de desplazamiento que se incorporan al Atleta Artificial para analizar la deformación vertical de los pavimentos (Imagen de Deltec®)

En el caso de la FIFA y la WR, esta variable se obtiene simultáneamente a la de absorción de impactos; por lo que la realización de la prueba es similar a la del caso anteriormente descrito (FIFA, 2015a; WR, 2016). La fórmula utilizada para calcular la DV a través del triple A es:

$$DV = D_{mass} - D_{spring}$$

donde $D_{mass} = \iint_{T2}^{T1} g \cdot dt$, con $D_{mass} = 0$ en T1; y $D_{spring} = (m \cdot g \cdot G_{max}) / C_{spring}$. G_{max} es la aceleración máxima durante el impacto (g); g es la aceleración mediante la gravedad (9,81 ms^{-2}); m es la masa que cae, incluyendo el muelle, la placa base y el acelerómetro (Kg); y C_{spring} es la constante del muelle que viene establecida por el certificado de calibración.

1.2.2.3. Energía de restitución

La energía de restitución (ER) puede definirse como la cantidad de energía liberada tras el impacto del jugador que el pavimento es capaz de disipar. Este ensayo proporciona información sobre la cantidad de energía que el sistema devuelve al deportista o al balón tras su impacto sobre ella; estando relacionado con los otros dos anteriores. Por ello, una excesiva energía de restitución incrementaría el riesgo de lesiones, mientras que unos niveles muy bajos, afectan a la interacción superficie-jugador y superficie-balón.

La energía de restitución sólo puede calcularse a través del Triple A, por lo que no está recogida en la normativa UNE EN. En cuanto a las federaciones, la normativa FIFA no contempla este ensayo como obligatorio en la certificación del pavimento. Utilizándose exclusivamente a modo informativo (FIFA, 2015b). En cambio, la WR sí exige la realización de esta prueba (WR, 2016) Al igual que ocurre con la deformación vertical, el Triple A proporciona este dato simultáneamente a las otras dos pruebas, por lo tanto, no es necesario realizar ensayos adicionales. Esta variable se obtiene a partir de la siguiente fórmula:

$$ER = (E_2 / E_1) \cdot 100$$

donde E_1 es a energía antes del impacto $E_1 = 0{,}5 \cdot m \cdot V^2_{max}$; y E_2 es la energía después del impacto $E_2 = 0{,}5\ m \cdot V^2_{min}$. V_{max} es la velocidad antes del impacto en m/s (T_1) y V_{min} corresponde a la velocidad después del impacto en m/s (T_2).

1.2.2.4. Tracción rotacional

La tracción rotacional (RT) determina la resistencia del terreno para realizar una rotación, es decir, el agarre del pavimento. Un adecuado agarre es fundamental para evitar caídas y para que el deportista pueda realzar los diferentes gestos deportivos. Sin embargo, un excesivo valor de esta propiedad puede causar bloqueos del pie que desemboquen en una lesión (Rosa et al., 2008).

Esta propiedad se mide al hacer girar un disco de peso predeterminado que está en contacto con la superficie a través de unos tacos de goma (15 tacos de 11 mm de longitud). En este caso tanto AENOR, a través de su norma EN 15301-1:2015, como la FIFA y la WR requieren la utilización un peso de 46Kg (AENOR, 2014; FIFA, 2015b; WR, 2016). Este peso se deja caer sobre la superficie de juego desde una altura que oscila los 600mm (±5 mm). Una vez los tacos se han clavado en el pavimento, se hace girar una llave dinamométrica 45º a una velocidad de 12 r/min, obteniendo información sobre la fuerza requerida para realizar un giro de una masa que está adherida a la superficie (N · m) (Figura 10).

Figura 10. Equipo de medición de la tracción rotacional (Imagen de Deltec®)

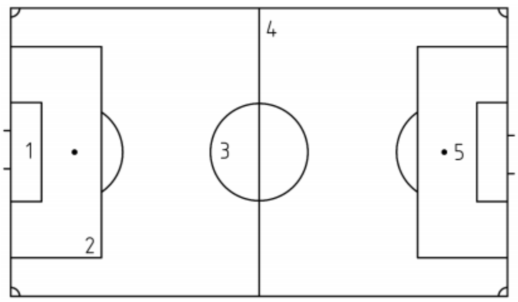
A pesar de la importancia de esta variable en la respuesta física y fisiológica de los deportistas, en ninguno de los estudios incluidos en la presente tesis doctoral se ha podido realizar este ensayo. Lo que supone una limitación a tener en cuenta a la hora de analizar los hallazgos obtenidos en la presente tesis doctoral.

1.2.2.5. Propiedades mecánicas adicionales

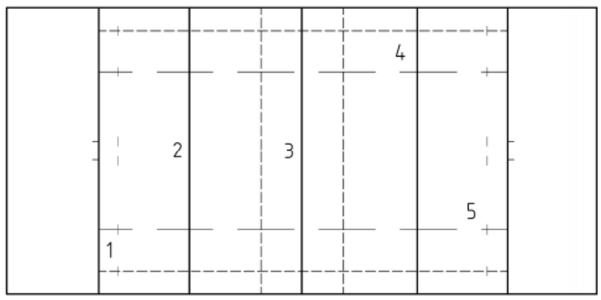
Como se ha explicado anteriormente, existen otras valoraciones *in situ* destinadas al análisis de la relación superficie-balón. Éstas son la rodadura de balón y el rebote de balón (AENOR, 2014; FIFA, 2015b). Además, la WR incluye una prueba extra relacionada con la superficie-jugador llamada atenuación del impacto (craneal), que tiene como objetivo garantizar la seguridad del deportista tras la caída (WR, 2016).

1.2.3. Zonas de evaluación *in situ*

Para establecer una valoración fiable de las propiedades mecánicas de una superficie, cada ensayo debe repetirse suficientes veces y sobre varias zonas del campo. El número de ensayos y de zonas donde estos se tienen que repetir viene predeterminado por la normativa que se va a aplicar. Así, AENOR (2014), a través de la normativa UNE EN 15330-1:2014 Establece 5 zonas de la superficie donde realizar dichas pruebas (Figura 11).



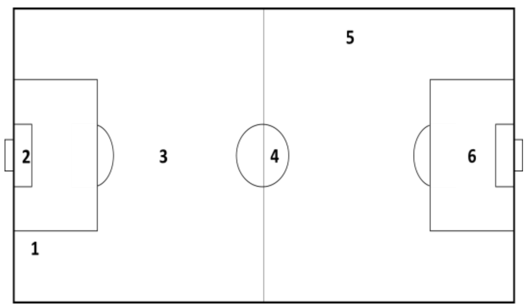
campos de fútbol 11



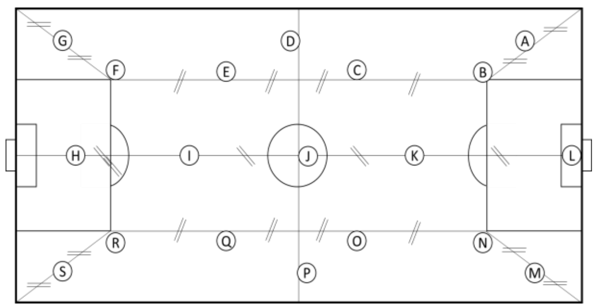
campos de rugby a 11

Figura 11. Posiciones de ensayo para campos deportivos (AENOR, 2014)

Por su parte, la FIFA establece seis zonas de evaluación para todas sus pruebas menos para las que se realizan con el Triple A: absorción de impacto, deformación vertical y energía de restitución. Las cuales deben ser medidas en diecinueve zonas (Figura 12).



Posiciones de ensayo (6 zonas)



Posiciones de ensayo (19 zonas)

Figura 12. Posiciones de ensayo para campos de fútbol 11 (FIFA, 2015a)

Por último, la WR marca el número de zonas según las dimensiones del campo, de forma que para campos grandes se requiere analizar un total de 19 localizaciones (Figura 13).

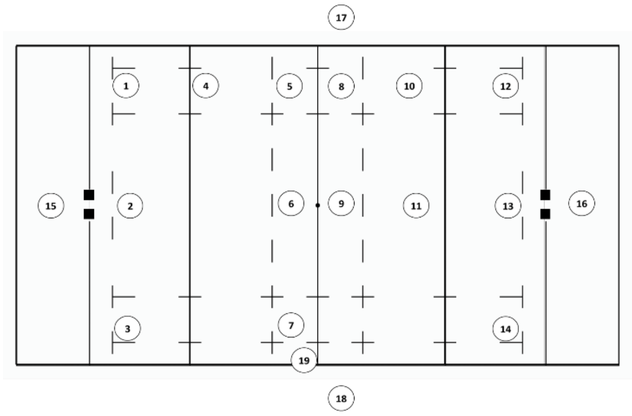


Figura 13. Posiciones de ensayo para campos de rugby a 11 (WR, 2016)

1.2.3.1. Requerimientos para cada prueba

Tanto en el fútbol como en el rugby, el césped natural es considerado como la superficie con mejores propiedades mecánicas para la práctica de estos deportes. Por esa razón, los pavimentos de césped artificial han evolucionado utilizando como referencia la respuesta mecánica de estos pavimentos. Actualmente, los nuevos sistemas de césped artificial de tercera generación han conseguido alcanzar unas propiedades parejas a su homónimo el césped natural, por lo que los requerimientos establecidos para estas dos superficies son idénticos.

A pesar de tener unos requerimientos similares, en las normativas actuales, sólo es obligatorio controlar las propiedades mecánicas de los campos de césped artificial. Por ello, el estudio de las propiedades mecánicas de las superficies naturales es exclusivamente de carácter informativo. Esto se debe a que la respuesta mecánica de los sistemas de césped artificial es muy variada, influyendo decisivamente factores como la antigüedad del pavimento, las horas de uso a la semana o el mantenimiento que se le realiza. Además, este hecho unido a la gran variedad de componentes estructurales existentes en el mercado, hacen que no se encuentren dos campos de césped artificial iguales. Pese a ello, recientes estudios sugieren que la diferencia en la respuesta mecánica de los campos naturales entre sí es suficientemente grande como para tenerla en cuenta (Caple et al., 2012), por lo que parece recomendable certificar y controlar también las propiedades mecánicas de dichos pavimentos. Los valores permitidos para cada prueba varían ligeramente entre normativas. En la Tabla 1, se exponen todas las pruebas *in situ* y los requerimientos según cada normativa (AENOR, 2014; FIFA, 2015a; WR, 2016).

Tabla 1. Valores de las pruebas de certificación *in situ* según cada normativa (AENOR, 2014; FIFA, 2015b; WR, 2016)

Ensayo	Normativa EN Fútbol	Normativa EN Rugby	FIFA Quality (variación permitida*)	FIFA Quality Pro (variación permitida*)	World Rugby (variación permitida*)
Absorción de impactos	55 - 70%	55 - 70%	55 - 70% (±5%)	60 - 70% (±10%)	55 - 70% (±5%)
Deformación vertical	4 - 9 mm	4 - 10 mm	4 - 11 mm (±10%)	4 - 10 mm (±15%)	5,5 - 11 mm (±2 mm)
Energía de restitución	–	–	–	–	20 - 50% (±6%)
Tracción rotacional	25 - 50 Nm	30 - 50 Nm	25 - 50 Nm (±6%)	30 - 45 Nm (±10%)	30 - 45 Nm (±4 Nm)
Rodadura de balón	4 – 12 m	–	4 – 12 m (±15%)	4 - 8 m (±10%)	–
Rebote de balón	60 - 100 cm	60 - 100 cm	60 - 100 cm (±10%)	60 - 85 cm (±5%)	60 cm - 100 cm (±10 cm)
Atenuación de impacto (craneal)	–	≥1.3 m	–	–	≥1.3 m

* **Variación permitida**: Los valores obtenidos en las diferentes zonas no podrán variar entre ellos más de del porcentaje permitido en cada caso.

1.3. Rendimiento y superficies de juego

1.3.1. Limitaciones del estudio de los pavimentos deportivos a través de las propiedades mecánicas y cómo complementarlo

Los diferentes equipos mecánicos descritos anteriormente están reconocidos por la mayoría de los estándares y federaciones deportivas para la evaluación y regulación de los equipos deportivos debido a que reproducen, de alguna forma, el contacto de los atletas con el pavimento deportivo (Colino et al., 2017; FIFA, 2015b; WR, 2016). Representa pues, una herramienta práctica y reproducible para predecir el comportamiento de la superficie durante los movimientos atléticos, facilitando la comparación entre superficies y la elaboración de estándares o normativas (Burillo et al., 2012; FIFA, 2015b; WR, 2016). Pese a ello, cada vez más estudios afirman que estos dispositivos son excesivamente simplistas y, por ende, incapaces de imitar fielmente el movimiento humano durante la práctica deportiva. Por esa razón, varios autores proponen realizar valoraciones directas de los deportistas (Fleming & Forrester, 2014; Hughes et al., 2013; Meyers, 2016; Nédélec et al., 2013).

Debido al creciente interés de los sistemas de césped artificial para la práctica del fútbol, rugby y otros deportes similares, la mayoría de los estudios que analizan la influencia de la superficie en la interacción superficie-jugador se han realizado sobre estos pavimentos; utilizando las superficies de césped natural como gold estándar (Hughes et al., 2013; Meyers, 2016; Nédélec et al., 2013; Sánchez-Sánchez et al., 2016). Sin embargo, cada vez más autores han optado por ampliar estos estudios a otro tipo de superficies, incluso con propiedades mecánicas totalmente opuestas, habiéndose comparado el rendimiento de los deportistas sobre césped artificial con otras superficies como la arena de playa, el parqué, o el asfalto (Brito et al., 2012; Ubago-Guisado, 2017).

Por medio de las valoraciones directas de los atletas durante la práctica deportiva en diferentes pavimentos, se intenta conocer cómo la superficie de juego influye en el rendimiento de los deportistas y en el riesgo de sufrir una lesión (Brito et al., 2012; Meyers, 2016; Nédélec et al., 2013; Ubago-Guisado, 2017); aportando información relevante para mejorar los programas de entrenamiento. Desafortunadamente, la mayoría de estos estudios no incluyeron el análisis de las propiedades mecánicas de las superficies utilizadas, por lo que los hallazgos de estas investigaciones no pueden generalizarse (Sánchez-Sánchez, 2014).

Con el objetivo de mejorar los pavimentos deportivos y adaptarlos a las demandas de la competición, varios autores destacan la importancia de combinar ambos métodos de evaluación de las superficies deportivas (Sánchez-Sánchez et al., 2014b; Sassi, Stefanescu, Bosio, Riggio, & Rampinini, 2011). Esto, principalmente se debe a que los pavimentos deportivos han demostrado tener una respuesta mecánica muy heterogénea (Caple et al., 2012; Guisasola et al., 2009), de ahí que, para poder analizar la influencia de la superficie de juego en el rendimiento deportivo y el riesgo de lesión, se deban controlar las propiedades mecánicas de las superficies que se van a estudiar.

1.3.2. Rendimiento aplicado al estudio de los pavimentos deportivos

A la hora de estudiar la influencia del pavimento sobre el juego y los deportistas, existen dos tendencias principales. La primera se centra en el riesgo que el atleta tiene de sufrir una lesión en función de la tipología del pavimento (Meyers, 2016), mientras que la segunda analiza como el pavimento deportivo afecta al rendimiento del deportista y a la subsecuente recuperación en los días posteriores (Hughes et al., 2013; Nédélec et al., 2013; Stone et al., 2014). Dado que la presente Tesis Doctoral estudia la influencia del pavimento deportivo en el rendimiento de los deportistas, nos vamos a centrar en este segundo parámetro. En los deportes colectivos, el rendimiento suele estudiarse a través del análisis de los patrones de juego y de la carga experimentada por el jugador durante la práctica deportiva (Nédélec et al., 2013; Sánchez-Sánchez et al., 2016; Stone et al., 2014); utilizando para ello tanto partidos reales (Sánchez-Sánchez et al., 2016) como ejercicios de entrenamiento y test estandarizados (Brito et al., 2012; Hughes et al., 2013).

Los patrones de juego son aquellos factores que describen y analizan las acciones técnico-tácticas de los deportistas en función tanto de la tipología del pavimento, como de sus propiedades mecánicas (Andersson et al., 2008; Garcia, Román, Calleja-González, & Dellal, 2015; Sánchez-Sánchez et al., 2014b). Por su parte, la carga del jugador puede definirse como el estímulo al que se ve sometido el jugador durante la práctica deportiva, que provoca un descenso del rendimiento como consecuencia de la alteración metabólica, neuromuscular y/o mental (Campos & Toscano, 2014; Fessi et al., 2016). En la terminología utilizada en los deportes como el fútbol y el rugby, esta carga suele dividirse en carga externa (respuesta física) y carga interna (respuesta psicológica y fisiológica) (Paulson, Mason, Rhodes, & Goosey-Tolfrey, 2015; Zurutuza, Castellano, Echeazarra, & Casamichana, 2017).

La carga externa se define como el trabajo completado por el deportista en términos de distancia, velocidad, o potencia (Halson, 2014; Lambert & Borresen, 2010; McLaren, Weston, Smith, Cramb, & Portas, 2016), describiendo, la repuesta física de los jugadores ante las demandas de la actividad que están realizando. La carga externa es la que analiza las variables de volumen e intensidad de una tarea o un partido (Paulson et al., 2015; Sánchez-Sánchez, 2014; Zurutuza et al., 2017). Dentro del estudio de los pavimentos deportivos, diversos trabajos han revelado que las acciones de alta intensidad como los esprines lineales a máxima intensidad o los esfuerzos máximos intercalados con pequeñas fases de recuperación (acciones máximas repetidas) se ven afectados por las propiedades mecánicas de la superficie de juego (Hughes et al., 2013; Sánchez-Sánchez et al., 2014b; Sassi et al., 2011). Por ende, es recomendable incluir la monitorización de los patrones de movimiento y de las acciones de alta intensidad a la hora de analizar la respuesta física de los deportistas en diferentes superficies de juego (Brito et al., 2012; Sánchez-Sánchez et al., 2016).

Por otro lado, la carga interna estudia el efecto que estas acciones físicas (desplazamientos, saltos, aceleraciones esprines, etc.) tienen sobre el estrés fisiológico y psicológico de los deportistas (Halson, 2014; Zurutuza et al., 2017). En otras palabras, la carga interna se centra en estudiar tanto la respuesta de los sistemas cardiovasculares, metabólicos y neuromusculares durante la práctica deportiva, como los factores que influyen en la aparición de fatiga y en la recuperación posterior al ejercicio (Hughes et al., 2013; Nédélec et al., 2013; Stone et al., 2014).

1.3.2.1. Tareas utilizadas para el estudio de los pavimentos deportivos

A la hora de analizar el rendimiento de los deportistas en función de la superficie, varios autores han optado por utilizar tareas reales de juego como los partidos simulados de 11 contra 11 (Sánchez-Sánchez et al., 2016) o los juegos reducidos (Brito et al., 2012). Esto se debe a que permiten conocer desde un punto de vista global cómo el pavimento y sus propiedades mecánicas afectan al perfil cinemático y fisiológico de los jugadores en acciones similares a las que se van a encontrar en competición (Sánchez-Sánchez, 2014). Sin embargo, la gran variabilidad en el rendimiento de los deportistas asociado a este tipo de tareas reduce el grado de reproductibilidad, por lo que los resultados obtenidos son menos fiables al poseer un nivel de sesgo más elevado.

Para evitar esta situación, una gran cantidad de investigadores han optado por realizar test estandarizados, ya que permiten una reproductibilidad más fiable en cada una de las superficies que se quieren estudiar (Nédélec et al., 2013; Sánchez-Sánchez et al., 2014b; Stone et al., 2014). En este sentido, autores como Sánchez-Sánchez et al. (2014b) proponen el uso de test de esprines repetidos (RSA), porque las acciones lineales a máxima intensidad seguidas de breves periodos de recuperación son las que tienen una mayor influencia en la competición (Bradley et al., 2009). Así mismo, los RSA parecen ser una herramienta útil para evaluar si la superficie de juego influye de manera decisiva en la fatiga aguda de los deportistas (Chaouachi, 2010; Ferrari-Bravo et al., 2008; Sánchez-Sánchez, 2014).

Pese a ello, es preciso señalar que estos test no sirven para reproducir fielmente las demandas físicas y fisiológicas de la competición. Por eso, varios autores han preferido optar por alguno de los protocolos de partido simulado validados científicamente (Hughes et al., 2013; Nédélec et al., 2013; Stone et al., 2014). Estos test tienen una duración similar a la de los encuentros competitivos y han sido diseñados para replicar los estímulos de la competición, incluyendo en algunos casos desplazamientos lineales y no lineales a máxima intensidad. No obstante, la mayoría de estos protocolos no incluyen la utilización del balón, por lo que no tienen en cuenta la posible influencia de la superficie en las decisiones técnico-tácticas de los deportistas (Andersson et al., 2008).

1.3.2.2. Evaluación de la carga externa

Gracias al creciente desarrollo de la industria deportiva y al avance científico aplicado al alto rendimiento, los métodos de evaluación y equipos de monitorización de la carga externa de los deportistas están en continua evolución. Por ello, en la presente Tesis Doctoral sólo podemos hacer una pequeña aproximación a los mismos.

Fotocélulas: Las fotocélulas son unos dispositivos que permiten medir el tiempo que los deportistas tardan en recorrer una distancia previamente establecida, utilizándose frecuentemente para evaluar el rendimiento de los futbolistas en desplazamientos lineales y no lineales a máxima velocidad. Estos equipos están formados por la unión de dos dispositivos, por lo que la literatura científica suele referirse a ellos como “pares de fotocélulas”. El primer dispositivo, está compuesto por un terminal que emite un láser infrarrojo de forma continuada, el cuál es interceptado por el segundo de ellos formando una “puerta” por la que tiene que cruzar el deportista (Figura 14). Por medio de este láser, se identifica el momento exacto en el que el deportista cruza el espacio existente entre los dos pares de fotocélulas; registrando el tiempo transcurrido hasta que el láser vuelve a ser traspasado de nuevo con una precisión de hasta 0.001 s. Debido a las particularidades de estos equipos, suelen combinarse dos o más pares de fotocélulas entre sí, registrando los tiempos de la carrera en los diferentes tramos que componen el recorrido que tiene que realizar el deportista (Sánchez-Sánchez et al., 2014b; Stone et al., 2014).

Figura 14. Par de fotocélulas Witty, Microgate, Bolzano, Italy (Imagen de Microgate®)

Acelerómetros: Los acelerómetros son dispositivos de pequeño tamaño que permiten registrar todas las aceleraciones a las que se ve sometido el organismo del deportista en los tres ejes de movimiento (vertical, horizontal y anteroposterior). Por ello, han sido utilizados tanto para evaluar las fuerzas de reacción de los pavimentos (Encarnación-Martínez, García-Gallart, Gallardo, Sánchez-Sáez, & Sánchez-Sánchez, 2017) como la carga externa de una tarea deportiva (Sánchez-Sánchez et al., 2016). En deportes colectivos, estos aparatos suelen medir a una velocidad de 100 Hz o más; teniendo una precisión de al menos 50 gravedades (1 g = 9.8 m/s^2) para identificar todas las aceleraciones que ocurren durante los saltos y la carrera (Encarnación-Martínez et al., 2017).

Sistemas de Posicionamiento Global (GPS): Los GPS son una tecnología que permite estudiar los patrones de movimiento y las acciones de alta intensidad que se producen durante la práctica deportiva de forma global (Buchheit, Méndez-Villanueva, Simpson, & Bourdon, 2010; Cunniffe, Proctor, Baker, & Davies, 2009). Aunque en el mercado existen otras tecnologías alternativas como son la captura por vídeo o la radiofrecuencia (Castellano, Alvarez-Pastor, & Bradley, 2014; Frencken, Lemmink, & Delleman, 2010), los GPS (Figura 15) son quizás la herramienta más utilizada para el análisis de los patrones de movimiento sobre diferentes pavimentos deportivos debido a su bajo coste y su portabilidad (Brito et al., 2012; Sánchez-Sánchez et al., 2016).

La tecnología GPS registra y evalúa la carga externa a través de la monitorización en tiempo real de los parámetros de tiempo, velocidad, distancia, posición, altitud y dirección (Sánchez-Sánchez, 2014), habiendo demostrado ser una herramienta suficientemente válida y fiable para detectar alteraciones en los patrones de carrera a 5 y a 10 Hz (Aughey, 2011; Barbero-Álvarez, Coutts, Granda, Barbero-Álvarez, & Castagna, 2009; Delaney, Cummins, Thornton, & Duthie, 2017; Johnston et al., 2012). Pese a ello, es preciso resaltar que incluso los GPS a 10 Hz tienen un coeficiente de variación de entre 1,2% y 6,5% al analizar las aceleraciones y desaceleraciones de los deportistas (Delaney et al., 2017), por lo que hay que ser cuidadoso a la hora de interpretar los resultados obtenidos por medio de estos dispositivos.

Figura 15. Dispositivo GPS HPU; GPSports, Canberra, Australia (Imagen GPSsports®)

1.3.2.3. Evaluación de la carga interna

Al igual que en el caso anterior, los equipos y métodos de evaluación de la carga interna en los deportes colectivos están en constante evolución. Por ello, a continuación, sólo se muestran unos pocos ejemplos de cómo se puede monitorizar esta carga en los deportes colectivos como el fútbol y el rugby.

Bandas de monitorización de la frecuencia cardiaca (pulsómetros): Normalmente, el estudio de la frecuencia cardiaca (FC) durante la práctica deportiva se realiza mediante pulsómetros adheridos al pecho de los jugadores. A través de ellos, se monitoriza el número total de latidos por cada unidad de tiempo, permitiendo conocer la frecuencia cardiaca pico (FC_{pico}; máximo número de latidos) y la frecuencia cardiaca media (FC_{media}; promedio de latidos por minuto) durante la práctica deportiva. Estos equipos, por lo tanto, aportan la información en latidos por minuto (l.p.m). Para poder hacer comparaciones entre los deportistas, muchos autores han optado por medir estas dos variables en función de la frecuencia cardiaca máxima real de cada participante (FC_{max}) porque aporta información sobre la respuesta fisiológica ante una tarea de una forma mucho más precisa (Brito et al., 2012; Sánchez-Sánchez et al., 2016). Por otro lado, gracias al conocimiento de la FC_{max} se pueden establecer diferentes zonas de intensidad (ej. *Alta intensidad*: 90-100% de la FC_{max} del deportista); midiendo el tiempo total que el jugador pasa en cada una de estas zonas de intensidad durante la práctica deportiva (Guisasola et al., 2009; Hodgson, Akenhead, & Thomas, 2014).

La forma más común de conocer esta la FC_{max} es por medio de test máximos, ya que varios autores han demostrado que, en este tipo de tareas, la FC_{pico} se equipara a la FC_{max} real de los participantes. En deportes intermitentes como el fútbol, Yo-Yo test parece ser una de las mejores opciones para evaluar la FC_{max} de los jugadores (Bangsbo, Iaia, & Krustrup, 2008; Bradley et al., 2014). Este test, se caracteriza por la realización de esfuerzos repetidos de carrera de ida y vuelta (2 x 20 m) al ritmo de unos pitidos emitidos por un dispositivo externo. Este ritmo de carrera se incrementa periódicamente, de forma que el tiempo disponible para completar cada ciclo de ida y vuelta se va reduciendo cada cierto tiempo. Así mismo, la principal particularidad de este test es que al acabar cada ciclo de ida y vuelta existe un pequeño periodo de recuperación activa en el que los deportistas deben recorrer por partida doble una pequeña distancia a una menor intensidad (Figura 16).

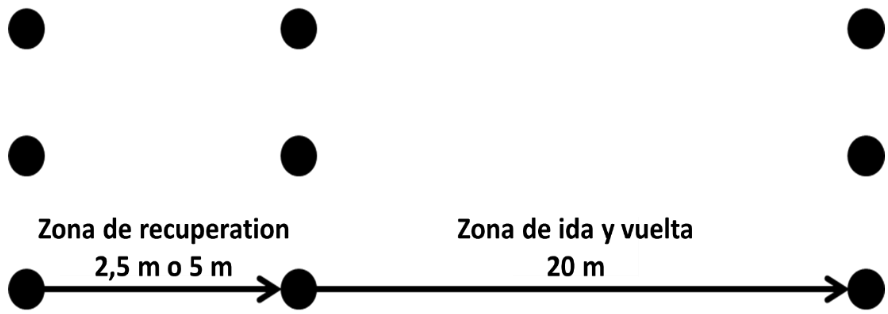


Figura 16. Ejemplo de Yo-Yo Test (Bangsbo, Mohr, & Krustrup, 2006; Bradley et al., 2014)

Actualmente, en la literatura existen dos protocolos de Yo-Yo Test que varían en función de la distancia habilitada para la recuperación activa. Se conoce como Yo-Yo Test de Recuperación intermitente a aquellos test cuya distancia de recuperación es de 10 m (2 x 5 m) (Bangsbo et al., 2008), mientras que cuando la distancia de recuperación es de 5 m (2 x 2.5 m), el test se denomina Yo-Yo Test de Resistencia Intermitente (Bradley et al., 2014). Por otro lado, en función del ritmo inicial al que se tiene que completar el ciclo de ida y vuelta y, la progresión posterior, existen dos niveles de dificultad, el Nivel 1 y el Nivel 2. Así, el Nivel 1 cuenta con un mayor tiempo inicial para completar el ciclo de ida y vuelta que el Nivel 2 unido a una progresión más suave en el ritmo al que se tiene que completar cada ciclo (Bangsbo et al., 2008).

Percepción subjetiva de esfuerzo: La percepción que un jugador tiene sobre el esfuerzo que le ha costado realizar una tarea o la fatiga aguda que le ha supuesto, ha demostrado ser un buen indicador para medir la respuesta fisiológica de los deportistas (Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011), correlacionándose positivamente con variables fisiológicas como la frecuencia cardiaca o el volumen máximo de oxígeno (Coutts, Rampinini, Marcora, Castagna, & Impellizzeri, 2009). Normalmente, se suele utilizar la escala de percepción de esfuerzo de Borg de 1 a 10 (Hill-Haas et al., 2011). Sin embargo, la percepción subjetiva también puede emplearse para conocer el esfuerzo percibido y la dificultad de ejecución de determinadas tareas técnicas en diferentes pavimentos. Para ello, varios autores han optado por un cuestionario de varias preguntas que se responden por medio de una escala visual análoga (VAS) (Andersson et al., 2008; Brito et al., 2012). La escala VAS, se responde haciendo una marca sobre una línea de 10 cm, que posteriormente se mide para obtener un valor numérico del 1 al 100.

Tensimiografía (TMG): La tensimoigrafía es una técnica no invasiva que permite medir el tono muscular o la rigidez y el balance entre estructuras musculares por medio de un estímulo eléctrico (Rey, Lago-Peñas, Lago-Ballesteros, & Casáis, 2012; Tous-Fajardo et al., 2010). Para ello, a través de dos electrodos autoadhesivos colocados en los extremos del vientre muscular que se quiere medir a una distancia previamente establecida se aplica una corriente eléctrica bipolar de intensidad variable y 1 ms de duración (Figura 17). Este estímulo se efectúa por medio de un electroestimulador y causa la contracción del vientre muscular, la cual es registrada a través de un preciso transductor digital Dc-Dc Trans-Tek® (GK 40, Panoptik d.o.o., Ljubljana, Eslovenia) colocado sobre el vientre muscular (Rey et al., 2012).

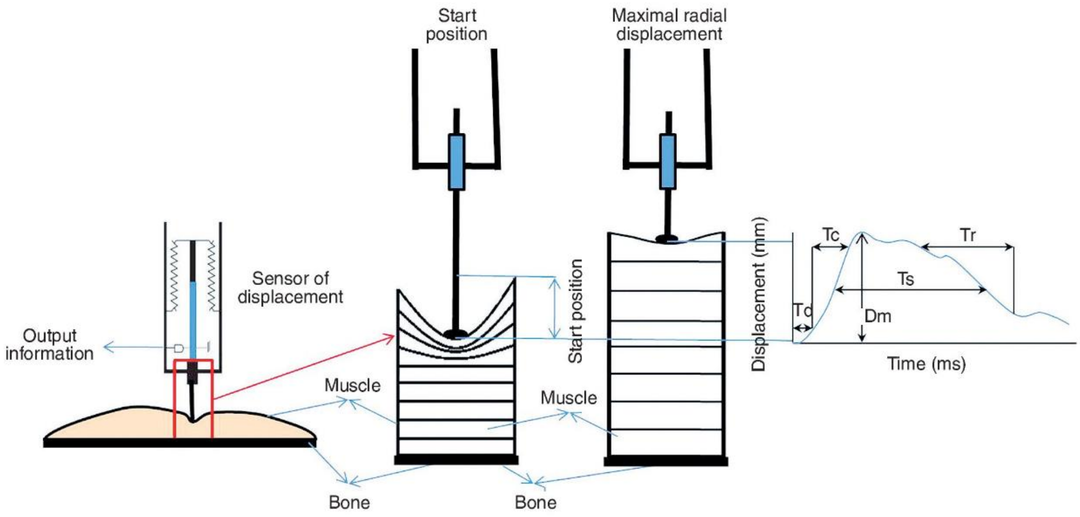


Figura 17. Explicación del funcionamiento de la Tensiomiografía (Rodríguez-Matoso et al. 2010)

En TMG, la fatiga se manifiesta a través de cambios en la actividad eléctrica del musculo, debido a la incapacidad del músculo para contraerse o mantener un nivel determinado de fuerza durante la contracción (García-Manso et al., 2011). Esta herramienta ha sido validada para medir las siguientes variables: el máximo desplazamiento radial del vientre muscular (Dm) el tiempo de reacción (Td), el tiempo de contracción (Tc), el tiempo que se mantiene la contracción (Ts) y el tiempo de relajación (Tr) (Figura 17), mostrando un nivel de error bajo (0,5% a 2,0%) y una alta reproductibilidad (correlación entre clases de 0,85 – 0,98) en estos cinco parámetros (Dm: 0,98; Tc: 0,97; Td: 0,94; Ts: 0,89; Tr: 0,86) (Benítez Jiménez, Fernández Roldán, Montero Doblas, & Romacho Castro, 2013; Krizaj, Simunic, & Zagar, 2008). Sin embargo, recientemente, varios autores han mostrado su disconformidad con esta herramienta, argumentando que no es lo suficientemente sensible como para evaluar la fatiga muscular (Wiewelhove et al., 2017). Consecuentemente, es preciso tener en cuenta estas limitaciones, a la hora de interpretar los resultados obtenidos por esta herramienta.

Capítulo 2

JUSTIFICACIÓN [JUSTIFICATION]

Desde hace ya varios años, se sabe que la naturaleza del juego está influida por las características del terreno donde se lleva a cabo la práctica del deporte (Andersson et al., 2008; Lees & Nolan, 1998). Por eso, mantener unas propiedades mecánicas óptimas a lo largo del tiempo se ha convertido en uno de los retos principales de las superficies deportivas (Rosa et al., 2007). La evidencia científica, tanto en el estudio de las superficies naturales, como artificiales, ha dejado patente el papel que juegan los componentes estructurales de las superficies en su capacidad para ofrecer unas propiedades mecánicas adecuadas a lo largo del tiempo (Lees & Nolan, 1998; Sánchez-Sánchez et al., 2014a). Tal y como destacan autores como Gallardo (2007), el césped natural es la mejor superficie para la práctica de deportes como el fútbol y el rugby, pero sólo cuando está en "perfecto estado". Normalmente, en países como España, obtener ese estado es una tarea ardua de conseguir, además de costosa, por lo que tradicionalmente han sido utilizadas en el deporte profesional (Felipe, 2011), mientras que el deporte de base, sub-élite y amateur se ha desarrollado sobre superficies de tierra o de césped natural de mala calidad (Burillo, 2009; Garcia et al., 2015).

El aumento de la calidad de los sistemas de césped artificial de tercera generación a principios del siglo XXI ha convertido a estos pavimentos en una alternativa real a los de hierba natural, habiendo sido aceptados para la práctica tanto del fútbol como del rugby (FIFA, 2015a; WR, 2016). Entre los principales beneficios de los sistemas artificiales destacan sus menores costes de mantenimiento, la posibilidad de ser usado sin límite de tiempo y su capacidad para mantener una uniformidad y regularidad en toda la superficie (Burillo, 2009). No obstante, dado que no todos los sistemas poseen las mismas propiedades mecánicas (Sánchez-Sánchez et al., 2014a), la FIFA, la WR o el Comité Europeo de Certificación (CEN) a través de AENOR han desarrollado unos protocolos de certificación destinados a homologar estos sistemas para la práctica deportiva (AENOR, 2014; FIFA, 2015a; Sánchez-Sánchez et al., 2014a; WR, 2016).

A pesar del incremento en la calidad del césped artificial de tercera generación, los deportistas han mantenido cierto recelo al uso de estas superficies para la práctica deportiva; asociándolo con un mayor riesgo de lesión y un peor rendimiento durante la práctica deportiva (Williams, Trewartha, Kemp, Michell, & Stokes, 2016). Sin embargo, su constante evolución, junto con una mayor adaptación a los mismos, ha hecho que la satisfacción de los usuarios con estos pavimentos se haya equiparado a la de la hierba natural (Burillo et al., 2014). En este sentido, desde un punto de vista de la seguridad de los deportistas, los últimos estudios epidemiológicos entre el césped artificial y la hierba natural, tanto en fútbol como en rugby, muestran una ratio de lesión similar o incluso menor sobre los pavimentos artificiales (Meyers, 2016); aunque, el número de lesiones por abrasión sigue siendo superior en los pavimentos de césped artificial (Swaminathan, Williams, Jones, & Theobald, 2016). Sin embargo, el mayor índice de lesión traumatológica encontrado sobre aquellos pavimentos artificiales con menor relleno (Meyers, 2016), demuestran la importancia de incluir las propiedades mecánicas en estos estudios y la dificultad para determinar relaciones causa-efecto.

En cuanto a la influencia de la superficie de juego sobre la respuesta física y fisiológica de los deportistas, ésta ha sido estudiada a través de diferentes aproximaciones. Por ejemplo, autores como Brito et al. (2012), han utilizado acciones reales como son los juegos reducidos para analizar el rendimiento de los deportistas sobre varias superficies. Sin embargo, estos trabajos se han centrado exclusivamente en el fútbol masculino, por lo que la influencia de la superficie de juego en rendimiento de las mujeres es desconocida. Los estudios 1, 2 y 3 presentes en esta tesis doctoral pretenden aportar más información sobre la influencia del pavimento en el rendimiento de las mujeres futbolistas en esta tipología de juegos. Además, también se analiza la influencia del espacio en dicho rendimiento, ya que numerosos estudios han encontrado que la respuesta física y fisiológica aumenta a medida que aumenta el espacio de los juegos reducidos.

Por otro lado, a través de test estandarizados como son los protocolos de partido simulado o los test de esprines, se ha evidenciado que el césped artificial no retrasa la recuperación de los jugadores ni incrementa el tiempo de los esprines y de las acciones de agilidad a máxima intensidad con respecto al césped natural (Hughes et al., 2013; Nédélec et al., 2013; Stone et al., 2014). De hecho, varios autores han reportado una respuesta fisiológica similar sobre ambas superficies, no hallándose diferencias en los niveles de lactato, la frecuencia cardiaca media y pico o la fatiga muscular (Hughes et al., 2013; Nédélec et al., 2013; Sassi et al., 2011; Stone et al., 2014). Sin embargo, la mayoría de estos estudios no han evaluado las propiedades mecánicas de las superficies utilizadas en los mismos; por lo que no es posible generalizar los resultados. De hecho, de acuerdo a trabajos como el de Sánchez-Sánchez et al. (2014a), existe una gran heterogeneidad en las propiedades mecánicas de los campos de césped artificial, por lo que no pueden tratarse como un grupo homogéneo. Así mismo, la evidencia científica demuestra que los jugadores corren más rápido y hacen más acciones de alta intensidad sobre los sistemas de césped artificial más duros, mientras que los sistemas más blandos están relacionados con una respuesta fisiológica más alta (Sánchez-Sánchez et al., 2016;

Sánchez-Sánchez et al., 2014b). Por esa razón, los estudios 4 y 5 comparan la respuesta de dieciséis jugadores amateur sobre una superficie de césped artificial y otra de hierba natural, cuyas propiedades mecánicas fueron evaluadas.

Por último, la alta absorción de impactos de las superficies de arena ha llevado a varios autores a querer conocer cómo este factor afecta a la respuesta de los deportistas (Binnie et al., 2014; Impellizzeri et al., 2008; Pinnington et al., 2005). Así, a pesar de que los deportistas alcanzan velocidades mucho más bajas sobre la arena que sobre el resto de superficies, estas acciones requieren una mayor respuesta fisiológica, causando una frecuencia cardiaca y unos valores de lactato más altos (Brito et al., 2012). Por otro lado, esta baja absorción de impactos también tiene un efecto directo en la técnica de carrera (Binnie et al., 2014), por lo que es muy posible que la arena tenga una incidencia distinta en la respuesta muscular del deportista. En España, es relativamente común que los mismos deportistas que realizan la temporada jugando al rugby a 11 sobre césped natural o artificial, en verano participen en torneos de rugby playa. Por esa razón, el estudio 6 analiza la respuesta muscular de las jugadoras de rugby al realizar un test de esprines repetidos sobre arena y sobre hierba natural.

Capítulo 3

HIPÓTESIS Y OBJETIVOS [HYPOTHESES AND OBJECTIVES]

3.1. Hipótesis

La superficie de juego es un elemento fundamental en la preparación de los deportistas. Sin embargo, su influencia en la respuesta física y fisiológica de las mujeres futbolistas es desconocida. De igual forma, el pavimento no es la única variable que puede afectar al rendimiento de las jugadoras de fútbol durante la realización de juegos reducidos. Por ello, las hipótesis planteadas en los estudios 1, 2 y 3 incluidos en esta tesis son:

- **Estudio 1:** la respuesta física de las jugadoras de fútbol sobre tierra es menor que sobre hierba natural y césped artificial, no existiendo diferencias entre estas dos superficies. Además, esta respuesta será mayor a medida que aumente las dimensiones del espacio del juego reducido.
- **Estudio 2:** la respuesta fisiológica de las jugadoras de fútbol sobre tierra es menor que sobre hierba natural y césped artificial, no existiendo diferencias entre estas dos superficies. Por otro lado, los juegos reducidos con una mayor dimensión del espacio suponen un mayor estímulo fisiológico que los de menor extensión.
- **Estudio 3:** la potencia metabólica de las jugadoras de fútbol no varía entre el césped artificial y la hierba natural; pero es más baja sobre tierra. Así mismo, los juegos reducidos con una menor dimensión del espacio causan una potencia metabólica más baja que los de una extensión mayor.

Por otro lado, el césped artificial de tercera generación parece haber igualado las prestaciones de la hierba natural. De esta forma, los jugadores no muestran diferencias ni en el rendimiento físico, ni en la respuesta fisiológica y muscular. No obstante, estos trabajos comparativos no tienen en cuenta las propiedades mecánicas de las dos superficies, por lo que estos hallazgos no pueden generalizarse. Así, las hipótesis de los estudios 4 y 5 son:

- **Estudio 4:** las diferencias entre las propiedades mecánicas del césped artificial y la hierba natural no son suficientes para causar una respuesta física y fisiológica diferente en los jugadores de fútbol amateur.
- **Estudio 5:** las diferencias en la respuesta mecánica del césped artificial con respecto a la hierba natural no son suficiente altas como para causar una respuesta muscular y fisiológica distinta en los jugadores de fútbol amateur.

Por último, numerosos autores están interesados en conocer el papel de la arena en la preparación y rehabilitación de los deportistas. Así, la evidencia científica sugiere que la práctica deportiva sobre arena causa un mayor estímulo fisiológico y un menor daño muscular que sobre superficies más duras. Por esta razón, la hipótesis del estudio 6 es:

- **Estudio 6:** después de realizar un test de esprines repetidos, la respuesta muscular ante un mismo estímulo eléctrico será diferente en función de la superficie donde se haya realizado el test.

3.2. Hypothesis

The game Surface is an essential element in training, but its influence on the physic and physiological response in female footballers is unknown. Likewise, the pavement is not the only variable that can affect the players performance in small-sided games. Therefore, the hypotheses of the manuscripts 1, 2 and 3 included into this thesis are:

- **Manuscript 1:** the physic response of female footballers on dirt is lower than on artificial turf and natural grass; not being differences between these two surfaces. Moreover, this response will be higher as the space of the small-sided games increases.
- **Manuscript 2:** the physiological response of female footballers on dirt is lower than on artificial turf and natural grass; not being differences between these two surfaces. Moreover, larger pitch size small-sided games provoke higher physiological stimulus than the smaller ones.
- **Manuscript 3:** the metabolic power of female footballers is similar between artificial turf and natural grass, but it is lower on dirt. Likewise, the small-sided games with lower size cause a lower metabolic power than those SSG with bigger size.

On the other hand, the outputs of playing football on artificial turf of third generation seems to be similar to natural grass. Thus, players do not present differences neither on the physic performance nor on the physiological and muscular responses. Nevertheless, these findings cannot be widespread. For that reason, the hypotheses of the manuscripts 4 and 6 are:

- **Manuscript 4:** the differences in the mechanical differences between natural grass and artificial turf would affect the physical patterns of players during the SSP, but not their physiological responses.
- **Manuscript 5:** the differences in the mechanical properties of both surfaces are not great enough to cause differences in the physiological and neuromuscular responses of soccer players.

Finally, several authors are interested in knowing the role of sand in training and rehabilitation of athletes. The scientific evidence suggests that the sports practice on sand increases the physiological stimulus and reduces the muscular breakdown regarding harder pavements. For that reason, the hypotheses of the study 6 is:

- **Manuscript 6:** sand causes different neuromuscular responses to natural Grass after a test that induces fatigue.

3.3. Objetivos

El objetivo principal de esta Tesis Doctoral fue analizar la influencia de la superficie de juego en la respuesta física, fisiológica y muscular de los deportistas. Para ello se han realizado seis estudios con aproximaciones distintas. Los objetivos específicos de estos estudios son:

- **Estudio 1:** evaluar la influencia de la superficie de juego y las dimensiones del espacio en el perfil de movimiento de las mujeres futbolistas sub-élite durante varios juegos reducidos de cuatro jugadores por equipo.
- **Estudio 2:** evaluar la influencia de la superficie de juego y las dimensiones del espacio en la respuesta fisiológica, la fatiga y la percepción de las jugadoras de fútbol sub-élite en diferentes juegos reducidos de cuatro jugadores por equipo.
- **Estudio 3:** analizar las demandas de potencia metabólica de varios juegos reducidos de posesión y sin portero jugados sobre tres superficies de juego diferentes.
- **Estudio 4:** analizar la influencia de la superficie de juego sobre la respuesta física y fisiológica de los jugadores de fútbol amateur a través de un protocolo de partido simulado.
- **Estudio 5:** evaluar la influencia de la superficie de juego sobre los patrones fisiológicos y la respuesta muscular de los jugadores de fútbol mediante un protocolo de partido simulado que incorpora esprines repetidos y acciones no lineales a máxima velocidad.
- **Estudio 6:** descubrir la influencia de la arena y el césped natural sobre los parámetros musculares en jugadoras de rugby tras un test que induce a la fatiga.

3.4. Objectives

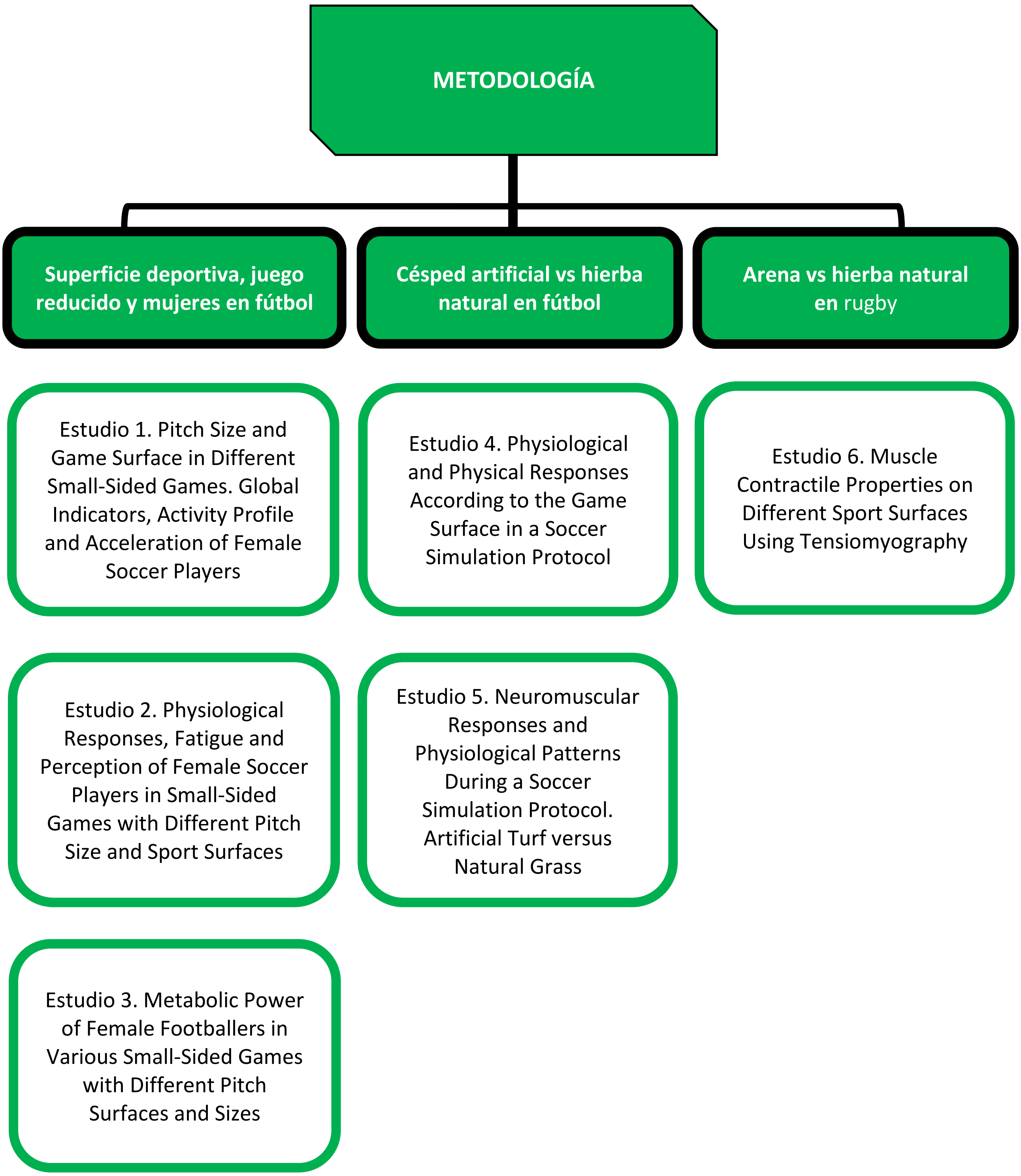
The main objective of this Doctoral Thesis was to assess the influence of game surface on the physic, physiological and muscular responses of athletes. Thus, to address this objective, this dissertation includes six studies with different approaches. The specific objectives of these studies are:

- **Manuscript 1:** to evaluate the influence of game surface and pitch size on the movement profile in sub-elite female soccer players during small-sided games of four aside.
- **Manuscript 2:** to evaluate the influence of game surface and pitch size on the physiological responses, fatigue and perception in sub-elite female soccer players during small-sided games of four-a-side.
- **Manuscript 3:** to analyse the metabolic power demands of various small-sided games on possession play without goal-keepers, played on three different surfaces.
- **Manuscript 4:** to analyse the influence of the game surface on amateur soccer player's physical and physiological responses using a soccer simulation protocol.
- **Manuscript 5:** to assess the influence of the game surface on physiological patterns and neuromuscular responses of soccer players during a soccer simulation protocol that incorporates repeated sprints and nonlinear actions at maximum speed.
- **Manuscript 6:** to discover the influence of sand and natural grass on muscle parameters in female rugby players after an induced fatigue test.

Capítulo 4

METODOLOGÍA [METHODOLOGY]

A continuación, se explica la metodología utilizada en la presente Tesis Doctoral. La descripción detallada y concreta se encuentra en el Capítulo 5 de Resultados y Discusión [Results and Discussion], donde aparecen cada uno de los estudios incluidos en esta Tesis Doctoral.



4.1. Participantes

En esta Tesis Doctoral han participado diferentes voluntarios. De esta forma, en los estudios 1, 2 y 3 se midió a un total de 16 jugadoras de fútbol (19,56 ± 1,97 años; 57,74 ± 4,89 kg; 161,57 ± 5,83 cm; 24,93 ± 4,1% masa muscular) pertenecientes a un equipo de segunda división (sub-élite). Las futbolistas llevaban 5,81 ± 0,75 años jugando al fútbol y tenían experiencia entrenando y jugando tanto sobre césped artificial, como hierba natural. Así mismo, todos los años jugaban entre cuatro y cinco encuentros sobre tierra.

Por su parte, los estudios 4 y 5 utilizaron una muestra de 16 jugadores de fútbol amateur (22.,17 ± 3,43 años; 177,12 ± 5,24 cm; 74,42 ± 4,87 kg), pertenecientes a varios equipos de la provincia de Toledo. Todos los jugadores tenían una experiencia de más de 10 años jugando al fútbol (13,57 ± 1,85 años). Por último, para el estudio 6 se reclutó un total de 15 jugadoras de rugby (23,4 ± 4,42 años), pertenecientes todas ellas a un equipo de rugby.

Todos los deportistas que formaron parte de estos estudios participaron de forma voluntaria en los mismos. Previamente a comenzar cada estudio, todos ellos fueron informados sobre los objetivos de la investigación y de los riesgos asociados a la práctica deportiva. Así mismo, se les indicó que eran libres de abandonar la investigación en cualquier momento sin dar ninguna explicación y sin sufrir ningún tipo de penalización. Por último, todos ellos firmaron un consentimiento informado por escrito. En el caso de las jugadoras menores de edad, los padres también fueron informados y tuvieron que firmar dicho consentimiento. Por último, todos estos estudios fueron aprobados por el Comité de Ética de investigación Clínica del área sanitaria de Toledo (Anexo 1).

4.2. Diseño de los estudios

Dado que estos estudios requieren la realización de ejercicios físicos en diferentes superficies, durante la toma de datos, se pidió a los jugadores que siguiesen las siguientes pautas de comportamiento:

- ***Descanso***: Todos los días de toma de datos estaban precedidas por 72 horas de reposo. Durante este tiempo, las jugadoras se comprometieron a no realizar ningún tipo de ejercicio físico moderado o vigoroso.
- ***Alimentación***: Se pidió a los participantes que mantuviesen unos hábitos alimenticios similares durante todo el estudio.
- ***Calzado***: Los deportistas utilizaron el mismo calzado en todas las pruebas de cada estudio.
- ***Preparación***: todos los estudios fueron precedidos de una prueba piloto para que los participantes se familiarizasen con los instrumentos utilizados en el estudio y con los test físicos o deportivos.
- ***Calentamiento***: En todos los estudios los deportistas realizaron un calentamiento estandarizado que consistió en 5 minutos de carrera continua, 5 minutos de movilidad articular y 3 esprines de 30 m a velocidad incremental. Igualmente, se acordó con los deportistas no realizar ningún tipo de estiramiento ni antes ni después del calentamiento.
- ***Condiciones de las pruebas***: todas las mediciones se realizaron en condiciones de seco y coincidiendo con el horario de entrenamiento habitual de los participantes, evitando así la influencia de los ciclos circadianos.
- ***Orden de las superficies***: En todos los estudios, la elección de la superficie se estableció aleatoriamente. Además, en los estudios 4, 5 y 6, esta aleatorización se realizó para cada jugador, de forma que la mitad hizo la primera prueba sobre una superficie y la otra mitad sobre la otra.

4.2.1. Estudios 1, 2 y 3

Siguiendo las indicaciones de los entrenadores, las 16 voluntarias se dividieron en cuatro equipos de cuatro jugadoras cada uno. Los entrenadores recibieron la instrucción de realizar equipos compensados para garantizar la competitividad durante la tarea. Los equipos y los enfrentamientos fueron los mismos durante todo el estudio. Cada equipo disputó tres juegos reducidos (SSGs) de posesión, de 4 contra 4, sobre tres superficies distintas (tierra, césped artificial y hierba natural). El objetivo principal de los juegos reducidos fue mantener la posesión de balón el máximo tiempo posible, no limitándose el número de toques por jugador. En la tabla 2 se explican las características de estos juegos reducidos. Por último, para aumentar la fiabilidad de los resultados, todos los juegos reducidos se repitieron dos veces en sesiones distintas.

Table 2. Características de los juegos reducidos

	Duración (min)	Tiempo de recuperación (min)	Dimensiones del campo (m)	Area total de juego (m^2)	Área de juego por jugador (m^2)
SSG 400	4	10	20 x 20 m	400 m^2	50 m^2
SSG 600	4	10	24.5 x 24.5 m	600 m^2	75 m^2
SSG 800	4	10	28.3 x 28.3 m	800 m^2	100 m^2

SSG: Juego reducido

4.2.2. Estudios 4 y 5

Los 16 futbolistas amateur realizaron los tres primeros bloques (una parte, 48 minutos) de un protocolo de partido simulado (SSP) que replica las demandas físicas y fisiológicas de la competición (Stone et al., 2011). Cada bloque está compuesto por ocho ciclos y un test de esprines repetidos (6 x 15 m saliendo cada 18 s) entre el ciclo 4 y el 5 (Figura 18). Cada ciclo se estructura de la siguiente forma:

- 3 × 20 m caminando a 1.43 m/s
- 1 × test de agilidad (S-AR) a máxima velocidad (20 s para realizar el esprín y recuperar)
- 3 × 20 m corriendo a trote a una velocidad de 2.5 m/s
- 3 × 20 m corriendo a una velocidad de 4.0 m/s

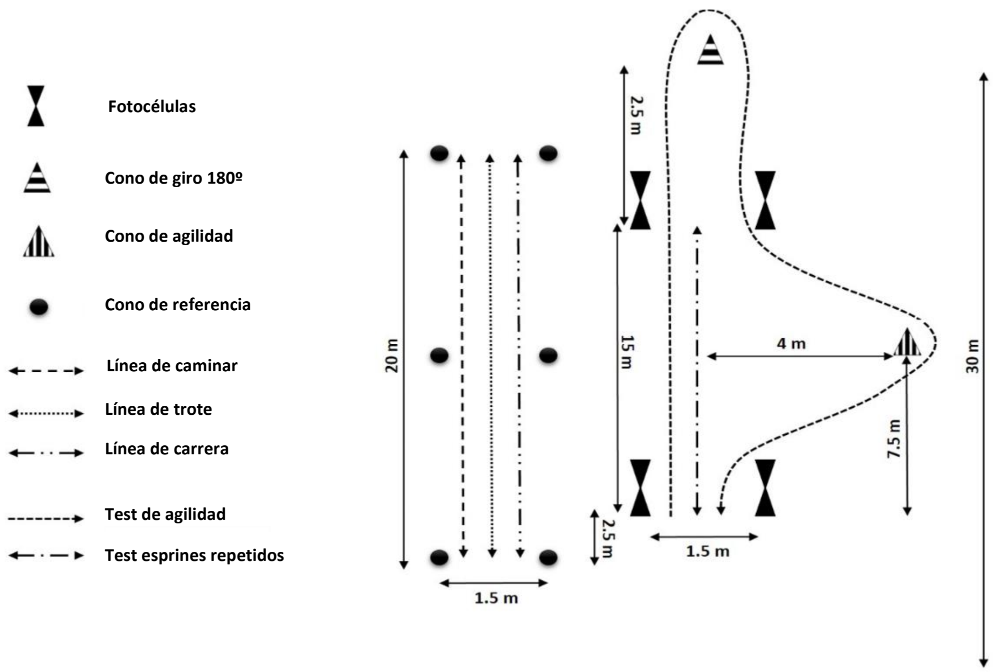


Figura 18. Protocolo de partido simulado (Stone et al., 2011)

4.2.3. Estudio 6

En este trabajo, las jugadoras de rugby realizaron un test RSA de 40 m, con un giro de 180º a los 20 m (Figura 19). Entre cada esprín se estableció una recuperación pasiva de 20 segundos. Este test ha sido utilizado en otros estudios comparativos de superficies (Sánchez-Sánchez et al., 2014b). 5 minutos antes de comenzar el test RSA, las jugadoras realizaron un primer esprín a máxima velocidad para validar el rendimiento del RSA. De esta forma, si el rendimiento del primer esprín del RSA era peor (5%) que este esprín preliminar, el test no se consideró válido, teniendo que parar automáticamente y repetirlo tras 5 minutos de descanso (Chaouachi, 2010).

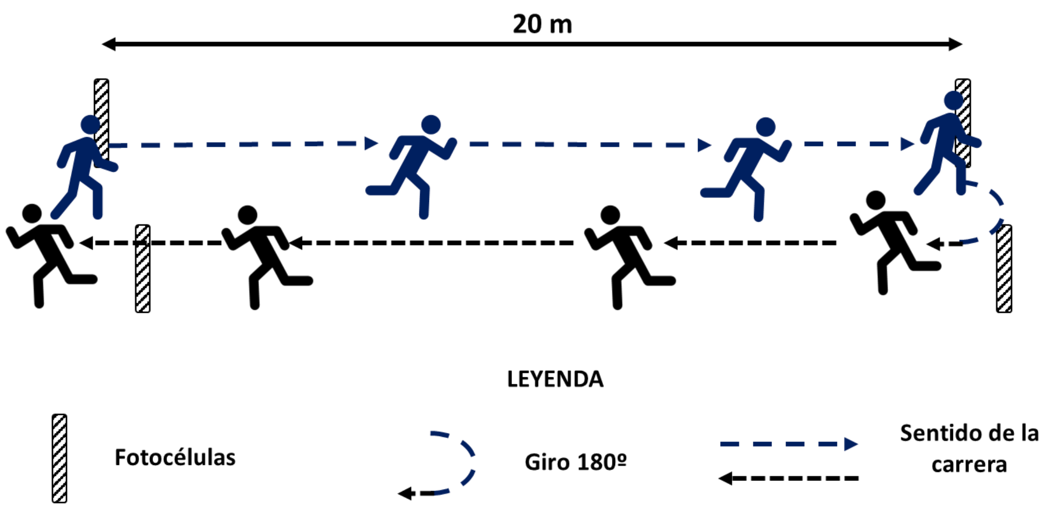


Figura 19. Test de esprines repetidos con giro de 180º

4.3. Métodos de medida

A continuación, se explican las características de los instrumentos de medida y fórmulas utilizadas en la toma de datos de cada uno de los seis estudios incluidos en la presente Tesis Doctoral.

4.3.1. <u>Análisis de las propiedades mecánicas de las superficies</u>

En los estudios 4 y 5, las propiedades mecánicas de las superficies examinadas se evaluaron *in situ* siguiendo los criterios establecidos en trabajos previos (Sánchez-Sánchez et al., 2016; Sánchez-Sánchez et al., 2014b). Así, a través del Triple A se registró la absorción de impactos, la deformación vertical y la energía de restitución tanto de la superficie de hierba natural como del sistema de césped artificial. Para ello, desde una altura previamente establecida, se dejó caer una masa de 20 Kg que contiene una célula de carga sobre la superficie. Esta prueba se repitió en las cinco zonas utilizadas en los estudios previos (Figura 11). En cada zona se analizaron tres puntos separados aproximadamente 100 mm. En cada uno de estos puntos se tomaron tres medidas, pero para el análisis estadístico se utilizó la media de las dos últimas medidas.

4.3.2. Rendimiento físico de los deportistas durante los juegos reducidos

En los estudios 1 y 3 la respuesta física de las deportistas se registró a través de dispositivos GPS Spi Pro X (GPSports, Canberra, Australia). Siguiendo la metodología de estudios previos, estos dispositivos se encendieron 15 minutos antes de comenzar la parte principal del estudio (Sánchez-Sánchez et al., 2016). Así mismo, cada jugadora utilizó el mismo GPS durante todo el estudio, para reducir las posibles variaciones entre los dispositivos (Sánchez-Sánchez et al., 2016). Por último, sólo se tomaron aquellas mediciones monitorizadas por al menos 8 satélites.

Patrones de movimiento: A través de los dispositivos GPS se registró directamente el pico de velocidad (V_{max}) y la velocidad media (V_{media}) de los participantes, así como la distancia total de cada juego reducido o los metros recorridos por minuto. La variable trabajo/descanso se calculó a través del software Team AMS (GPsports, Camberra, Australia), dividiendo la distancia total recorrida a más de 4 km/h (trabajo) entre la distancia total recorrida a menos de esa velocidad (descanso) (Cunniffe et al., 2009). Además, por medio del acelerómetro triaxial de 100 Hz incluido en el GPS se calculó la carga externa (body load) de cada jugador. Para ello, se combinan los movimientos en los tres ejes (vertical, horizontal y anteroposterior), dando la información en unidades arbitrarias (u.a.) (Sánchez-Sánchez et al., 2016).

Variables físicas: a través del software Team AMS, se establecieron 6 zonas de intensidad (todas en Km/h; 0–7; 7–10; 10–13; 13–16; 16–18; y > 18) (Hewitt, Norton, & Lyons, 2014). Estas zonas se pueden modificar en base a diversos criterios, como son el tipo de tarea, el género de los futbolistas, la superficie, etc (Casamichana & Castellano, 2010; Hewitt et al., 2014; Sánchez-Sánchez et al., 2016). Así, por ejemplo, en partidos de 11 contra 11, se suelen establecer zonas de velocidad más altas que en los juegos reducidos (Sánchez-Sánchez et al., 2016). Por otro lado, también se registraron las aceleraciones y deceleraciones por encima de 1.5 m/s^2, dividiéndolas en las siguientes zonas (todas en m/s^2; 1,5–2; 2–2,5; 2,5–2,75; y 2,75) (Sánchez-Sánchez et al., 2016). Por último, todas las acciones realizadas por encima de 18 Km/h fueron estudiadas al detalle, registrando las siguientes variables: distancia recorrida a alta intensidad (m), número de acciones a alta intensidad (nº), media de la distancia en esprín (m), aceleración máxima media (m/s^2).

Potencia metabólica fue calculada a través del software Team AMS (Versión 2016.7, GPSports, Canberra, Australia) siguiendo las ecuaciones de Di Prampero et al. (2005) y de Osgnach, Poser, Bernardini, Rinaldo, y Di Prampero (2010). De esta forma, se obtuvieron las siguientes variables: Carga Metabólica Absoluta (KJ); Carga Metabólica Relativa (KJ/kg); La Potencia Metabólica Media (ratio de energía consumido por segundo) (W/Kg); La Distancia Metabólica (distancia total recorrida a ≤ 20 W/Kg) (m) y la Distancia Equivalente (Máxima distancia que el futbolista puede correr con la energía total consumida si corre a velocidad constante) (m).

4.3.3. Rendimiento físico de los deportistas en esprines repetidos

En los estudios 4 y 6 el rendimiento de los jugadores durante los esprines repetidos se analizó por medio de un equipo de fotocélulas (Witty, Microgate, Bolzano, Italy). Siguiendo la metodología de estudios previos (Barbero-Álvarez et al., 2009), los jugadores iniciaron cada uno de los esprines en posición de bipedestación y sin realizar ningún tipo de contramovimiento para impulsarse. Además, el pie más adelantado se colocó encima de una línea situada entre 40 y 60 cm de distancia de las fotocélulas.

En ambos estudios, se registró el tiempo de cada uno de los esprines. Posteriormente, a partir de estos valores, se calcularon las siguientes variables: el mejor tiempo de esprín (RSA_{mejor}), el tiempo medio (RSA_{media}), el tiempo total (RSA_{TT}), el porcentaje de decrecimiento (%Dec; [[tiempo medio/mejor tiempo x 100] – 100]) y la diferencia entre el mejor y el peor esprín (%DIf). El %Dec tiene como objetivo evaluar la fatiga del deportista ante este test, habiendo sido definida como la forma más eficaz de valuar dicha fatiga (Buchheit, Horobeanu, Mendez-Villanueva, Simpson, & Bourdon, 2010; Glaister, Howatson, Pattison, & McInnes, 2008). Así mismo, varios autores han destacado una correlación alta entre el %Dec y el %Dif (Chaouachi, 2010). Por último, a través de los dispositivos GPS HPU (GPSports, Canberra, Australia) se calculó el pico máximo de velocidad en cada uno de los esprines y la velocidad media de los mismos.

4.3.4. Respuesta fisiológica de los deportistas

En los estudios 2, 4, 5 se analizó la respuesta fisiológica de los deportistas a través de unos pulsómetros adheridos a su pecho (Polar Team System, Kempele, Finland). Siguiendo la metodología empleada en trabajos previos, los deportistas realizaron un test para identificar la frecuencia cardiaca máxima (FC_{max}) de cada deportista. El Yo-Yo Test de Resistencia nivel 2 fue empleado en el estudio 2, debido a que utilizamos una muestra de mujeres futbolistas semiprofesionales (Bradley et al., 2014), mientras que el Yo-Yo Test Intermitente de Recuperación nivel 1 fue empleado en los estudios 4 y 5 por utilizar una muestra amateur (Bangsbo et al., 2008; Sánchez-Sánchez et al., 2016).

Por medio de dichos pulsómetros, se obtuvo la frecuencia cardiaca media (FC_{media}) y la frecuencia cardiaca pico (FC_{pico}) de cada jugador durante su participación en el estudio. Estas dos variables se incluyeron tanto en forma de latidos por minuto, como en porcentaje de la FC_{max} de cada jugador. Para identificar la carga interna de la tarea, se establecieron 6 zonas de intensidad, teniendo como referencia dicha FC_{max} de cada participante, (> 75 %; 75-80; 80-85%; 85-90; 90-95; 95-100%). Por último, todas las acciones por encima del 85% de la FC_{max} se agruparon en la variable frecuencia cardiaca alta intensidad (FC alta intensidad).

4.3.5. Respuesta neuromuscular de los deportistas

En los estudios 2, 5 y 6, la fatiga muscular se analizó a través de un protocolo de salto CMJ porque ha demostrado ser suficientemente sensible para evaluar la influencia de la superficie en la capacidad de explosividad de los miembros inferiores de los jugadores de fútbol (Brito et al., 2012; Sánchez-Sánchez et al., 2014b). Estos saltos fueron registrados gracias a un sistema de laser infrarrojo (Optojump Next, Microgate, Bolzano, Italia); tomando datos en condiciones basales (antes de realizar el calentamiento) y nada más finalizar la tarea principal de cada estudio.

Por otro lado, a través de un dispositivo de TMG (TMG–BMC Ltd., Ljubljana), en los estudios 4 y 5, se analizaron las propiedades contráctiles de los músculos bíceps femoral y recto femoral por ser dos de los principales grupos musculares tanto en el fútbol como en el rugby (Rey et al., 2012). Al igual que con el salto CMJ, estas mediciones se llevaron a cabo en estado basal y nada más finalizar la prueba principal de cada test, registrándose las siguientes variables: el máximo desplazamiento radial del vientre muscular (Dm) el tiempo de reacción (Td), el tiempo de contracción (Tc), el tiempo que se mantiene la contracción (Ts) y el tiempo de relajación (Tr).

En estos dos trabajos, estos dos vientres musculares se midieron de la siguiente manera: ***Recto femoral***: el sujeto se coloca en posición supina y en condiciones relajadas, con la rodilla de la pierna que se va a medir flexionada 120º. Para garantizar esta flexión, se utiliza un cojín triangular (Rey et al., 2012). ***Bíceps femoral***: el voluntario se tumba boca abajo, con las rodillas flexionadas 5º gracias a la ayuda de un cojín (Šimunič, 2012). Una vez el sujeto está en la postura adecuada para medir el músculo deseado, se coloca un transductor digital (Dc–Dc Trans-Tek®; GK 40, Panoptik d.o.o., Ljubliana, Slovenia) perpendicularmente al vientre muscular. Así mismo, los electrodos autoadhesivos (TMG electrodes, TMG-BMC d.o.o. Ljubljana, Slovenia), se posicionan simétricamente al transductor a una distancia de 50-60 mm (Rey et al., 2012). Una vez colocados los sensores, se aplica el estímulo eléctrico deseado. Como en estos dos estudios se realizaron medidas pre-post, tanto el punto donde se colocó el transductor, como la posición de los electrodos fueron marcados con un rotulador permanente, garantizando que la posición de estos dispositivos en la medición posterior era exactamente la misma que en la prueba inicial. Esto es muy importante, porque varios autores han encontrado que la posición de estos dos elementos puede condicionar la validez de los resultados obtenidos (Tous-Fajardo et al., 2010).

A la hora de aplicar los estímulos, cada investigación utilizó un protocolo distinto. En el estudio 5, se comenzó con un estímulo de 20 mAp, que fue incrementando en 10 mAp cada vez, hasta alcanzar un máximo de 110 mAp o encontrar el máximo desplazamiento muscular. Por el contrario, en el estudio 6, se comenzó con una amplitud de 25 mAp, la cual se incrementó 25 mAp cada vez hasta llegar a un máximo de 100 mAp o encontrar el máximo desplazamiento muscular. Así mismo, para garantizar la fiabilidad de los resultados, un mismo técnico especializado en TMG realizó todas las mediciones.

4.3.6. Percepción de los deportistas

En el estudio 2, la satisfacción percibida de las futbolistas con las tres superficies analizadas (tierra, césped artificial y hierba natural), por medio de un cuestionario de 12 preguntas (Tabla 3) adaptado de estudios previos (Andersson et al., 2008; Brito et al., 2012). Estas preguntas se respondieron a través de una escala visual análoga (VAS). En ella, había una línea de 100 mm, donde 0 era "nada duro, cansado o confortable" y 100, "muy duro, cansado o confortable".

Tabla 3. Cuestionario de satisfacción con las superficies deportivas

Nº de pregunta	Pregunta realizada
VAS1	¿Cómo puedes clasificar el esfuerzo realizado durante el juego?
VAS2	¿Cómo estás de cansado en este momento?
VAS3	¿Qué dificultad has percibido al realizar un pase preciso?
VAS4	¿Cómo has percibido la velocidad del balón tras realizar un pase?
VAS5	¿Qué dificultad has percibido para realizar un control de balón?
VAS6	¿Qué dificultad has percibido para realizar un regate?
VAS7	¿Qué dificultad has encontrado al realizar un giro o cambio de dirección?
VAS8	¿Cómo te has sentido al realizar una entrada o tacle?
VAS9	¿Cómo te has sentido durante la carrera conduciendo balón?
VAS10	¿Cómo te has sentido durante la carrera sin balón?
VAS11	Cómo has percibido el bote del balón en la superficie de juego
VAS12	En general, ¿Cómo te has sentido a lo largo de la sesión?

4.4. Estadística

4.4.1. Estudios 1 2 y 3

Los resultados se presentan en forma de media y desviación estándar (±SD). La distribución de las variables y la normalidad se comprobó y verificó mediante la prueba de Kolmogorov-smirnov y el estadístico de Levene. En los ***estudios 1 y 2***, la comparación entre resultados se realizó a través de un ANOVA de dos vías (superficie x juego reducido), mientras que en el ***estudio 3*** se utilizó un modelo linear mixto de medidas repetidas de dos vías (superficie x juego reducido). En los tres estudios, las interacciones por pares fueron identificadas a través de la prueba post-hoc de Bonferroni. El intervalo de confianza (IC de 95%) fue incluido para identificar la magnitud de los cambios. El tamaño del efecto (ES; d de Cohen) se evaluó mediante los siguientes criterios: trivial, < 0,19; pequeño, 0,2-0,49; medio, 0,5-0,79; y largo >0,8 (Cohen, 1992). Los resultados se analizaron a través de software estadístico SPSS versión 20.0 (IBM, Armonk, NY, USA). El nivel de significancia fue establecido para $p < 0{,}05$.

4.4.2. Estudios 4 y 5

Los resultados se presentan en forma de media y desviación estándar (±SD). La distribución de las variables y la normalidad se comprobó y verificó mediante la prueba de Kolmogorov-smirnov y el estadístico de Levene. Todas las variables presentaron una distribución normal en cada una de las medidas y grupos de análisis. En el ***estudio 4 y 5*** la comparación entre resultados se realizó a través de un ANOVA de dos vías (superficie x bloque). Además, los resultados de las variables de la TMG y del salto CMJ antes y después del protocolo de partido simulado, pertenecientes al ***estudio 5***, se analizaron con el mismo método (superficie x momento). El intervalo de confianza (IC de 95%) fue incluido para identificar la magnitud de los cambios. El tamaño del efecto (ES; d de Cohen) se evaluó mediante los siguientes criterios: trivial, < 0,19; pequeño, 0,2-0,49; medio, 0,5-0,79; y largo >0,8 (Cohen, 1992). Los resultados se analizaron a través de software estadístico SPSS versión 21.0 (IBM, Armonk, NY, USA). El nivel de significancia fue establecido para $p < 0,05$.

4.4.3. Estudio 6

La fiabilidad de los parámetros de la TMG se calculó a través de un coeficiente de correlación intraclase (ICCRs). Los resultados se presentan en forma de media y desviación estándar (SD). La verificación de la normalidad y la homogeneidad de las varianzas se asumió por medio de test Kolmogorov-Smimov y el estadístico de Leven. La comparación entre resultados recogidos en el test de esprines repetidos y la evaluación de la TMG antes y después de dicho test sobre ambas superficies (hierba natural y arena) se realizó a través de una T-Student. Los datos fueron analizados con el software estadístico SPSS versión 20.0. El nivel de significancia fue establecido en 0,05 y el tamaño del efecto (ES, d de Cohen) fue evaluado siguiendo los siguientes criterios < 0,19; pequeño, 0,2-0,49; medio, 0,5-0,79; y largo >0,8 (Cohen, 1992). Por último, el intervalo de confianza (IC de 95%) fue calculado para identificar la magnitud de los cambios. El nivel de significancia fue estipulado para $p < 0,05$.

Capítulo 5

RESULTADOS Y DISCUSIÓN [RESULTS AND DISCUSSION]

5.1. Resultados

Los resultados de los estudios que componen la presente Tesis Doctoral se muestran en formato artículos científicos. Estos estudios aparecen en el modo en el que han sido enviados a la revista.

5.1.1. Estudio 1. Pitch size and Game Surface in Different Small-Sided Games. Global Indicators, Activity Profile and Acceleration of Female Soccer Players

Journal of Strength and Conditioning Research Publish Ahead of Print
DOI: 10.1519/JSC.0000000000002090

Pitch size and Game Surface in Different Small-Sided Games. Global Indicators, Activity Profile and Acceleration of Female Soccer Players

Running Head: Physical profile of women in various four-a-side

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Abstract

The aim of this research was to evaluate the influence of game surface and pitch size on the movement profile in female soccer players during Small-Sided-Games (SSGs) of 4 v 4. 16 women played three different 4-a-side (400 m^2, 600 m^2 and 800 m^2) on three surfaces (ground [GR], artificial turf [AT] and natural grass [NG]). Time-motion variables were assessed through GPS devices (Spi Pro X, GPSports, Australia). GR had the worst outputs on most variables. NG achieved higher results than AT in terms of total distance [SSG 400 (+37.000 m; $p=0.006$); SSG 600 (+59.989 m; $p<0.001$); SSG 800 (+42.284 m; $p=0.001$)]. On the other hand, the smaller SSG (400) had the lowest values on most variables. However, while the middle SSG (600) presented higher output than the bigger one (800) for Body Load [NG (+7.745 a.u.; $p<0.001$); AT (+8.207 a.u.; $p<0.001$); GR (+5.879 a.u.; $p<0.001$)], it had lower results for High Intensity Distance [NG (-13.15 m; $p=0.025$); AT (-13.59 m; $p=0.026$)]. Despite women's performance being higher on AT than GR, the NG surface still showed the highest outcomes in the most intense SSG. Moreover, although the performance increase in bigger pitches, if the size is too large the outputs could be reduced.

Key Words: Four-a-side; GPS; Motion Analysis; Sports pavement; Women's football

INTRODUCTION

Female soccer is growing year by year, exceeding 1.2 million federative licenses only in this continent (30). Thus, there are now several studies quantifying the physical demands of matches and drills (14, 22, 25, 32-34). Due to their influence in goal situations, high-intensity actions (jumps, kicks, high-speed running, sprints, changes of direction, turns, accelerations and decelerations) are considered the most relevant ones in performance despite their short duration (4, 33). That is the reason why coaches design their training to replicate the high-intensity demands of matches together with other objectives.

Nowadays, it is common to use Small-Sided Games (SSG) in training, as they allow coaches to replicate the technical tactical and physical demands of competition through controlled drills (6, 11, 26). However, the numerous studies focussed on SSG have demonstrated that the intensity of these games is influenced by several external variables such as the game surface (5), the number of players (18, 24), the size of the pitch (21), the presence or absence of keepers or goals (23), the length of the game (20) or the number of touches allowed (8).

Among all these variables, some authors have analysed the influence of the game surface on physical and physiological responses of soccer players due to the importance of these factors in developing a suitable performance level (12, 18, 27). However, only a few studies have studied these factors in SSGs (5, 22). Thus, for example, Brito et al. (5) found a greater number of high intensity-actions and sprints on asphalt and higher physiological load on artificial turf than sand, thus demonstrating the importance of this factor on players' responses.

On the other hand, authors like Fradua et al. (13) highlight that soccer players' ability to get used to small spaces is an essential element in soccer success; SSGs being useful for increasing this ability. However, as demonstrated by Kelly and Drust (21), and, Rampinini et al. (26) among others, players' responses and game intensity may change depending on the pitch size of the SSG. Thus, coaches should consider this variable when designing their drills as players seem to perform higher number of high-intensity actions whenever the pitch size increases (6, 19).

Despite the importance of the game surface and pitch size as well as the other external factors in the planning of SSGs, to the authors' knowledge, only a few studies have analysed the effect of different types of SSGs in female soccer (14, 22, 24). Among the findings of these works, SSGs seem to be useful for replicating the aerobic and movement patterns of female matches. However, contrary to male soccer, SSGs in women may not provide sufficient high-intensity or repeated sprint stimuli in top female players (14). On the other hand, most investigations on SSGs either on female or male soccer only assess the effect of one extrinsic factor on SSG performance (5, 6, 14, 21). Thus, to address the gap in the literature regarding the effect of two or more extrinsic factors on SSGs performance, this work aims to evaluate the influence of game surface and pitch size on the movement profile in sub-elite female soccer players during SSG of 4 v 4. This work is focused on possession games as it seems to be more intense than those SSGs with goalkeepers (15). Therefore, this study expects to provide relevant information for designing training based on the use of SSGs.

METHODS

Experimental Approach to the Problem

Prior to starting the study, players performed a familiarisation session to gain previous experience with either the three surfaces or the three SSGs pitch sizes. Moreover, players also became accustomed to the Global Positioning System devices (GPS; Spi Pro X, GPSports, Canberra, Australia) used during the study during this familiarisation session.

The main part of the study took place on three consecutive weeks (2 days per week) in which participants played three four-a-side games with different pitch size (Table 1) on the three selected surfaces: natural grass (NG; grass' height: 25 mm); artificial turf (AT; fibre: monofilament of polyethylene, 60 mm in height; infill: 20 kg·m−2 of styrene-butadiene rubber and quartz sand with 0.3–0.8 granulometry); and ground (GR; uniform and dry dirt). To increase the reliability of data, each SSG was played twice in non-consecutive days. Therefore, players completed 18 drills altogether and there were recorded a total of 96 events. The order of both the pitch size and the surfaces were stablished randomly for each test day, so that every day participants played one sort of SSG on each surface. To guarantee a full recovery between SSGs players performed 10-min of active recovery (ball pass exercises at low intensity and three incremental sprints at the end of the recovery time).

All tests were conducted under the same environmental conditions (dry condition, 20-24.5ºC and 22%-30% relative humidity) and same training time (19:00 to 21:00) to reduce the possible influence of circadian rhythms. Moreover, the soccer field were located at the same altitude (770 m over the sea level). An independent expert on sports ground surfaces stated that the three surfaces were in good condition for playing soccer; but the mechanical properties of the selected surfaces were not measured.

" Please, insert Table I about here"

Subjects

Sixteen women from one team of the Spanish Second Division participated in the study (19.56 ± 1.97 years; 57.74 ± 4.89 kg; 161.57 ± 5.83 cm; 24.93 ± 4.1% body fat). All of them have previous experience playing soccer on artificial turf and natural grass (5.81 ± 0.75 years) and play soccer three days per week with a weekly competition. Moreover, players used to play from four to five matches on ground every season, although most of them were friendly matches. All participants passed the examination required to play soccer and did not reported any cardiopulmonary disease nor took any kind of medication during the study.

Players, coaches and the club were informed about the possible risks of this study and signed the informed consent form. Parents of all players younger than 18 years old also signed the informed consent. The methodology of this work was approved by the local Clinical Research Ethical Committee based on The Declaration of Helsinki.

Procedures

Participants agreed to rest for 72h before each test day and maintain the same eating habits. Moreover, they used the same soccer boots in all tests (always rubber studs). Fifteen minutes before the beginning of each test, players attached the GPS (Spi Pro X, GPSports, Canberra, Australia) (2). To avoid possible alterations in data and get the maximum accuracy, a minimum of eight satellites was established and participants used the same GPS device during the whole research. Finally, before the first four-a-side drill, players carried out a standardised warm-up of 10 minutes and three sprints of 30 m at increasing intensity before the beginning of each test-day (29).

Four-a-side SSG. With the aim of get balanced teams, coaches gathered the players in four teams of four participants each. Teams and matches were the same during the whole investigation. Contrary to other previous studies, the SSG's objective was to maintain the ball as much time as possible; so, neither goals nor keepers were included in the study (5, 6, 19). Players were encouraged by their coaches during the whole study and balls were replaced whenever they went outside the pitch to optimise the playing time.

Physical performance: global indicators. Through GPS attached to the players, the following global indicator data were recorded: total distance of each SSG (TD); meters covered by minute (m/min); peak speed (V_{max} Peak); average speed (V_{mean}); work/rest rate (W:R) defined as distance covered at speed ≥ 4 km/h (work) / distance covered at speed ≤ 4 km/h (rest); and body load (BL) registered in arbitrary units (a.u.) which is determined through the 100 Hz triaxial accelerometer included in the GPS combining the body movement axes (vertical [y], horizontal [x], anteroposterior [z]) (7, 10, 28). All these variables were calculated through the manufacturer software Team AMS (version 2016.7, GPSports, Canberra, Australia).

Physical performance: physical variables. Physical variables were assessed in three ways using also the Team AMS software: the speed ranges (establishing 6 speed zones [all in Km/h] 0-7; 7-10; 10-13; 13-16; 16-18; and >18) which were tracked as both absolute and relative variables regarding the total distance (17); the acceleration and deaccelerating ranges (selecting 4 zones for both [all in m/s^2] 1.5-2; 2-2.5; 2.5-2.75; and >2.75) (10); and the high speed actions (HI) (all actions over 13 Km/h) which were analysed in detail recording the following values: high-intensity distance (m), number of high intensity actions (nº), average duration of sprints (s), average maximum speed (Km/h), average distance of sprint (m), and acceleration max mean (m/s^2).

Statistical Analysis

Results are presented as means and standard deviations (±SD). The verification of the normality and homogeneity of the variance was assumed by means of the Kolmogorov-Smirnov test and the Levene's statistic. The comparison between results were developed through two-way ANOVA (surface x game situation) tests. Confidence interval (CI of 95%) was included to identify the magnitude of changes. Effect sizes (ES) were calculated and defined as follows: trivial, <0.19; small, 0.2–0.49; medium, 0.5–0.79; large, >0.8 (9). Data were analysed with the statistical software SPSS v 20.0. The level of significance was established at $p<0.05$.

RESULTS

Global Indicators and High Intensity Actions

Table II displays the global indicator results and the high intensity actions. The natural grass surface had significantly higher values than ground in the three SSG for TD [SSG 400 (+37m; P=0.006; ES: 0.964; CI: 8.400 – 65.600); SSG 600 (+59.989 m; P<0.001; ES: 1.152; CI: 31.824 – 88.155); SSG 800 (+42.284 m; P=0.001; ES: 0.880; CI: 15.074 – 69.494)] and V_{mean} [SSG 400 (+0.556 m/s; P=0.006; ES: 0.974; CI: 0.127 – 0.985);

SSG 600 (+0.900 m/s; $P<0.001$; ES: 1.154; CI: 0.477 – 1.322); SSG 800 (+0.633; $P=0.001$; ES: 0.875; CI: 0.225 – 1.042)]. Natural grass also had significantly higher values than artificial turf for TD [SSG 600 (+11.582 m; $P=0.047$; ES: 0.633; CI: 0.252 – 56.062)]; W:R [SSG 600 (+2.974 a.u.; $P=0.034$; ES: 0.561; CI: 0.17 – 5.779)]; V_{mean} [SSG 600 (+0.422 m/s; $P=0.047$; ES: 0.627; CI: 0.004 – 0.841)]; high intensity distance [SSG 600 (+13.71 m; $P=0.025$; ES: 0.546; CI: 1.3 – 26.11); SSG 800 (+13.46 m; $P=0.023$; ES: 0.545; CI: 1.37 – 25.56] and number of high intensity actions [SSG 600 (+2.54 a.u.; $P=0.049$; ES: 0.50; CI: 0.88 – 5.07)].

On the other hand, despite SSG 400 having lower results than the other SSG for the global indicator variables, the significant differences for the three surfaces only appeared for TD, m/min and V_{mean}. Moreover, the SSG 600 had significantly higher results than SSG 400 for BL [NG (+7.745 a.u.; $P<0.001$; ES: 1.685; CI: 5.467 – 10.023); AT (+8.207 a.u.; $P<0.001$; ES: 1.499; CI: 5.853 – 10.56); GR (+5.879 a.u.; $P<0.001$; ES: 0.996; CI: 3.483 – 8.274)]; and lower outcomes than SSG 400 for high intensity distance [NG (-13.15 m; $P=0.025$; ES: 0.439; CI: -25.44 – -1.25); AT (-13.59 m; $P=0.026$; ES: 0.539; CI: -25.99 – -1.18)] and number of high intensity actions [NG (-1.59 a.u.; $P=0.036$; ES: 0.498; CI: -2.83 – -0.36); AT (-1.72 a.u.; $P=0.004$; ES: 0.565; CI: -2.99 – -0.45)].

" Please, insert Table II about here"

Activity Profile

Figure 1 shows the results for each of the six zones of speed. The significant differences across surfaces were only found in Zone 1, Zone 2 and Zone 4; the significant differences in the high-speed zones were only present for Zone 5 but among SSG instead of among surfaces. The main significant differences among SSG appeared in Zone 5 where the SSG 800 had higher values than the SSG 400 in the three surfaces [NG (+1.21 % DT; P<0.001; ES: 0.935; CI: 0.46 – 1.96); AT (+1.13 % DT; P=0.001; ES: 1.224; CI: 0.37 – 1.89); GR (+0.85 % DT; P=0.025; ES: 0.762; CI: 0.08 – 1.61)]. The values of the SSG 800 were also higher than the SSG 600 ones on the artificial turf [AT (+0.89 % DT; P=0.015; ES: 0.819; CI: 0.13 – 1.65)].

" Please, insert Figure 1 about here"

Accelerations and Decelerations

Table III displays the accelerations and decelerations in each of the four zones established. The most significant differences among surfaces were between natural grass and ground, where the natural grass had higher outcomes than ground. However, natural grass also had higher values than artificial turf in the acceleration variables of Zone 2 in the SSG 800 [+1.53 m/s^2; P=0.046; ES: 0.858; CI: 0.02 – 3.04]; and Zone 4 in the SSG 600 [+1.28 m/s^2; P>0.001; ES: 0.885; CI: 0.52 – 2.03]; as well as in the deceleration variable of Zone 1 in the SSG 600 [+1.94 m/s^2; P=0.043; ES: 0.667; CI:

0.04 – 3.84]. On the other hand, the only difference among SSG was found in the acceleration variable of Zone 1, where the SSG 600 had higher results than the SSG 400 on the natural grass surface [+1.24 m/s^2; P<0.001; ES: 0.858; CI: 0.50 – 1.99].

" Please, insert Table III about here"

DISCUSSION

This is the first study that compared the activity profile in sub-elite female soccer on SSG of different pitch size played on three distinct surfaces: natural grass, artificial turf, and ground. Contrary to some previous studies this work was focused on possession games (5, 6, 19) as these games are related with higher intensity levels than those games which include goal-keepers (15). The main finding of this research show that either the game surface or the pitch size have a direct influence on high intensity actions in sub-elite female soccer players; what makes advisable to control both variables when designing a SSG. However, it is important to be cautious when comparing these findings to other studies as they may use other sort of SSGs with different number of players, distinct objectives or other pitch size proportions.

In line with the findings of Brito et al. (5), but on NG, AT and GR, the significant differences among surfaces found in this study indicate that the game surface have a direct influence on the high-intensity actions. Among the three selected surfaces, GR seem to be the less recommended surface for playing soccer as players got lower outputs on GR than on NG and AT either in movement profile variables or High-Intensity Actions. However, most of these differences were found in the SSG 600 which was the most intense SSG. Therefore, the lower outcomes in variables such as m/min, peak speed or body load in GR than on the other both surfaces in the SSG 600 may be due to a lower players' stability on GR (27, 29), thereby causing a lower number of explosive actions (3, 5). On the other hand, the synthetic surface also showed lower values in most variables of the SSG 600 than the natural one, as well as lower high-intensity distance and lower number of high-intensity actions in the SSG 800. These results, suggest higher rate of creatine phosphate breakdown and glycolysis on NG because of greater rates of anaerobic energy turnover (3, 5, 27) what contradict the findings of previous research in men as they reported similar performance on AT either in linear sprints or in high-intensity actions with change of direction. However, these findings may be due to different technical behaviour on both surfaces, as players seem to perform a higher number of short passes and a lower rate of tackles on AT than on NG (1). Nonetheless, the high variability existing in the mechanical properties of artificial turf systems makes further research necessary (29).

Previous research in male soccer concluded that game intensity of SSGs increase in bigger pitches (6, 19) so that, variables such as DT, m/min, W:R, V_{mean}, V_{max}, distance covered at high speed, and number of high intensity actions increase in SSGs with a higher pitch ratio per player (6, 19). The findings of this work are in line with these studies probably due to the higher effective playing time associated with bigger pitches (6). Moreover, most differences between the smaller SSG and the bigger ones were reported on NG and on AT as game intensity of SSGs is higher on these surfaces. On the other hand, contrary to the findings of these authors, there were no significant differences in the global indicator variables between the middle SSG (600) and the bigger one (800) except on BL, distance covered at high speed and number of high intensity actions. Therefore, this work suggest that the intensity of game may stop to increase if the pitch size of the SSG is too big, agreeing with those studies which did not report differences when increasing the individual playing area (21). For that reason, similar muscle damage and oxidative stress (16) may be expected for either SSG 600 or SSG 800. These results are especially important because both technical and tactical actions seem to change according to the pitch size (21); therefore, when coaches use bigger pitch size as a control variable for the intensity of a SSG, they can choose the pitch size most suitable for the tactical and technical actions that they want players to train.

The accelerations of high intensity were mainly performed in actions such as dribbling, change of directions or running; therefore, although they often start at low speed they involve high metabolic cost (31). Opposite to Sánchez-Sánchez (28), this research did show significant differences among surfaces in both accelerations and decelerations likely due to the three selected surfaces are quite different. However, there were no significant differences in either the accelerations or decelerations regarding the pitch size contrary to previous studies (19). The ability to accelerate quickly has been identified as a key element in the players' performance (10, 31). However, since GPS systems are not very accurate in distinguishing between accelerations and decelerations, further researches are needed.

This research expects to help coaches to design their training since extrinsic variables such as game surface or pitch size can affect players' performance during SSG. However, it is important to be cautious when comparing this current study with previous ones due to the lack of studies about SSG in female soccer players. Moreover, since SSGs used in this investigation only last 4 minutes, more research is needed to understand the effect of these two variables in sub-elite female soccer.

PRACTICAL APPLICATIONS

The main practical applications for coaches is that changes in the pith size of SSG or training on different surface seem to affect the physical responses of sub-elite female soccer players. Training on natural grass seems to be more suitable when the objective of the SSG is higher intensity. However, artificial turf does not reduce the intensity of game drastically. On the other hand, the intensity of game seems to be higher in bigger SSG. Nonetheless, coaches should take care when designing SSG since the intensity of game may decreases when the pitch size is too large.

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Figure 1. Activity profile in the three surfaces and three SSGSignificant differences (p<0.05):

Natural grass = *; Artificial turf = #; Ground = †Significant differences (p<0.05): SSG 400 = a; SSG 600 = b;

SSG 800 = c

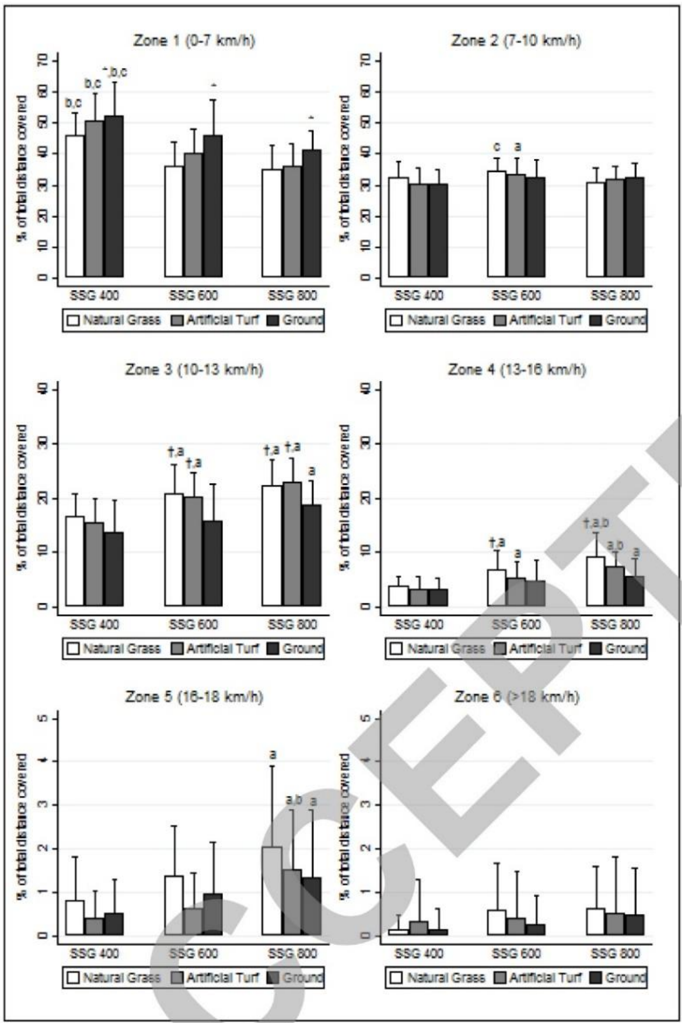
Zone 1 (0-7 km/h)
Zone 2 (7-10 km/h)
Zone 3 (10-13 km/h)
Zone 4 (13-16 km/h)
Zone 5 (16-18 km/h)
Zone 6 (>18 km/h)
% of total distance covered
SSG 400
SSG 600
SSG 800
Natural Grass
Artificial Turf
Ground

Table I. SSG characteristics

	Game duration (min)	Duration of the recovery between SSG (min)	Pitch area (m)	Pitch total area (m^2)	Pitch ratio per player (m^2)
SSG 400	4	10	20 x 20 m	400 m^2	50 m^2
SSG 600	4	10	24.5 x 24.5 m	600 m^2	75 m^2
SSG 800	4	10	28.3 x 28.3 m	800 m^2	100 m^2

SSG: Small Sided Game

Table II. Covered distance, load indicators and heart rate values during the 4 min. game in the three surfaces and the three SSG.

	Natural Grass (NG) (*)			Artificial Turf (AT) (#)			Ground (GR) (†)		
	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)
Movement Profile									
TD (m)	398.98 (33,35)†	457.18 (45.17)$^{\#,\dagger,a}$	458.63 (52.03)^{†,a}	371.94 (40.83)	429.02 (43.88)^{†,a}	442.88 (40.87)^{a}	361.98 (43.39)	397.19 (58.99)^{a}	416.35 (44.03)^{a}
m/min (m)	99.75 (8,34)†	114.29 (11.29)$^{\#,\dagger,a}$	114.66 (13.01)^{†,a}	92.99 (10.21)	107.26 (10.97)^{†,a}	110.72 (10.22)^{a}	90.50 (10.85)	99,30 (14.75)^{a}	104.09 (11.01)^{a}
W:R (a.u.)	6.36 (2.42)	12.52 (6.39)$^{\#,\dagger,a}$	12.02 (5.44)^{†,a}	6.63 (2.99)	9.54 (4.24)^{a}	10.06 (4.33)^{a}	5.33 (2.14)	8.15 (5.90)	8.76 (4.66)^{a}
BL (a.u.)	9.70 (2.72)	17.44 (4.66)^{†,a,c}	11.30 (2.63)	8.30 (2.13)	16.51 (5.90)^{†,a,c}	10.32 (2.36)	7.50 (2.32)	13.30 (5.97)^{a,c}	9.21 (2.24)
V_{max} peak (Km/h)	16.55 (1.93)	18.05 (2.36)^{†,a}	18.07 (1.89)^{a}	16.02 (2.48)	16.96 (2.34)	17.35 (1.83)^{a}	15.65 (2.53)	16.07 (1.98)	17.30 (1.84)^{a}
V_{mean} (Km/h)	5.99 (0.50)†	6.86 (0.68)$^{\#,\dagger,a}$	6.88 (0.78)$^{\dagger a}$	5.58 (0.61)	6.44 (0.66)^{†,a}	6.64 (0.61)^{a}	5.43 (0.65)	5.96 (0.88)^{a}	6.25 (0.66)^{a}
High-intensity actions									
High-intensity distance (m)	21.03 (11.33)	42.98 (23.74)$^{\#,\dagger,a}$	55.06 (31.27)$^{\#,\dagger,a,b}$	18.25 (11.69)	31.54 (18.13)^{a}	41.59 (19.19)^{a,b}	14.86 (11.61)	31.19 (24.25)	32.39 (16.07)^{a}
Number of high intensity actions (a.u.)	2.27 (1.73)	4.20 (2.26)$^{\#,\dagger,a}$	5.66 (3.21)$^{\#,\dagger,a,b}$	1.70 (1.03)	3.08 (1.73)^{a}	4.38 (1.84)^{†,a,b}	2.09 (0.95)	3.00 (2.15)	3.03 (1.80)
Average duration of sprints (s)	1.69 (0.51)	1.93 (0.34)	1.95 (0.34)	1.81 (0.76)	1.95 (0.52)	1.80 (0.40)	1.83 (0.88)	1.96 (0.53)	2.11 (0.57)
Sprint V_{max}mean (Km/h)	15.70 (1.73)	15.91 (1.12)	16.03 (0.86)	15.68 (1.36)	15.70 (1.38)	15.74 (1.08)	16.03 (1.72)	15.22 (1.35)	16.24 (2.71)
Average distance of sprint (m)	9.50 (13.66)	8.28 (2.30)	8.06 (1.61)	7.41 (3.56)	8.61 (3.14)	7.63 (2.40)	8.06 (4.55)	10.08 (9.09)	8.90 (2.80)
Acceleration max mean (m/s/s)	2.39 (0.15)	2.50 (0.15)	2.40 (0.13)	2.39 (0.12)	2.40 (0.12)	2.46 (0.16)	2.42 (0.14)	2.39 (1.86)	2.41 (0.17)

$^{*,\#,\dagger}$ Significant differences with the surface indicated ($p<0.05$)
^{a,b,c} Significant differences with the SSG indicated ($p<0.05$)
NG=Natural Grass; AT=Artificial Turf; GR=Ground.
SSG400=Small Sided Game 400; SSG 600= Small sided Game 600; SSG 800=Small Sided Game 800
a.u.= arbitrary units

Table III. Number of accelerations and decelerations in the three surfaces and the three SSG.

	Natural Grass (NG) (*)			Artificial Turf (AT) (#)			Ground (GR) (†)		
	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)
Accelerations									
Accel. between 1.5 and 2 m/s^2 (n)	11.80 (3.03)	11.59 (3.21) †	11.47 (3.81) †	10.14 (4.01)	10.93 (2.86) †	10.56 (3.46)	9.75 (3.99)	8.46 (4.17)	8.84 (3.40)
Accel. between 2.0 and 2.5 m/s^2 (n)	6.17 (3.41) †	5.91 (2.90) †	6.75 (2.54) #,†	5.21 (1.57)	5.62 (2.31) †	5.22 (2.70)	4.32 (1.98)	3.40 (2.39)	4.34 (2.21)
Accel. between 2.5 and 2.75 m/s^2 (n)	1.23 (1.17)	1.19 (1.18)	1.13 (0.91)	1.28 (1.07)	1.52 (1.24)	1.69 (1.33) †	1.11 (1.03)	1.07 (0.98)	0.97 (1.09)
Accel. >2.75 m/s^2 (n)	1.10 (1.12)	2.34 (1.77) #,†,a	1.63 (1.45)	1.00 (1.00)	1.07 (1.10)	1.34 (1.26)	0.89 (0.89)	0.67 (0.90)	1.03 (0.97)
Decelerations									
Decel. between 1.5 and 2 m/s^2 (n)	9.60 (2.91)	11.22 (2.64) #,†	9.97 (3.65)	9.38 (3.18)	9.28 (3.12)	8.69 (2.96)	8.36 (2.90)	7.54 (2.86)	8.88 (3.31)
Decel. between 2.0 and 2.5 m/s^2 (n)	6.10 (2.72)	5.88 (2.32) †	5.38 (2.10)	4.90 (2.30)	6.14 (2.66) †	5.97 (2.37)	5.25 (2.88)	4.21 (1.98)	4.97 (2.15)
Decel. between 2.5 and 2.75 m/s^2 (n)	2.03 (1.30) †	1.94 (1.37) †	1.81 (1.38)	1.28 (0.88)	1.55 (0.99)	2.09 (1.28)	1.18 (1.06)	1.07 (1.15)	1.53 (1.39)
Decel. >2.75 m/s^2 (n)	3.70 (2.28)	4.41 (1.93) †	4.41 (2.17) †	2.69 (1.83)	3.34 (2.29)	3.60 (2.18)	2.61 (2.04)	2.25 (1.80)	2.69 (1.71)

[*, #, †] Significant differences with the surface indicated ($p<0.05$)
[a,b,c] Significant differences with the SSG indicated ($p<0.05$)
NG=Natural Grass; AT=Artificial Turf; GR=Ground.
SSG400=Small Sided Game 400; SSG 600= Small sided Game 600; SSG 800=Small Sided Game 800

5.1.2. Estudio 2. Physiological responses, fatigue and perception of female soccer players in small-sided games with different pitch size and sport surfaces

Biology of Sport *(En 2ª revisión desde enero, 2018)*

PHYSIOLOGICAL RESPONSES, FATIGUE AND PERCEPTION OF FEMALE SOCCER PLAYERS IN SMALL-SIDED GAMES WITH DIFFERENT PITCH SIZE AND SPORT SURFACES

RUNNING HEAD: Physiological Patterns, Fatigue & Perception in four-a-side

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Disclosure statement

The authors report no conflicts of interest

PHYSIOLOGICAL RESPONSES AND PERCEPTION OF FATIGUE OF FEMALE SOCCER PLAYERS IN SMALL-SIDED GAMES WITH DIFFERENT PITCH SIZE AND SPORT SURFACES

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ABSTRACT

The aim of this research was to evaluate the influence of game surface and pitch size on the physiological responses, jump performance and perceptions of sub-elite female soccer players playing four-a-side games. Sixteen sub-elite female soccer players were divided into four groups of four players each. Three small-sided games (SSGs; Pitch size: 400 m^2, 600 m^2 and 800 m^2) were played on three surfaces (Dirt [DT], artificial turf [AT] and natural grass [NG]). Players' heart rate (HR) was monitored during each game. Before and after each SSG, participants performed two counter-movement jumps (CMJs) and answered a questionnaire based on visual analogue scales (VASs) to indicate their perception of the effort required on each surface. DT received lower outputs on most variables. On the SSG 600 mean HR was higher on NG than AT (+3.31 $\%HR_{max}$; $p = 0.029$), but players' overall satisfaction with both surfaces was similar ($p>0.05$). The SSG 400 received the lowest ratings on most variables whereas the SSG 600 resulted in higher HR mean than SSG 800 [NG (+9.14 b.p.m.; $p = 0.001$); AT (+7.32 b.p.m.; $p = 0.014$)]. No surface differences in CMJ performance were found. In conclusion, a higher internal load can be achieved on NG, whereas DT is not recommended for playing soccer. Moreover, the internal load on players in SSGs can be controlled by manipulating pitch size, but over-large pitches may entail a reduction in physiological profile of female soccer players.

Key Words: Artificial Turf; Football; Four-a-side; Heart Rate; Women

INTRODUCTION

The strong growth in female soccer in recent years, with over 1.2 million of federative licenses already granted in Europe alone (1), is matched by increasing scientific interest in this sport (2-8). Several studies have described the physical and physiological demands of female soccer matches at different levels (7-9); evidencing that the competitive demands of female soccer are different from those of the male game and so the training methods may not be the same (2, 3, 7).

Because soccer is a sport involving an intermittent burst of activity performance is heavily dependent on high-intensity actions such as jumps, hits and sprints. However, such actions impose high metabolic demands and lead to acute fatigue (3, 10-12). The ability of players to execute these actions throughout a game depends on fitness factors such as their VO_{2max}, muscular tone or maximum heart rate (HR_{max}) (3, 11).

Currently, Small-Sided Games (SSGs) are increasingly used in training because they reproduce the technical, tactical and even physical demands of soccer matches (13-16); whilst allowing players to increase their fitness regardless of age or gender (5, 17, 18). It is possible, however, that female SSGs not provide sufficient external load to replicate the physical demands of soccer matches (4). It is likely that some SSGs do not make sufficient physiological demands on some female players (19), bearing in mind that players' mean and peak heart rate (HR) should reach 81 87% and 97 98% respectively of their individual HRmax to reproduce the physiological demands of matches (20).

Research on male soccer has demonstrated that the physiological responses of players in SSGs are affected by several external factors, such as the length of the game, rest period, number of players, pitch dimensions, presence or absence of keepers or goalposts, number of touches or the game surface (16, 18, 21-23). However, the physiological responses of female soccer players during SSGs has only been investigated relative to the number of players (6); so further analysis is required to discover how external variables affect the physiological profile of female soccer players during SSGs.

Among all these variables, pitch size is considered a key factor in soccer because, in matches, players usually have to face game situations in a reduced space (24, 25). Nonetheless, the importance of the pitch size in SSGs also reflect the fact that it may influence game intensity and hence manipulations of pitch size may be used to adjust training loads (26, 27). The influence of pitch size on the physiological demands of SSGs has only been studied in men and there is no clear consensus on what the relationships are. Casamichana and Castellano (28) and Rampinini et al. (15) reported that players' physiological responses improve when the pitch size increases; suggesting that the physiological demands of SSGs increase with pitch size. However, Kelly and Drust (23) did not find this pattern in the physiological responses of professional soccer players, although the technical patterns of these players did change with the pitch size. One could conclude from these findings that the influence of pitch size on the physiological responses of soccer players in SSGs is mediated or moderated by other variables, such as competitive level or game format; this would imply that the effects of pitch size should not be investigated in isolation (27). Similarly, findings based on research on male soccer should not be assumed to generalise to female soccer; so separate research is required to determine how pitch size should be manipulated to regulate the intensity of female SSGs (29).

On the other hand, research into the intensity of SSGs has paid scant attention to the potential impact of the surface on which games are played. Only Brito et al. (21) have studied the influence of the sports surface in SSGs, but they compared artificial turf with two surfaces that are not used for eleven-a-side soccer (sand and asphalt). Professional soccer has traditionally been played on natural grass, whilst dirt pitches are widely used in amateur soccer due to the low number of uses per week and its maintenance costs. However, the newest artificial turf systems are now widely used in soccer because they are providing similar mechanical properties to natural grass (30).

The latest comparative studies have demonstrated that injury rate, sprint performance and recovery time are similar on artificial turf systems and natural grass (31-33). Moreover, it seems that playing on artificial turf does not alter the pattern of changes in heart rate and blood lactate relative to playing on natural grass (31, 34, 35), although most of this research involved standardised tests performed without a ball. It remains possible, therefore, that alterations in game style according to the surface (i.e. more short passes and lower tackles on turf than on natural grass) (36) may decisively influence the physiological responses of soccer players during SSGs. It follows that there is a need for more research into how the playing surface influences players' physiological responses during real games, including SSGs. This is especially important in female soccer as artificial turf is more prevalent in professional and sub-elite tournaments; being even used for the 2015 FIFA Women's World Cup (37).

To address these gaps in the literature, the aim of this research was to evaluate the influence of game surface and pitch size on the physiological responses, fatigue and perceptions of sub-elite female soccer players in Small-Sided Games of four-a-side. On the basis of previous works, we hypothesised that players' physiological responses would be affected by the game surface and would be more marked in SSGs played on larger pitches.

MATERIALS AND METHODS

Experimental Design

Prior to the main interventions performed a Yo-Yo Intermittent Endurance Test Level 2 to determine their maximum Heart Rate (HR max) (38, 39) (Figure 1). The total distance achieved of the test was recorded (777.1 ± 159.98 m). Heart rate (HR) was monitored using a pulsometer (Polar Team System, Kempele, Finland) attached to the participant's chest.

The study was conducted over four consecutive weeks (2 days per week). Three different SSGs conditions (Table I) were repeated twice on each of the three chosen surfaces, dirt (DT; uniform and dry dirt), artificial turf (AT; fibre: monofilament of polyethylene, 60 mm in height; infill: 20 $kg \cdot m^{-2}$ of styrenebutadiene rubber and quartz sand with 0.3–0.8 granulometry) and natural grass (NG; grass' height: 25 mm) to yield 96 observations. The three surfaces had the same orientation (north-south) and altitude (770 m above the sea level). All tests were conducted under similar weather conditions (dry; 20-24.5ºC; 22-30% relative humidity) the mechanical properties of sports surfaces are affected by meteorological conditions (40). The tests were also conducted at the player's regular training time (19:00 to 21:00) in order to reduce the possible influence of circadian rhythms (41). Before the test session, players completed a familiarisation session to get used to both the heart rate monitors and the SSG included in the study.

"Please, insert Table I about here"

Sample Characteristics

Sixteen women from the same Spanish Second Division team participated in the study (19.56 ± 1.97 years; 57.74 ± 4.89 kg; 161.57 ± 5.83 cm; 24.93 ± 4.1% body fat). All participants had been playing soccer on artificial turf and natural grass for at least 5 years (5.81 ± 0.75 years) and practiced for two hours, three days a week as well as playing a weekly competitive game. None of the participants reported any cardiopulmonary disease or took medication during the study and all confirmed that they had passed the medical examination required to play soccer.

The participating club, coaches and players were informed about the possible risks of taking part in this study. All players provided written informed consent to participation. The study was approved by the local Clinical Research Ethical Committee in accordance with the Declaration of Helsinki.

Experimental Protocol

Players were asked to rest for 72 hours before each test session. During this period, they were asked to avoid exhausting activity and to maintain the same eating habits. They were asked to use the same soccer boots (with rubber studs) for all test sessions.

The order of the SSGs and surfaces were randomly determined so that every test day participants played one sort of SSG (small, medium or large) on each surface. At the start of each test day, participants carried out a standardised warm-up consisting of 5 minutes of running, 5 minutes of joint mobility and three 30m sprints of increasing intensity (41).

Four-a-side SSGs. Coaches divided the players into four teams of four players matched with respect to level. Each team played three different four-a-side games on each surface (Table I). We used four-a-side games rather than the five-a-side games favoured by Mara et al Mara et al. (6) because this format is widely used in research (15), and there has already been some research on four-a-side female soccer games (26, 29). We also considered the findings of Zubillaga et al. (25) when designing our SSGs. They demonstrated that the individual player area in matches goes from 77.91 ± 32.72 m^2 and 96.19 ± 22.66 m^2. Moreover, length to wide ratio goes from 1:1 to 1:1.3 (24, 25).

Teams and match format remained the same throughout the whole investigation. The objective was to maintain the ball possession as much time as possible; so, neither goalposts nor keepers were included in the SSGs. We chose this option because possession SSGs appear to be more intense than those with goal-keepers (27, 42). Coaches encouraged the players during the whole study and balls were replaced when they went outside the pitch to maximise the playing time. Finally, to ensure maximum recovery between SSGs the players performed 10-min of active recovery work (low-intensity ball-passing exercises and three incremental sprints at the end of the recovery time).

Physiological responses and internal load. Physiological variables were recorded using HR monitors (Polar Team System, Kempele, Finland). HRmax was determined for each player in the Yo-Yo Intermittent Endurance Test Level 2. Taking this value as a reference the heart rate peak (HR peak) and the average heart (HR mean) in both beats-per-minute (b.p.m.) and percentage of the individual maximum heart rate (% HR_{max}) were calculated. The physiological responses were assessed establishing six zones of intensity (all in % HR_{max}: <75; 75-80; 80-85; 85-90; 90-95; >95%) (43). All activity at over 85% HR_{max} was also recorded as HR High Intensity.

Vertical jumping. Players performed two countermovement jumps (CMJ) before and after each SSG. During jumps, players kept their hands on their hips so that their performance was not influenced by arm movement. Jumps were recorded using an infrared system (Optojump Next, Microgate, Bolzano, Italy), and data from the best jump was used in statistical analyses. The maximum jump height in cm and the coefficient of variation after SSG were analysed.

Visual analogue scales. Perceptions of effort, fatigue and the difficulty of executing specific technical actions on each surface were assessed using a series of 100mm visual analogue scales (VASs) where 0 represented 'nothing, hard/tired/comfortable' and 100 'very, hard/tired/comfortable'. Data were registered in arbitrary units (a.u.) and players completed the questionnaire immediately following each SSG.

The questionnaire consisted of twelve questions adapted from previous research on sports surfaces (21, 36, 41): "How would you classify the effort you made during this session?"

(VAS1); "How tired are you at this moment?" (VAS2); "How difficult did you find it to make a precise pass?" (VAS3); "How fast was the ball speed after a pass?" (VAS4); "How difficult did you find it to control the ball?" (VAS5); "How difficult did you find it to dodge an opponent?" (VAS6); "How difficult did you find it to perform changes of direction?" (VAS7); "How easy did you find it to do a tackle?" (VAS8); How easy did you find dribbling? (VAS9) "How easy was it to run without the ball?" (VAS10); "How well did the ball rebound?" (VAS11); "In general, how did you feel during this session on this surface?" (VAS12).

Statistical Analysis

Results are presented as means and standard deviations (±SD). The Kolmogorov-Smirnov test and Levene's statistic were used to verify the normality of the data and the homogeneity of variance. The comparisons between results of the physiological variables were developed through two-way ANOVA (surface x game situation) tests. The results collected for the jump variables before and after the different game situations on all surfaces were analysed by the same method using the percentage of change. Interactions were assessed using post hoc pairwise Bonferroni tests. Confidence intervals (CI of 95%) were calculated to indicate the magnitude of change. Effect size (ES) was calculated and classified using Cohen's criteria (44) and defined as follows: trivial <0.19; small 0.2–0.49; medium 0.5–0.79; large >0.8. Data were analysed with the statistical software SPSS v 20.0. The level of significance was set at $p<0.05$.

RESULTS

Physiological Responses

Table II shows the physiological responses of the players in the different SSG and surfaces. The HR mean and HR peak in the SSG 400 and SSG 600 were higher on natural grass than on dirt ($p < 0.05$). Moreover, in the SSG 600, the natural grass also had higher outcomes than artificial turf for HR mean [+3.31 %HR_{max}; $p = 0.029$; ES: 0.856; CI: 0.49 – 12.87]; HR mean [+6.68 b.p.m.; $p = 0.012$; ES: 0.838; CI: 0.58 – 6.04]; and HR High Intensity [+19.07 %; $p = 0.041$; ES: 0.934; CI: 0.54 – 37.59].

"Please, insert Table II about here"

On the other hand, the main differences among SSGs were found for dirt since the values of the SSG 400 were lower ($p < 0.05$) than the SSG 600 and SSG 800 ones for HR mean (%HRmax and b.p.m.), and HR peak (%HRmax). Nonetheless, the SSG 600 also had higher outcomes than the SSG 800 for HR mean [NG (+9.14 b.p.m.; $p = 0.001$; ES: 1.014; CI: 3.11 – 15.18); AT (+7.32 b.p.m.; $p = 0.014$; ES: 0.850; CI: 1.13 – 13.51)] and HR High Intensity [NG (+26.60 %; $p = 0.001$; ES: 1.174; CI: 8.54 – 44.67); AT (+21.63 %; $p > 0.001$; ES: 0.727; CI: 3.11 – 40.16)].

Figure 2 displays the internal load in terms of the percentage of time that players spent in each of the six zones of intensity established. The main differences among surfaces were found in the SSG 600. Thus, in this SSG, players spent significantly more time in Zone 5 on natural grass than on dirt (+13.77 %; $p = 0.048$; ES: 0.564; CI: 0.08 – 16.35); while in Zone 6 the outcomes were higher on natural grass than on artificial turf (+19.21 %; $p < 0.001$; ES: 0.819; CI: 8.76 – 29.66) and dirt (+26.65 %; $p < 0.001$; ES: 1.420; CI: 16.11 – 37.20).

"Please, insert Figure 2 about here"

On the other hand, the main differences among pitch sizes were found on natural grass. Hence, players spent significantly more time in Zone 5 in the SSG 600 than the SSG 400

(+16.65 %; p = 0.016; ES: 0.666; CI: 2.21 – 29.10); while in Zone 6 the SSG 600 had higher outcomes than the SSG 400 (+21.32 %; p < 0.001; ES: 0.908; CI: 10.97–- 31.68) and the SSG 800 (+17.43 %; p < 0.001; ES: 0.645; CI: 7.24 – 27.62).

Countermovement Jump

The coefficients of variation for the CMJ jumps (Table III) were similar on all three surfaces and for all three pitch sizes (p > 0.05). However, in descriptive terms mean post-game CMJs were always higher than mean pre-game CMJs.

"Please, insert Table III about here"

Visual Analogue Scale

Table IV presents the players' perceptions of twelve specific variables. At all pitch sizes dirt got significantly lower results than the other two surfaces on most of the variables for the three SSGs (400, 600 and 800 m^2), indicating that players found it a less suitable playing surface. The main difference between natural grass and artificial turf was observed in VAS8 where players considered the natural grass more suitable for doing a tackle than artificial turf [SSG400 (+18.98 a.u.; p = 0.001; ES: 0.768; CI: 7.00 – 30.96); SSG600 (+19.16 a.u.; p < 0.001; ES: 0.837; CI: 7.47 – 30.84); SSG800 (+13.71 a.u.; p = 0.021; ES: 1.257; CI: 1.54 – 25.88)].

"Please, insert Table IV about here"

DISCUSSION

Small-sided games are a suitable way of improving soccer-specific aerobic fitness despite the difficulty of controlling work intensity (6, 21, 27, 28). This study analysed the physiological profile and perceptions of fatigue and exertion in sub-elite female soccer players in different-sized SSG played on three distinct surfaces: natural grass, artificial turf, and dirt. Analyses revealed that both surface and pitch size affected the physiological performance and perceptions of sub-elite female soccer players. The greatest physiological response to games was observed in the SSG 600 played on natural grass. Therefore, when planning training sessions coaches must take into account several variables that influence player's responses (27).

The findings of this research are in line with those of Jastrzebski et al. (29), who suggested that SSGs stimulate the cardiovascular system on both genders, as HR_{peak} and HR_{mean} of participants in this study were over 90% and 80% of individual HR_{max} except on dirt (6, 13, 22, 28). However, several studies that analysed the physiological responses of female soccer players during SSGs and real matches defined the HR_{max} as the highest HR_{peak} in the game (20, 45); meaning that we cannot compare our results directly, owing to this difference in methodology.

Regarding the pitch size of SSGs, Regarding the pitch size of SSGs, some authors assessed the most common reduced spaces in matches either in male or female soccer players. They reported that area per player goes from 78.97 ± 15.05 m^2 to 93.87 ± 16.25 m^2 in men (24) and from 77.91 ± 32.72 m^2 to 96.19 ± 22.66 m^2 in women (25). The pitch sizes chosen for this study are in line with the recommendation of these authors; with the area per player being lower than 110 m^2 per player (SSG 400 = 50 m^2 per player; SSG600 = 75 m^2 per player; SSG 800 = 100 m^2 per player). Nevertheless, most studies that have compared pitches of different sizes have included pitches yielding up to 200 m^2 per player (23, 28).

Previous studies in men have evidenced shown that playing on bigger pitches increase the physiological responses of soccer players (15, 27, 28), probably because smaller pitches led to lower effective playing time than the large pitches (28). Our findings in female soccer players corroborate the research on men, as we found that female players had a lower internal load

(HR_{mean} as b.p.m and HR High Intensity) on small pitches (SSG 400) than when playing on medium (SSG 600) or large pitches (SSG 800). However, unlike these studies, we found that female players playing on natural grass and artificial turf has smaller heart rate responses (HR_{mean} as b.p.m and HR High Intensity) when playing on large pitches rather than medium pitches. In the literature, not all published studies have reported differences in players physiological responses when the pitch size increases (23), but our research is the first to report that physiological responses were greater on medium-sized pitches than large pitches. We believe that the large pitch used in our study was so big that retaining possession of the ball was not a challenge and so there were fewer disputes over possessions when playing on the large pitch. In future, it would be helpful to record ball possession patterns in order to confirm this hypothesis.

One of the most important findings of this research is that the total time over the 85% of players' HR_{max} was higher on the SSG 600 (26.26% on natural grass and 21.63% on artificial turf) than on the SSG 800. This suggests that coaches should take care when selecting the pitch size for SSGs as playing on a large pitch may reduce the internal load on players. Nevertheless, one must consider that may have influenced our results and make it difficult to compare our findings with those of other studies, for instance, players' age and gender (10, 28), the absence of goalkeeper (27), the number of players (6), the pitch sizes selected (25) and the players' level (13). Our findings should, therefore, be interpreted with care.

On the other hand, this research proves that the game surface also influences players' physiological responses during SSGs. These findings are not new since, for instance, Brito et al. (21) reported that physiological responses of amateur soccer players in five-a-side games varied according to whether they were playing on asphalt, sand or artificial turf; however, neither sand nor asphalt are soccer-specific surfaces. The reduced physiological responses of players on dirt are probably due to the fact that this surface is harder than the natural grass and the artificial turf (41). This suggests that dirt is not suitable for playing soccer, what indeed was stated by players through the VAS questionnaire. Players perceived surface-ball and surface-player interactions to be worse on dirt than on the other surfaces and this may have had a negative impact on game intensity (36). To some extent, these results were expected because dirt surfaces are being replaced by artificial turf systems (30) and international bodies such as FIFA no longer support the use of dirt as a playing surface.

Regarding the remaining surfaces, the latest comparative studies suggest that soccer players have similar physiological responses on artificial turf systems and natural grass surfaces (31, 34), but they were carried out using a soccer-simulation protocol that does not include the use of the ball. Like Anderson et al. (36), our participants found easier to perform tackles on natural grass, whereas they perceived the ball speed faster on artificial turf. These results suggest that the higher HR_{mean} and HR High Intensity on the natural grass during the SSG 600 were influenced by the different game patterns associated with each surface (36). Nevertheless, it remains more likely that these results primarily reflect the differences in the mechanical properties of each surface. Previous studies have demonstrated that the mechanical properties of artificial turf systems vary widely and that these differences also affect the physical and physiological responses of soccer players (41). It seems that softer surfaces increase the heart rate responses of soccer players (41), so the greater internal load found on the SSG 600 played on natural grass may be due to this surface had a higher force reduction than the artificial turf system (34). This may also explain why, when playing the SSG 400, players found easier to dodge opponents on artificial turf than on natural grass, as harder surfaces are associated with higher running speed and faster turn times (41). However, these interpretations are offered somewhat cautiously as we did not assess the mechanical properties of the three surfaces used in the study (34). Besides, players' overall satisfaction rating was similar for artificial turf and the natural grass.

Finally, like with Brito et al. (21), we found that the playing surface did not affect the deterioration of the CMJ performance after the SSG. However, unlike other studies, players jumped more after the activity than before (21, 41). This could be because each SSG only lasted 4 minutes. Likewise, the lack of differences in players' perceived fatigue following games on each type of pitch might explain why CMJ was not sensitive to either play surface or pitch size.

As reported by this study, playing surface and pitch size are both extrinsic variables that coaches should consider when designing SSGs as both variables affect female soccer players' physiological responses. It should be remembered, however, that we did not assess the mechanical properties of the surfaces used in our research nor did we evaluate total possession time or the number of possessions per team in each SSG. Future research should include these variables as they could explain the differences in players' responses. Likewise, it is important to be cautious when comparing our results with those of previous studies, given the dearth of research on SSGs in female soccer and the differences between our method of analysing HR responses and that used in other studies with women.

CONCLUSIONS

Pitch size can be used to manipulate the internal load of SSGs as big pitches provoke greater heart rate responses than the smaller ones. However, coaches should bear in mind that playing on very large pitches may reduce the internal load on female soccer players.

On the other hand, it is recommended not playing soccer on dirt surfaces because surface-player and surface-ball interactions on this surface are rated poorly by soccer players. Moreover, playing on dirt also elicits smaller heart rate responses than playing on other surfaces. Finally, female players reported similar satisfaction with the artificial turf systems and the natural grass surfaces. However, playing on natural grass surface elicited greater heart rate responses in the SSGs, suggesting that a higher internal load can be achieved on natural grass than on artificial turf.

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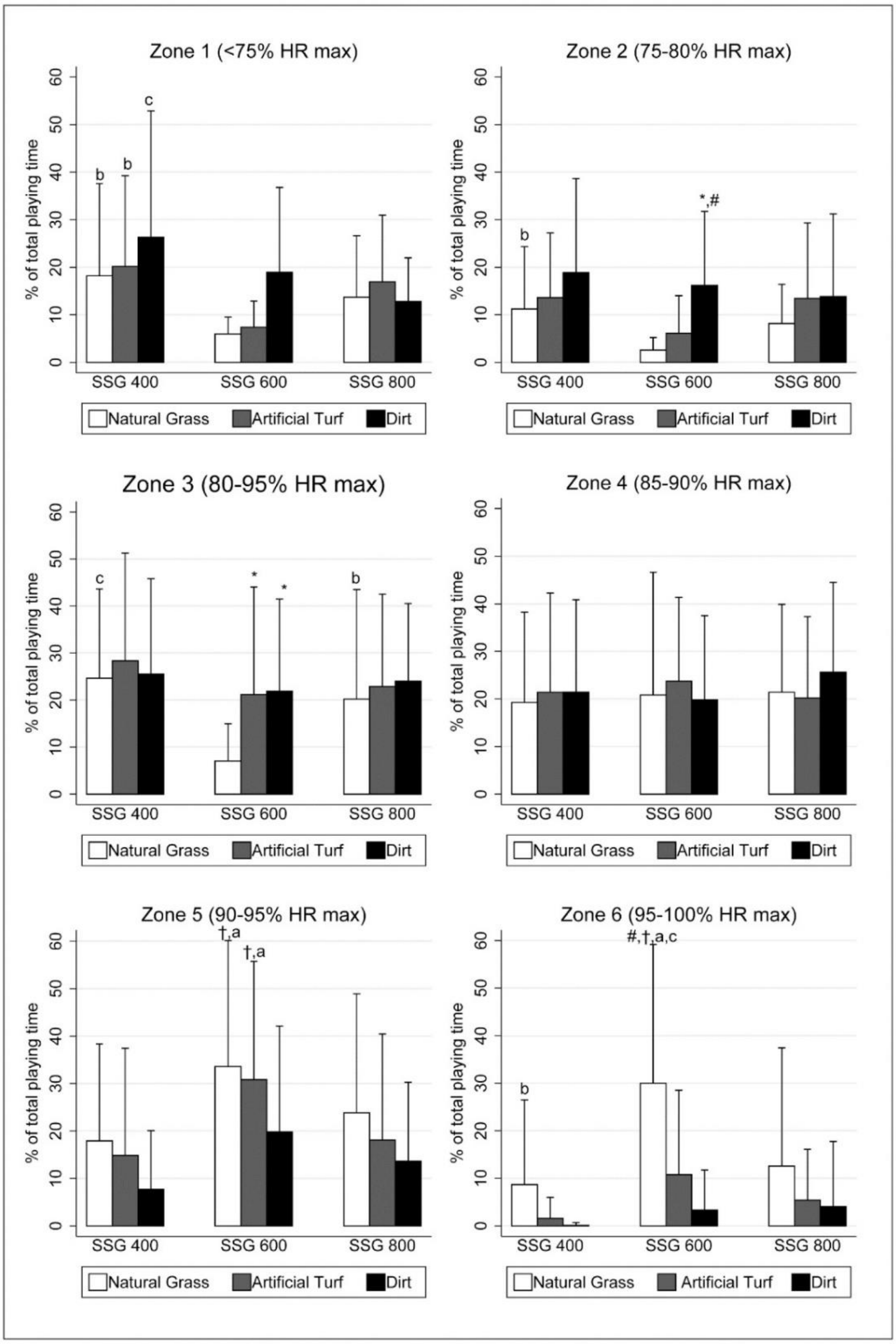

Figure 1. Physiological responses in the three surfaces and three SSGs

Significant differences (p<0.05): Natural grass = *; Artificial turf = #; Dirt = †

Significant differences (p<0.05): SSG 400 = a; SSG 600 = b; SSG 800 = c

Table I. SSG characteristics

	Game duration (min)	Duration of the recovery between SSG	Pitch area (m)	Pitch total area (m^2)	Pitch ratio per player (m^2)
SSG 400	4	10	20 x 20 m	400 m^2	50 m^2
SSG 600	4	10	24.5 x 24.5 m	600 m^2	75 m^2
SSG 800	4	10	28.3 x 28.3 m	800 m^2	100 m^2

SSG: Small Sided Game

Table II. Physiological responses in the three surfaces and the three SSG.

	Natural Grass (NG) (*)			Artificial Turf (AT) (#)			Dirt (DT) (†)		
	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)
HR mean (%HR_{max})	84.11 (5.80) †	89.88 (3.56) $^{\#,†}$	84.92 (6.06)	81.15 (5,52)	86.57 (4,17) ^{†,a}	82.40 (5,27)	79.18 (4.88)	82.45 (5.30) ^{a}	82,90 (4.41) ^{a}
HR mean (b.p.m.)	169.39 (12.11) †	178.43 (6.48) $^{\#,†, a,c}$	169.29 (11.55)	163.74 (10.92)	171.75 (8.44) $^{†,a, c}$	164.43 (9.74)	160.07 (8.83)	164.03 (12.17) ^{a}	165.54 (8.67) ^{a}
HR peak (%HR_{max})	92.58 (4.46) †	95.47 (3.64) †	92.77 (4.57)	89.32 (5.38)	92.88 (4.11) ^{a}	90.30 (7.92)	86,93 (5.89)	91,22 (5.60) ^{a}	91,51 (4.37) ^{a}
HR peak (b.p.m)	186.40 (8.86) †	189.56 (7.43) †	184.97 (8.95)	180.17 (9.87)	184.31 (8.98)	180.13 (14.91)	175.71 (10.52)	181.46 (12.87) ^{a}	182.79 (9.53)
HR High Intensity (t [%])>85% HR_{max})	45.89 (34.28)	84.43 (12.68) $^{\#,†,a,c}$	57.83 (32.64)	37.89 (34.73)	65.36 (28.14) ^{†,a,c}	43.73 (31.36)	29.27 (28.13)	42.97 (32.45)	43.34 (30.16)

$^{*, \#, †}$ Significant differences with the surface indicated (p<0.05)
^{a,b,c} Significant differences with the SSG indicated (p<0.05)
NG=Natural Grass; AT=Artificial Turf; GR=Ground.
SSG400=Small Sided Game 400; SSG 600= Small Sided Game 600; SSG 800=Small Sided Game 800

Table III. Differences between the high pre CMJ and the high post CMJ

	Natural Grass (NG)			Artificial Turf (AT)			Dirt (DT)		
	SGG 400	SSG 600	SSG 800	SGG 400	SSG 600	SSG 800	SGG 400	SSG 600	SSG 800
High Pre CMJ (m)	23.23 (3.43)	23.69 (4.11)	23.73 (3.38)	23.72 (3.89)	24.27 (4.08)	23.07 (3.72)	24.60 (3.89)	23.12 (4.84)	22.29 (3.50)
High Post CMJ (m)	24.09 (3.81)	24.56 (4.09)	24.45 (3.13)	24.39 (3.90)	24.93 (4.04)	24.13 (3.55)	25.47 (4.19)	23.76 (4.85)	23.00 (3.58)
Coefficient of variation	3.57 (4.42)*	3.84 (3.70)*	3.35 (5.23) †	2.99 (4.70) †	2.90 (3.24)*	4.83 (5.10)*	3.49 (4.00)*	2.99 (4.72) †	3.32 (5.09) †

* = p<0.001
† = p<0.01

Table IV. Post-session Visual Analogue Scale (VAS) results according to the three surfaces and the three SSG.

	Natural Grass (NG) (*)			Artificial Turf (AT) (#)			Dirt (DT) (†)		
	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)
VAS1: Perceived exertion (a.u.)	42.17 (18.81)	51.34 (16.92)	45.81 (17.10)	41.86 (16.04)	47.14 (15.40)	40.19 (15.83)	52.64 (20.84)	49.00 (19.53)	52.47 (19.66)$^{\#}$
VAS2: Level of fatigue (a.u.)	42.73 (17.48)	51.31 (18.50)	48.53 (14.38)	42.66 (15.97)	48.14 (16.03)	44.16 (15.88)	47.63 (22.61)	49.04 (18.30)	49.88 (16.33)
VAS3: Difficulty for making a precise pass (a.u.)	41.70 (16.18)	39.06 (18.71)	39.31 (11.93)	37.03 (14.05)	38.55 (16.50)	36.94 (11.84)†	66.41 (13.16)$^{*,\#}$	63.86 (18.30)$^{*,\#}$	63.72 (16.71)$^{*,\#}$
VAS4: Ball speed after a pass (a.u.)	63.60 (11.52)$^{\#,\dagger}$	60.56 (21.55)†	63.09 (11.90)$^{\#,\dagger}$	50.34 (14.81)†	52.24 (20.13)	47.34 (15.69)	36.63 (21.36)	44.07 (24.59)	50.81 (16.40)^{a}
VAS5: Difficulty to control the ball (a.u.)	42.00 (15.68)	44.81 (19.33)	37.34 (10.95)	38.00 (13.60)	39.86 (15.77)	36.44 (9.80)	63.07 (18.17)$^{*,\#}$	65.07 (16.52)$^{*,\#}$	64.59 (13.42)$^{*,\#}$
VAS6: Difficulty for a dodge (a.u.)	45.30 (16.78)$^{\#}$	46.03 (19.37)	37.41 (12.29)	34.76 (12.28)	38.59 (18.26)	35.97 (10.82)	62.78 (16.10)$^{*,\#}$	65.86 (15.56)$^{*,\#}$	65.50 (12.23)$^{*,\#}$
VAS7: Difficulty for changes of direction (a.u.)	41.70 (15.10)	41.31 (17.84)	38.93 (11.58)	37.10 (11.56)	38.34 (19.20)	36.00 (10.39)†	66.11 (12.49)$^{*,\#}$	65.14 (14.40)$^{*,\#}$	63.06 (12.23)$^{*,\#}$
VAS8: Amenity for a tackle (a.u.)	60.50 (17.56)$^{\#,\dagger}$	57.50 (22.49)$^{\#,\dagger}$	62.06 (13.23)$^{\#,\dagger}$	46.80 (18.12)†	38.52 (22.84)	42.91 (16.81)†	27.15 (22.26)	26.18 (21.85)	27.59 (18.25)
VAS9: Amenity when dribbling the ball (a.u.)	60.50 (15.36)†	60.28 (17.75)†	64.44 (8.87)†	57.90 (16.58)†	56.31 (16.86)†	62.66 (8.05)†	38.89 (24.87)^{b}	27.21 (16.61)	31.06 (12.83)
VAS10: Amenity when running without the ball (a.u.)	61.50 (18.65)†	60.28 (18.38)†	64.44 (14.71)†	58.87 (17.48)†	56.34 (16.87)†	56.09 (12.80)†	40.59 (23.44)	33.64 (14.93)	35.88 (13.91)
VAS11: Ball rebound quality (a.u.)	57.37 (10.99)†	66.88 (17.22)^{†,a,c}	61.78 (11.65)†	59.86 (16.75)†	55.55 (21.76)†	56.78 (14.56)†	25.19 (12.36)	21.36 (16.97)	24.56 (11.15)
VAS12: General perception of the surface (a.u.)	69.10 (10.82)†	68.06 (13.41)†	67.06 (10.25)†	64.14 (12.97)†	66.24 (16.31)†	61.25 (11.77)†	43.25 (22.63)^{b}	32.93 (20.48)	39.81 (18.08)

$^{*, \#, \dagger}$ Significant differences with the surface indicated ($p<0.05$)

^{a,b,c} Significant differences with the SSG indicated ($p<0.05$)

NG=Natural Grass; AT=Artificial Turf; GR=Ground.

SSG400=Small Sided Game 400; SSG 600= Small sided Game 600; SSG 800=Small Sided Game 800

VAS=Visual Analogue Scale

a.u.= arbitrary units

5.1.3. Estudio 3. Metabolic power of female footballers in various small-sided games with different pitch surfaces and sizes

sports MDPI

Article

Metabolic Power of Female Footballers in Various Small-Sided Games with Different Pitch Surfaces and Sizes

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Academic Editor: Filipe Manuel Clemente
Received: 30 December 2016; Accepted: 13 April 2017; Published: 17 April 2017

Abstract: Small-sided-games (SSGs) seem to be a useful tool for replicating most types of scenarios found in sport competitions, but it is not that clear in female soccer. Game surface and pitch size seem to affect the intensity of SSGs, but no one has yet analysed the influence of these two variables together. The objective of this research was to analyse the metabolic power demands of various SSGs on possession play without goal-keepers, played on three different surfaces. Sixteen sub-elite female players performed three different four-a-side games (400 m^2, 600 m^2, and 800 m^2) on three different surfaces (ground [GR]; natural grass [NG]; and artificial turf [AT]), recording a total of 96 events. Metabolic variables were recorded through a global positioning system (GPS). The GR condition obtained the lowest outputs for all variables in all of the SSGs. Furthermore, NG resulted in higher outcomes than AT for Average Metabolic Power (SSG 400 [+0.65; $p = 0.019$]; SSG 600 [+0.70; $p = 0.04$]); and equivalent distance (SSG 400 [+33.0; $p = 0.02$]; SSG 600 [+36.53; $p = 0.04$]). Moreover, SSG 400 obtained lower results than SSG 600 and SSG 800 for both AT and NG. In conclusion, playing on GR reduces the metabolic power of SSGs, While NG seems to be the most suitable surface for attaining highest metabolic responses for sub-elite female players. On the other hand, too big a pitch size may not increase the metabolic demands of the game.

Keywords: artificial turf; four-a-side games; GPS; soccer; sports pavement

1. Introduction

While the physical performance of female footballers is still a growing area of research [1], there are now a number of studies that quantify the physical performance of females during matches [2–7]. Like male footballers, high-intensity actions in female football are considered the most relevant in performance in spite of their short duration, as they are most often actions in goal situations [7,8]. Nevertheless, high-intensity actions are related to an increase in metabolic demands [9], causing muscle break-down, oxidative stress, and both biochemical and hormonal variations as a result of the eccentric component of these actions [3,9,10].

To quantify the effect of high-intensity actions either in matches and training, several instruments like the Global Positioning System (GPS) are becoming popular [11–13]. Indeed, several studies have focussed on quantifying these actions in small-sided games (SSGs), as coaches have been using such games for years to replicate competition demands [14–16]. Nevertheless, to the authors' knowledge, only Gabbett and Mulvey [2] and Mara et al. [14] have focused their research on SSGs in the context of female footballers, suggesting that SSGs are a useful tool for replicating aerobic and movement patterns, but that they may not provide sufficient high-intensity or repeated sprint stimuli. Traditionally, researchers have used both speed actions and distances to assess the body load of both training and matches. However, nowadays some authors are recommending the use of metabolic power and energy costs to assess the intensity in football, as these variables also account for accelerations at high intensity [17–19].

According to Di Prampero et al. [20], and later Osngnach et al. [21], all accelerations performed on a flat surface are equivalent to running on a slope the gradient of which is established by this acceleration. Therefore, through GPS devices and other tracking instruments, it is possible to estimate the metabolic power of a task. In spite of the controversy concerning the use of GPS devices for this purpose [22], several authors have reported that high-speed actions seem to underestimate the real load of a task regarding metabolic power [18,19,21]. Indeed, Gaudino, Alberti, and Iaia [17] reported greater high-intensity distance runs at high metabolic load (>20 W/kg) than at high speed (>14.4 $km \cdot h^{-1}$) when they studied the intensity of different SSGs with goalkeepers. Moreover, this argument may be confirmed by the findings of Akenhead et al. [23], as they found that 18% of the total distance covered is due to accelerations or decelerations at intensities greater than 1 m^2/s. Therefore, it seems that coaches should use the metabolic variables to compile more accurate information on the demands of training [17,24].

Previous studies on SSGs demonstrated that external factors, such as the number of players or touches, the length of the game, the pitch size, and the game surface cause different physical and physiological responses, and therefore affect the duration and number of high-intensity actions [12,16,25–27]. However, there is still a lack of knowledge about how physiological responses can change when two or more of these variables are combined. Among all of these variables, several authors consider the game surface especially important, due to it being part of the interaction between player and pitch [13,28,29], as high-intensity responses are related to their mechanical properties [13,25], so that surfaces with lower damping capacities, such as sand, reduce high-intensity actions in SSGs [25]. However, these studies only assessed the high-intensity activities through the traditional way, not by providing information about the metabolic power variables. To the authors' knowledge, only Gaudino et al. [17] have investigated the metabolic power responses of footballers on different surfaces, but using a standardised test instead of SSGs. Nonetheless, their findings confirm that the metabolic demands of high-intensity games are also altered by the surface. On the other hand, pitch size is also considered a key factor by authors such as Fradua et al. [30], given that players' abilities to play soccer in small spaces is an essential element in this sport. The evidence from SSGs demonstrates that football players perform a higher number of high-intensity actions whenever the pitch size increases [11,31]. However, no authors have studied the influence of this variable in women footballers or its effect on metabolic responses.

To address the gap in the literature on the effect of two or more extrinsic factors on SSG performance, the current research aims to analyse the metabolic power demands of various SSGs on possession play without goal-keepers, played on three different surfaces. As players seem to change some technical and tactical parameters according to the surface they are playing on, and players' load is also affected [25,32], the intensity of SSGs with different pitch sizes may also be influenced by the game surface. Finally, we focused on possession because previous research suggests that this format increases the game intensity in comparison to SSGs with goalkeepers [17]. Therefore, the authors expect that the results of this study will help to provide relevant information for designing training based on the use of SSGs.

2. Methods

2.1. Participants

Based on a convenience sample approach, sixteen women belonging to a Spanish Second Division team took part in this study (19.56 ± 1.97 year; 57.74 ± 4.89 kg; 161.57 ± 5.83 cm; 24.93% ± 4.1%

body fat). They had previous experience playing and training on both natural grass and artificial turf (5.81 ± 0.75 year). They also played about four to five matches on the ground every season, although most of them were friendly fixtures during the pre-season. All participants played football three times per week with a weekly match. As a requirement to participate in the study, players had to present the medical certificate required to play football. They testified that they were not taking any medication during the study and were free of cardiopulmonary diseases.

Both coaches and footballers signed the informed consent form testifying that they understood the possible risks of this investigation. Furthermore, the methodology of this research was approved by the local Clinical Research Ethical Committee in accordance with the Declaration of Helsinki.

2.2. Experimental Design

Prior to starting the study, the footballers took part in a familiarisation session to become accustomed to the Global Positioning System (GPS; Spi Pro X, GPSports, Canberra, Australia) and gain experience with both the three SSG pitch sizes and the three surfaces included in the study. The main part of this research was divided into three consecutive weeks (2 days per week) so that footballers played three four-a-side games with different pitch sizes (Table 1) on three different surfaces: ground (GR; uniform and dry dirt), natural grass (NG; height of grass: 25 mm), and artificial turf (AT; fibre: monofilament of polyethylene of 60 mm in height; infill: 20 $kg{\cdot}m^{-2}$ of styrene-butadiene rubber (SBR) and quartz sand with 0.3–0.8 granulometry). To increase the reliability of data, players played each SSG on each surface twice, playing in a total 18 matches. Every test-day, participants played three SSGs, one per surface. The order of both the pitch sizes and the surfaces were established randomly for each test-day, ultimately recording a total of 96 events. To guarantee a full recovery between SSGs, 10-min periods of active rest were performed by footballers (ball pass exercises at low intensity together with three incremental sprints at the end of the recovery time). Tests were performed during regular training times (19:00–21:00) to avoid the influence of circadian rhythms and were conducted under similar weather conditions (dry, 20–24.5 °C and 22%–30% relative humidity). Finally, the mechanical properties of the surfaces were not measured in this study. However, an independent expert on sports ground surfaces stated that the three surfaces were in good condition for playing football.

Table 1. Small-sided game (SSG) characteristics.

Name of SSG *	Game Objective	Game Duration (min)	Pitch Area (m)	Pitch Total Area (m^2)	Pitch Ratio Per Player (m^2)
SSG 400	Possession game	4	20 × 20 m	400 m^2	50 m^2
SSG 600	without	4	24.5 × 24.5 m	600 m^2	75 m^2
SSG 800	goal-keepers	4	28.3 × 28.3 m	800 m^2	100 m^2

SSG: Small-Sided Game. * Footballers replayed each SSG in a non-consecutive test-day to increase data reliability.

2.3. Experimental Protocol

The participants agreed not to perform either vigorous or exhausting physical activity before each test. In addition, they used the same football boots (always rubber studs) and maintained the same eating habits. Both the SSGs and surfaces were established randomly.

The GPS devices were attached to players 15 min before the beginning of the tests. They used the same device during the whole investigation to guarantee the reliability of data. Contact with a minimum of eight satellites was established to guarantee the accuracy of data [17]. Subsequently, footballers carried out a standardised warm-up for 10 min and three sprints of 30 m at increasing intensity [13,29].

Four-a-side game: The coaches gathered the footballers in four teams based on their skill levels to guarantee equitable teams. Teams and matches were held the same during the investigation and coaches encouraged the players the entire time. To optimise the playing time, balls were replaced when they went outside the pitch. Contrary to previous research, the objective of all SSGs was possession without goal-keepers; therefore, neither goalkeepers nor goals were included in this study [11,25,31]. We included only SSGs with possession because they seem to increase the intensity of games in comparison to those with goal-keepers [17].

Metabolic power: The variables of metabolic power were calculated through the manufacturer software Team AMS (version 2016.7, GPSports, Canberra, Australia) following the methodology and equations used by Di Prampero et al. [20] and Osgnach et al. [21]. Thus, the GPS devices were used to register the Metabolic Load Absolute (KJ); Metabolic Load Relative (KJ/kg); the Average Metabolic Power (rate of energy consumed per second) (W/kg); High Metabolic Load Distance (total distance covered at 20 W/kg or more) (m); and the Equivalent Distance (maximum distance that the footballer could have run with the total energy consumed if she ran at constant speed) (m). Following the methodology of Gaudino et al. [17,33], the GPS devices recorded at 15 Hz (5 Hz GPS unit interpolated to 15 Hz) [34,35]. Moreover, this study used the same GPS model as in previous research to increase data reliability.

2.4. Data Analysis

Data were analysed through the statistical software SPSS v 20.0 (IBM, Armonk, NY, USA). The level of significance was established at $p < 0.05$. The results are presented as means and standard deviations (±SD). The verification of the normality and homogeneity of the variance was assumed by means of the Kolmogorov-Smirnov test and Levene's statistic. A two-way repeated measures linear mixed model (surface x pitch size) was used to compare results among SSGs, whereas the interactions were identified through Bonferroni post-hoc pairwise comparisons. Effect sizes (ES) were calculated and defined as follows: trivial <0.19; small, 0.2–0.49; medium 0.5–0.79; large >0.8 [36].

3. Results

Table 2 displays the results of the metabolic variables. Footballers obtained lower values on GR than NG in the three SSGs (SSG 400, SSG 600, and SSG 800) for all metabolic variables. Moreover, GR presented lower outputs than AT for all metabolic variables, but only in SSG 600 and SSG 800. The results also show higher outcomes on NG than AT for the variables of Metabolic Load Relative (SSG 400 [+0.16; p = 0.017; ES: 0.762; CI: 0.02–1.29]); Metabolic Power (SSG 400 [+0.65; p = 0.019; ES: 0.749; CI: 0.08–1.21]; SSG 600 [+0.70; p = 0.04; ES: 0.648; CI: 0.02–1.38]); and Equivalent Distance (SSG 400 [+33.0; p = 0.02; ES: 0.738; CI: 4.18–61.82]; SSG 600 [+36.53; p = 0.04; ES: 0.662; CI: 1.21–71.84]). On the other hand, SSG 400 obtained lower results than SSG 600 and SSG 800 for all metabolic variables related to metabolic power in both the AT and NG conditions.

Table 2. Metabolic Load Parameters on the three surfaces and the three SSG pitch sizes.

Metabolic Power's Variables	Natural Grass (NG) (*)			Artificial Turf (AT) (#)			Ground (GR) (†)		
	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)	SGG 400 (a)	SSG 600 (b)	SSG 800 (c)
Metabolic Load Relative (KJ/kg)	2.26 (0.19) †,#	2.57 (0.28) †,a	2.56 (0.29) †,a	2.10 (0.23)	2.40 (0.26) †,a	2.47 (0.21) †,a	2.04 (0.25)	2.17 (0.34)	2.30 (0.23) a
Average Metabolic Power (W/kg)	9.38 (0.82) †,#	10.67 (1.12) #,†,a	10.66 (1.21) †,a	8.73 (0.93)	9.97 (1.04) †,a	10.31 (0.87) †,a	8.48 (1.04)	9.02 (1.40)	9.59 (0.96) a
High Metabolic Load Distance (m)	65.39 (15.80) †	89.48 (26.72) †,a	99.14 (28.48) †,a	56.27 (15.07)	77.35 (25.00) †,a	88.94 (18.96) †,a	50.53 (19.48)	57.56 (32.56)	70.88 (17.00) a
Equivalent Distance (m)	484.82 (42.25) †,#	552.21 (57.63) #,†,a	551.89 (62.80) †,a	451.82 (47.22)	515.68 (54.26) †,a	532.94 (44.68) †,a	438.69 (54.11)	466.34 (72.57)	496.66 (49.26) a
Metabolic Load Absolute (KJ)	132.57 (19.40) †	148.95 (19.80) †,a	149.82 (19.77) †,a	121.44 (20.29)	138.86 (17.24) †,a	144.90 (17.97) a	115.28 (18.04)	124.61 (20.36)	134.77 (15.55) a

*,#,† Significant differences with the surface indicated ($p < 0.05$). a,b,c Significant differences with the size indicated ($p < 0.05$). NG = Natural Grass; AT = Artificial Turf; GR = Ground; SSG400 = small-sided game with 400 m^2 playing area; SSG 600 = small-sided game with 600 m^2 playing area; SSG 800 = small-sided game with 800 m^2 playing area.

4. Discussion

The main objective of this research was to analyse and determine the effect of altering both pitch size and the game surface on the metabolic power of sub-elite female footballers in SSGs using a four-a-side format. However, contrary to previous studies, the objective was focused on possession games [11,25,31] because this sort of SSG seems to result in higher intensity levels than those that include goal-keepers [17]. The main results show that metabolic load is influenced by both the game surface and the pitch size; thus, in line with Gaudino, Alberti, and Iaia [17], different SSG formats were shown to have effects on different performance indicators. However, the lower outcomes in Metabolic Load Relative and Average Metabolic Power in our study than those obtained by Gaudino et al. [17] suggest that SSGs in sub-elite female football are less intense than in elite male football; therefore, comparisons between studies should be done with caution. Moreover, it is important to be cautious when extrapolating these findings to another sort of SSG, as they may be different in other formats such as three-a-side or five-a-side.

The significant differences among surfaces indicate that the metabolic demands change according to the game surface characteristics, which is in line with the findings of Brito et al. [25], although they assessed high-intensity actions on turf, asphalt, and sand. Among the surfaces analysed in this study, GR seems to be the less recommended surface for high-intensity actions, as the energy costs—both relative (Metabolic Load Relative) and absolute (Metabolic Load Absolute)—to complete the SSGs played on GR were lower than on NG and AT. Moreover, players' work rate was lower on GR than on the other two surfaces, as the rates of energy expended per second (Average Metabolic Power) observed in the participants were also inferior on GR. These outcomes may be due to such a high rotational traction of GR affecting the players' stability [13,29], thereby causing a lower number of explosive actions [9,25]. On the other hand, the higher Metabolic Power and Equivalent Distance on NG than on AT, both for SSG 400 and SSG 600, suggest a higher rate of creatine phosphate breakdown and glycolysis on NG as a consequence of greater rates of anaerobic energy turnover [9,13,25], although no differences were found between AT and NG for SSG 800. These findings contradict the conclusions of previous studies in men, as they found that the newest artificial turf systems do not entail lower performance in linear sprint nor cause greater fatigue [37]. However, this may be due to different technical behaviour on both surfaces, since players perform a higher number of short passes and a lower rate of tackles on AT than on NG [32]. Nonetheless, the high variability existing in the mechanical properties of artificial turf systems makes further research necessary [29].

Previous research in men footballers concluded that bigger pitches improve the intensity of the game in male footballer so that, variables such as sprint rate, distance covered at high-intensity speed, workload or work-rest rate increase in SSGs with a higher pitch ratio per player [11,31]. The findings of our research are in line with those previous studies, as SSG 400 resulted in lower values in all metabolic variables in comparison to the other two bigger pitches. In addition, the lower rate of energy expended per second (Average Metabolic Power) for SSG 400 indicates a higher intermittent activity of players in this SSG [11]. Therefore, the higher effective playing time associated with bigger pitches could explain the lower values of Average Metabolic Power and the lower outcomes in metabolic demands of these situations [11]. On the other hand, it should be noted that a few studies with SSGs did not report this trend with increases in individual playing area [27]. In line with these other studies, this research found that metabolic responses stop to increase if the pitch size of the SSG is too big, as it is supported by the lack of differences between the SSG 600 and SSG 800 sub-elite female players. Therefore, similar muscle damage, oxidative stress, and biochemical and hormonal variations in female players [3] may be expected for either SSG 600 or SSG. These findings are important, as either technical or tactical behaviour of players seem to also be different according to the pitch size [27]. Thus, coaches should not overlook pitch size when they use it as a control variable for the intensity of the game, as there is no need to increase the pitch size in excess.

This research, therefore, will help coaches to design SSGs and training with greater accuracy, as both the game surface and pitch size seem to influence the high-intensity demand of one task.

Nonetheless, it is necessary to be cautious when interpreting these findings due to the short duration of the SSGs used in this study and the lack of previous investigations of SSGs and metabolic power in female footballers. Moreover, contrary to previous research, the objective of the SSGs used in this research was possession, which seems to result in higher intensity levels in comparison to SSGs that include goal-keepers [11,17,25,31]. Therefore, more investigations are required to establish the relationship between these two variables with the intensity of the game.

Finally, despite the increasing use of these variables in studies investigating football teams, some doubts have been cast about the reliability of GPS systems in measuring metabolic load [19,21,38]. Indeed, Buchheit et al. [22] found that data recorded through GPS systems considerably underestimate the energetic demands of a task, especially during rest phases. However, Coutts et al. [38] concluded that metabolic power variables may contribute to improving our understanding of the physical demands of collective sports. The main concern about using GPS devices for measuring the Metabolic Power variables is in regard to their reliability in measuring accelerations, decelerations, and high-speed actions accurately. For that reason, there is a need to exercise caution when interpreting the findings of this manuscript. Nevertheless, according to Osgnach et al. [39], GPS systems that record at 10Hz or more may be considered valid for measuring Metabolic Load, although there are other variables that can affect the quality of data.

5. Conclusions

This study focussed on possession games played by sub-elite women footballers. Nevertheless, the findings are in line with previous studies in men, as the game intensity levels of small-sided games were altered by both game surface and pitch size.

Regarding the game surface, outcomes of this work evidence that playing football on ground reduces the intensity of the tasks. Thus, coaches should avoid this surface for training when they want players to work at the highest intensity possible. The differences found between natural grass and artificial turf show higher metabolic demands than natural surfaces. Therefore, contrary to the findings in male football, higher game intensity on natural grass than on turf in sub-elite female football may be expected.

On the other hand, pitch size also influences the metabolic demands of small-sided games. Consequently, coaches should not overlook this variable when designing training drills, as women seem to play more intensely on bigger pitches. Nonetheless, the findings of this research evidence that metabolic responses stop increasing when the pitch size is too big. Therefore, whenever trainers use big pitches in small-sided games, they should aim to choose the size that better fits additional objectives, like improving players' tactical or technical skills.

Author Contributions: Jorge López-Fernández: study design, data collection, and manuscript writing. Javier Sánchez-Sánchez: statistical analysis, data interpretation, and manuscript revision. Leonor Gallardo: data collection and manuscript revision. Jorge García-Unanue: data collection, statistical analysis, and data interpretation.

Conflicts of Interest: The authors declare no conflict of interest.

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5.1.4. Estudio 4. Physiological and physical responses according to the game surface in a soccer simulation protocol

International Journal of Sports Physiology and performance Accepted (05-Dec-2017)

Physiological and physical responses according to the game surface in a soccer simulation protocol

Submission type: Original Investigation

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Preferred running Head: Artificial turf vs natural grass in a soccer protocol

Supporting Statement
This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Disclosure of interest:
Authors report no conflicts of interest to disclose

Abstract

Purpose: Recent studies have shown that soccer player's responses are similar on natural grass (NG) and artificial turf (AT), but they did not control the mechanical properties of these surfaces. This work aimed to analyse the influence of the game surface on amateur soccer player's physical and physiological responses using a soccer simulation protocol (SSP). **Methods**: Sixteen amateur players performed three bouts of the SSP on AT and NG. The mechanical properties of both surfaces were recorded. The order of surfaces was randomly established for each participant. Physiological responses of players were assessed before and after the six-repeated sprints test existing at the midpoint of each bout. Fatigue (% Best; % Diff) and general variables (total time; best time, mean time; maximum speed) for both the repeated sprint test and the agility tests (nonlinear actions at maximum speed) incorporated into the SSP were also analysed. **Results**: The two surfaces displayed different mechanical properties. Physical responses were found similar for both surfaces ($p>0.05$) before and after the repeated sprint test. There were no surface differences in sprint times or fatigue variables for the repeated sprint test ($p>0.05$). The agility test was faster on AT than on NG in bout 1 (average speed [+1.17 Km/h; $p=0.037$]; agility test cut time [-0.31 s; $p=0.027$] and best time [-0.52 s; $p=0.042$]). **Conclusions**: The differences in the mechanical properties of the two surfaces are not sufficient to cause differences in the physiological and physical responses of soccer players, although they may affect turns and cuts.

Keywords: Exercise Performance; Motion Analysis; Physical Performance; Sport; Training

Introduction

In recent years the third generation artificial turf (AT) systems have become an alternative to natural grass (NG) surfaces, mainly due to the standardisation of AT systems under the aegis of international bodies such as the Fédération Internationale de Football Association (FIFA) and the European Committee for Standardisation (CEN).[1-3] However, soccer players still consider AT more physically demanding than NG.[4,5] The latest comparative studies have shown that soccer players' fatigue, sprint times, and recovery are similar on the two surfaces.[6-8] Nevertheless, these findings cannot be widespread due to the wide variation in the mechanical properties of AT systems reported by previous works.[9-11] Thus, soccer players seem to run faster and perform more high-intensity actions on harder surfaces whilst the softer systems are associated with a greater physiological responses.[3,11]

Most studies have used standardised tests to compare surfaces because they have lower variance than soccer matches. This is true of the soccer simulation protocol (SSP) and the soccer-specific aerobic field test (SAFT90) which attempt to replicate the physiological and physical demands of real matches.[7,12] Authors such as Stone et al.[8] recommend the SSP because it includes a repeated sprint test halfway through each of the six bouts and nonlinear sprint actions at maximum speed (agility tests). The latest comparative studies, suggest that players' performance is similar on AT and NG,[6-8] although it has been reported slight surface-interaction in the recovery time after the SAFT90 and better sprint performance on AT during the SSP.[7,8] Hughes et al. found that players' sprint times and agility performance were similar on NG and AT,[6] whereas Stone et al. reported that creatine kinase levels in blood and perception of muscle soreness were similar for the two surfaces immediately after the SSP and, 24 and 48 hours post-test.[8] These studies also found that physiological responses and blood lactate accumulation were similar for NG and AT.[6,8] Together, these studies suggest that although there may be some surface-specific effects, one would expect players' responses to be similar on both types of surfaces.[6-8]

To the best of our knowledge, the studies that have the SSP to compare AT and NG have only analysed the mean times for each series of sprints and have not looked at the times for individual sprints.[6,8] Moreover, these studies did not analyse the effects of the repeated sprint test on soccer players' physiological responses or performance in the second half of each bout. It is possible therefore that there are interactions (surface x time) with respect to these SSP variables during the SSP. For these reasons, the aim of this research was to analyse the influence of the game surface on amateur soccer player's physical and physiological responses using the SSP. Previous studies used AT systems that complied with FIFA standards,[6,8] but they did not report the mechanical properties of the surfaces used despite that the mechanical properties of AT systems are highly variable. Consequently, we expect to add further information about how the players' responses are influenced by the game surface. On the other hand, several authors have reported a high diversity in the mechanical properties of AT systems.[3,11] For that reason, we hypothesised that the mechanical differences between NG and AT would affect the physical patterns of players during the SSP, but not their physiological responses.

Methods

Subjects

Sixteen amateur soccer players (22.17 ± 3.43 years; 177.12 ± 5.24 cm; 69.16 ± 4.55 kg) with more than 10 years of experience of playing soccer (13.57 ± 1.85 years) were recruited for this study. All volunteers presented the medical examination required to play soccer and they did not reported any cardiopulmonary pathology or other diseases. They did not take any medication during the study. All players were informed about the possible risks of participating in this study, and provided written informed consent before the beginning of the study. In accordance with the latest version of the Helsinki Declaration, this research was approved by the ethics committee of Toledo.

Design

A NG surface (25 mm high; certified as high quality by two independent gardeners) and an AT system (fibre: monofilament of polyethene of 60 mm of height; infill: 20 kg/m^2 of Styrene-Butadiene Rubber and quartz sand with 0.3–0.8 mm of granulometry) were used in this study. The mechanical properties of both surfaces were assessed as in previous studies.[10,11] Shock absorption (%), vertical deformation (mm), and energy return (%) were recorded using an Advanced Artificial Athlete (Labosport, Le Mans, France), the FIFA-certified equipment for assessing these variables.[2] Each variable was measured three times in each of five zones on each surface (Figure 1), but only the last two measurements from each zone were used in the statistical analysis.

*** Figure 1 near here***

Prior to the main test players completed a yo-yo test of intermittent recovery level 1.[13] Maximum heart rate (HR_{max}) was recorded from a heart rate monitor attached to the volunteers' chest (Polar Team System, Kempele, Finland).[11] Players also completed a familiarisation session to allow them to get used to the procedures and equipment used in this research. In the main test players completed three bouts of the SSP on the NG surface and three further bouts on the AT system, [8,12] because previous authors have demonstrated that 45 min of playing time is sufficient to detect differences between surfaces.[11,14] Test order was randomised so that eight players did their first trial on AT and the remaining eight on NG. The two trials were separated by a 72-h recovery period.

All tests were performed at training time to avoid the results being affected by circadian rhythm and in dry conditions (temperature: 18 Cº ± 3ºC; relative humidity: 25% ± 5%; wind speed: 0.0-0.5 m/s). Players agreed to keep a resting time of rest for 72 h before each trial (no vigorous or exhausting activity) and to maintain the same diet throughout the test period. Finally, all volunteers agreed to use the same type of footwear on both surfaces. The selected shoes had rubber cleats of a non-aggressive design in order to minimise traction effects (Munich Mundial® multiground, 25 cylindric rubber cleats).

Methodology

Players performed a standardised warm-up consisting of 5 min of continuous running, 5 min of articulation mobility and three sprints at increasing intensity before completing the SSP.

Soccer-simulation protocol (SSP). Players completed the first half of the SSP, which consists of three 16-min bouts with 3 min of rest between bouts[8,12]. Each bout consists of eight cycles and one repeated sprint test (6 × 15 m sprints departing every 18 s) block between cycles 4 and 5 (Figure 2) structured as follows:

- 3 × 20 m at a walking pace of 1.43 m s−1
- 1 × sprint-agility run at maximal intensity (20 s for sprint and recovery)
- 3 × 20 m at a running speed of 2.5 m s−1
- 3 × 20 m at a running speed of 4.0 m s−1

*** Figure 2 near here***

Physiological indicators and speed performance of SSP. The maximum speed and average speed (km/h) in each bout of the SSP were recorded through a global positioning device (GPS; HPU, GPSports, Australia). Using individual HR_{max} as a reference, we also calculated the peak heart rate (HR_{peak}) and mean heart rate (HR_{mean}) in both beats per minute (bpm) and as a percentage of the maximum heart rate ($\%HR_{max}$). The percentage of total time that players spent at over 85% of their HR_{max} was recorded as HR-high intensity (%). These values were recorded for the three bouts, dividing them as pre-values (the four cycles before the repeated sprint test) and post-values (the four cycles after the repeated sprint test).

Repeated sprint test variables. Maximum speed in each sprint of the rerepeated sprint test was measured through a GPS (HPU, GPSports, Australia) attached to the back of the players 15 min before the beginning of each test. The total time that participants took to complete each sprint of 15 m was recorded through two pairs of photocells (Witty, Microgate, Bolzano, Italy). The best time, the average time, the total time, the percentage decrease (% Best) and the difference between the best and the worst sprint of each repeated sprint test (% Diff) were also recorded.

Agility test variables. The total time (s) for each agility test was recorded through the two pairs of photocells, the total time (s) of each agility test was registered. We also recorded the average time (s) for the three sections of the agility test (S-AR 15 m sprint time [first 15 m of the agility test]; S-AR turn time [next 10 m of the agility test, includes the 180º turn]; and S-AR cut time [last 17 m of the agility test, includes a 73º change of direction]) and the average speed (km/h) of each agility test. The GPS devices were also used to record the maximum speed achieve on each agility test. Finally, the best time, average time, total time, percentage decrease (% Best) and the difference between the best and the worst agility test (% Diff) were also calculated for the pre- and post-sprint phases of each bout.

Statistical analysis

The statistical analysis was carried out through the SPSS v. 21.0 was used to carry out the statistical analyses. Results are presented as mean ± standard deviation. The normality of the distribution of variables and homogeneity of variance was checked using the Kolmogorov–Smirnov test and Levene's statistic. A two-way (surface x bout) ANOVA was used to assess differences between surfaces and bouts for all variables. Interactions were assessed using post hoc pairwise Bonferroni tests. The magnitude of changes was quantified by calculating 95% confidence intervals (CIs). Effect sizes (ES) were also calculated and defined as follows: null: <0.3; mild: 0.3–0.5; moderate: 0.5–0.7; strong: 0.7–0.9; and very strong: 0.9–1.0.[15] The level of significance was set at $p < 0.05$.

Results

Mechanical properties of surfaces

The NG surface was softer (higher shock absorption) (+6.10 %; p=0.07; ES: 0.54; CI: 1.81–10.40) values, whereas the AT system displayed greater vertical deformation (+1.48 mm; p<0.01; ES: 2.07; CI: 0.94–2.02) and was more rigid (greater energy return) (+14.62 %; p<0.01; ES: 3.25; CI: 10.85–18.38).

Physiological indicators and speed performance of SSP

The physiological responses and maximum and average speeds of players on both surfaces are displayed in Table 1. Data are divided into pre- and post-sprints values. Mean heart rate was higher (as $\%HR_{max}$) in the post-sprint phase (after the repeated sprint test) on both surfaces: AT [bout 1 (+7.59 $\%HR_{max}$; p<0.001; ES: 1.465; CI: 4.13–11.05); bout 2 (+4.11 $\%HR_{max}$; p=0.017; ES: 0.849; CI: 0.75–7.46); bout 3 (+8.24 $\%HR_{max}$; p=0.036; ES: 0.786; CI: 0.30–8.71)] and NG [bout 1 (+8.24 $\%HR_{max}$; p<0.001; ES: 1.946; CI: 4.76–11.69); bout 2 (+8.24 $\%HR_{max}$; p<0.001; ES: 1.328; CI: 4.76–11.69); bout 3 (+4.25 $\%HR_{max}$; p=0.048; ES: 0.967; CI: 0.44–8.46)]. Also, on NG some significant differences in HR_{mean} among bouts were found before the repeated sprint test (bout 3>1; +11.9 b.p.m.; p=0.006; ES: 1.434; CI: 0.77–43.76).

*** Table 1 near here***

The total time for the six sprints in the repeated sprint test was similar for both surfaces and in all bouts (Table 2). There were also no differences (p>0.05) between bouts or surfaces for the variables total time, best time, meantime, maximum speed, % Best and % Diff for the repeated sprint tests (Figure 3).

*** Table 2 near here***

*** Figure 3 near here***

Table 3 presents all results pertaining to the agility test. In pre-sprint phase (before the repeated sprint test) of bout 1, players presented greater time on NG than AT for the agility test 2 (+0.60 s; p=0.018; ES: 1.034; CI: 0.11–1.10), S-AR turn time (+0.31 s; p=0.027; ES: 1.016; CI: 0.04–0.58), and best time (+0.52 s; p=0.042; ES: 0.867; CI: 0.02–1.02). Moreover, the average speed of the agility test in bout 1 during the pre-sprint phase was higher on AT than NG (+1.17 Km/h; p=0.037; ES: 0.807; CI: 0.07–2.26).

*** Table 3 near here***

Discussion

The use the SSP to assess the influence of the playing surface on players' responses is not new,[6,8] but previous studies did not assess the mechanical properties of the surfaces or analysed this influence on each component of the SSP.
This research found that the fatigue response in the second half of each bout and the time for the repeated sprint tests were similar on AT and NG. Although most of the agility test variables were similar on the two surfaces, times were quicker and speeds higher on AT in some components of the agility test. Many of the previous studies used AT systems that met FIFA standards so it is likely that these surfaces were of higher quality than the one used in this study which did not meet this standard for shock absorption.[6,8] Sánchez-Sánchez et al. have reported that players run faster and display lower physiological responses on more rigid AT systems (systems that offer less shock absorption).[3,11] Therefore, AT systems cannot be treated as a homogeneous group.[10] The differences among AT systems are evident from published values for shock absorption (31.45% ± 6.24 to 70.30% ± 61.47),[9,10] vertical deformation (3.43 mm ± 0.43 to 7.34 mm ± 60.43) [10,11] and energy return (32.66% ± 3.17 to 50.50% ± 2.19).[11,16]

Analysis of the physiological load on players before and after each repeated sprint test showed similar responses to those obtained in matches and small-sided games: HR_{mean} over 80% of HR_{max} and HR_{peak} over 90% of HR_{max}.[11,14] However, the increase in HR_{mean} after the repeated sprint test suggests that players experienced greater energy and physiological demands in the second half of each bout.[11,14,17] On the other hand, the lack of surface difference in either before or after the repeated sprint test indicates that playing soccer on AT entails similar physiological effects and internal load to playing on NG.[6] It is remarkable that on NG players presented a greater increase in HR_{mean} and HR high intensity (total time over 85% of HR_{max}) between bout 1 and the other bouts; yet no differences between surfaces were found. These results suggest that the physiological activation of soccer players is slightly influenced by the surface. However, the general lack of differences between surfaces indicates that these alterations are probably due to the players' running technique or prior adaptation to each surface.[18] A previous study of different AT systems reported differences of up to 20% in shock absorption among artificial turf systems, finding that HR_{peak} is higher on those systems with greater damping capacity (greater shock absorption).[11] This suggests that the 6.10% difference between the shock absorption of the two surfaces used in this study was probably not high enough to affect player's physiological responses. The lack of differences between AT and NG with respect to HR_{mean} and HR_{peak} in this and previous studies suggests that both surfaces elicit similar physiological responses,[6,8] although perceived effort may be higher on AT than on NG.[4] Nevertheless, the variability of AT systems together with the low shock absorption of the AT system used in this study means that caution must be exercised in comparing our findings with those of others.[11]

Several studies have found that sprint times are slower on surfaces with higher shock absorption and lower energy return,[3,11,14] probably due to lower surface contact times.[19] On this basis, one would expect to see some differences in the sprint times between the surfaces used in this study as the AT system had lower shock absorption than the NG surface; however, in line with other studies, no such differences were found.[6,8,20] In our study, the AT system was only 6.10% harder than the NG surface, whilst Sánchez-

Sánchez et al. reported differences of up to 21.76% in shock absorption between the softer AT system and the harder one.[3] Thus, players' performance in linear sprints appears to be similar on AT and NG, [6,20] despite the differences in their mechanical properties. There were no surface difference in the fatigue variables for the repeated sprint test (% Best and % Diff) and the general variables for the repeated sprint test (total time, best time, mean time and maximum speed). Although soccer players may perceive running to be more effortful on AT than on NG,[4] the findings of this study suggest that AT systems are not more demanding in this sense. We conclude that the differences in the mechanical properties between of AT and NG surfaces were not high enough to cause differences in the players' physical responses.[11,14] It also indicates that dependence on creatine phosphate is similar in these two surfaces,[11,14] as other studies that included surfaces with higher shock absorption, such as sand, did find differences in energy costs among surfaces.[21] Nonetheless, one must consider that our findings can be influenced by the lower capacity of the AT system selected for this study.

The main finding of this research is that there are some differences in agility performance on NG and AT, despite the general lack of difference in physical and physiological responses. These findings may reflect differences in the biomechanics of players in turning cutting movements probably due to lower muscle-sinew efficiency on NG.[8,19,22] It appears likely that the differences between surfaces with respect to shock absorption and energy return were not high enough to cause differences in physiological responses, although they were sufficient to affect turning performance.[9,11] It is probable that the two surfaces also have different rotational traction capacity, but we did not measure this. Previous research suggest that rotational traction capacity and energy return are the most important mechanical determinants of performance in sprints including turns,[3,11] so both these variables should be measured in future research. Unlike Hughes et al.,[6] who reported higher performance in 180º turns on NG than on AT, but in line with Gains et al.,[20] this research found that peak turns were faster on AT. This suggests that players' contact time in turns is lower when they run on a synthetic surface.[3,8,19] This study suggests that performance of actions requiring high agility will be better on AT systems than on NG, provided that the AT surfaces offer a higher energy return.[11] However, as the differences in agility only occurred in the first bout of the SSP, it is possible that the surface effect are too weak to be taken into account by coaches. Finally, another important finding of this work is that the increased physiological activation observed after the repeated sprint test did not affect performance on the agility test and linear sprints. This indicates that the agility test imposed similar external load before and after the repeated sprint test.[17]

Practical Applications

Our findings on in linear and non-linear sprints are consistent with earlier research in which the mechanical properties of the test surfaces were not assessed. [6-8,20] The study provides clear evidence that the differences in shock absorption and energy return between AT and NG may not be high enough to affect linear sprint times or the physiological response to repeated linear sprints, but may be sufficient to affect high-intensity turning and cutting movements. However, these differences in turning and cutting performance may not be great enough to be taken into account in training or matches. For that reason, more research that analyses the mechanical properties of the surfaces are required. [11,23]

An AT system with a low shock absorption was used in this study and so our findings cannot be generalised to other AT systems with greater shock absorption. We consider that the mechanical properties of a surface are more important factors in sporting performance than its category (artificial or natural turf). The findings of this research may have been influenced by the nature of the sample which was made up of amateur players who will have been less able to perform the repetitive sprint tests and the agility tests at high speeds than professional players. In addition our, volunteers only completed three SSP bouts instead of the six bouts that are standard for this test.[12] On the other hand, the protocol used in this study is not affected by surface differences in game characteristics existing in the real matches (i.e. fewer sliding tackles and more short passes on AT).[4]

Conclusion

There may be small differences in agility performance on AT and NG even when there are no surface-related differences in other physical or physiological variables. We only observed such difference in the first SSP bout, so they may not be important enough to warrant consideration by coaches. These findings suggest that the mechanical properties of sports surfaces are more important than their category and so future studies of surfaces should include information about the mechanical properties of the sports surfaces.

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Figures

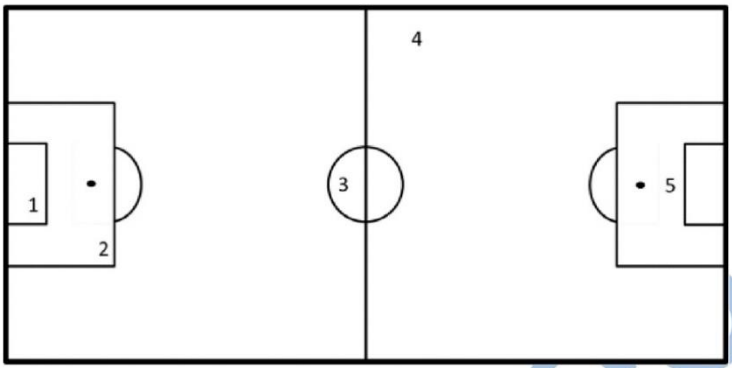

Figure 1. Zones to assess the sport surfaces

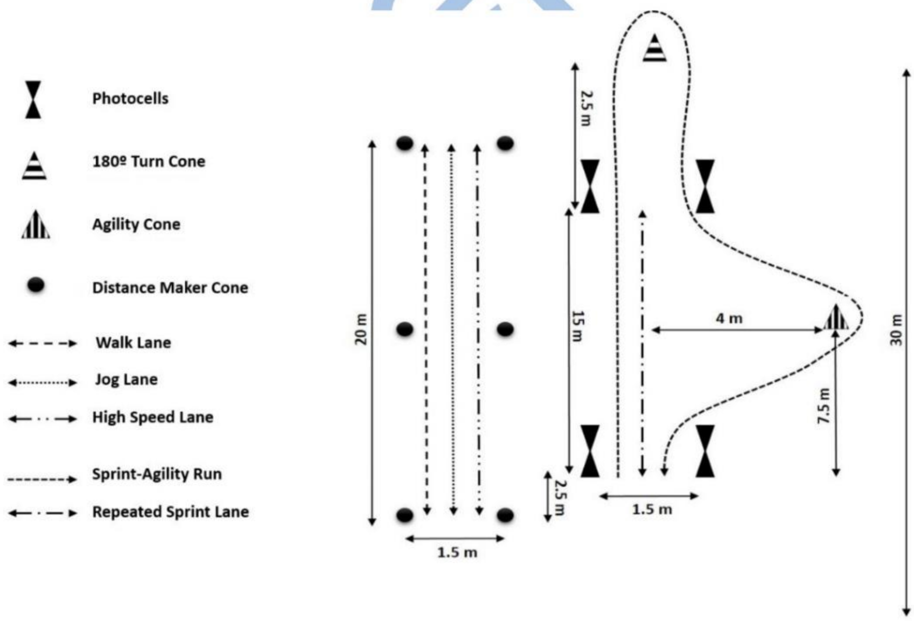

Figure 2. Soccer-simulation protocol (SSP)

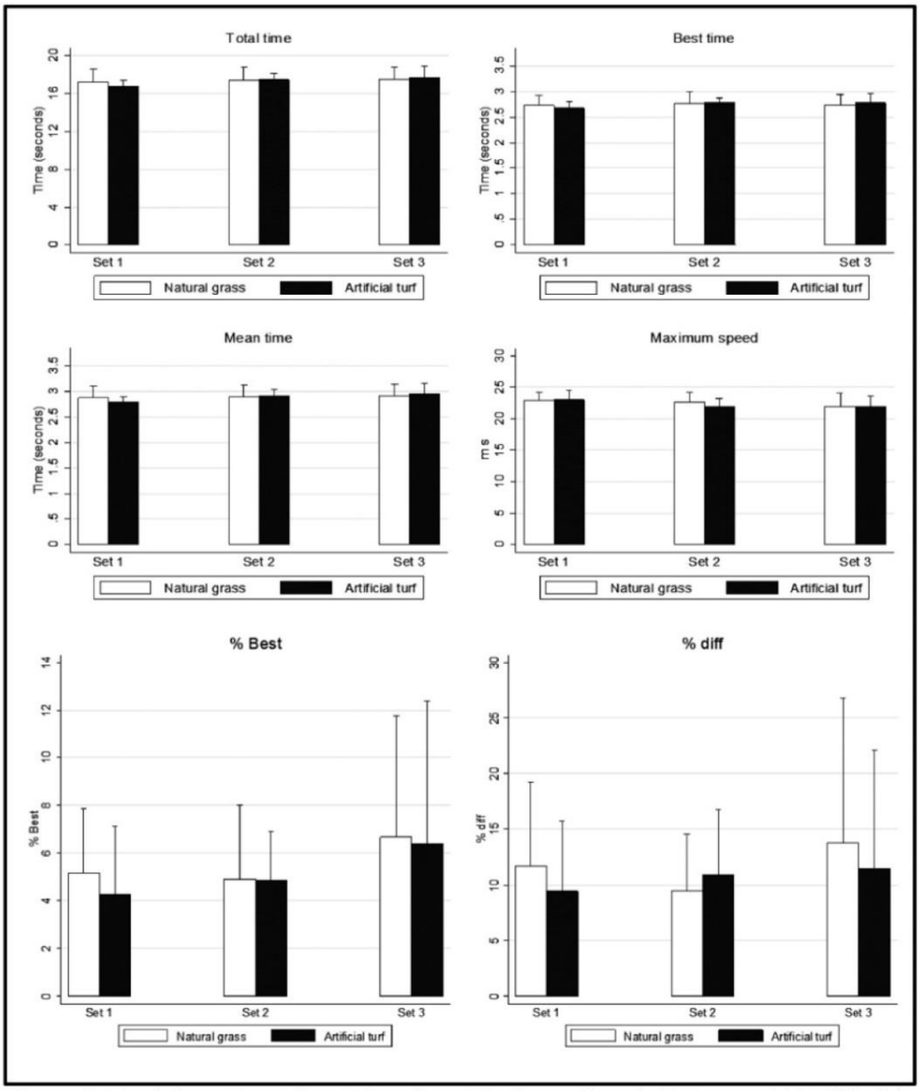

Figure 3. Total time, Best Time, Meantime, Maximum Speed, % Best and % Diff of the repeated sprint test among bouts and surfaces

Tables

Table 1. Physiological indicators and speed performance of SSP among bouts before and after the RS and between surfaces

Variable	Bout	Artificial Turf: Before the repeated sprint	Artificial Turf: After the repeated sprint	Natural Grass: Before the repeated sprint	Natural Grass: After the repeated sprint
V max (Km/h) of the S-AR	1	25.03 ± 1.71	24.44 ± 1.20	24.34 ± 1.50	24.16 ± 1.69
	2	24.31 ± 1.42	24.00 ± 1.47	24.07 ± 1.82	23.93 ± 1.35
	3	23.63 ± 1.47	24.15 ± 1.23	23.75 ± 1.82	24.01 ± 1.45
V mean (Km/h) of the S-AR	1	8.23 ± 0.40	8.10 ± 0.32	8.27 ± 0.36	8.24 ± 0.35
	2	8.09 ± 0.38	8.02 ± 0.32	8.19 ± 0.36	8.13 ± 0.36
	3	7.98 ± 0.32	8.06 ± 0.32	8.16 ± 0.43	8.13 ± 0.39
HR peak (b.p.m.)	1	184.07 ± 8.92	187.47 ± 8.50	179.73 ± 8.66	184.53 ± 8.43
	2	184.80 ± 9.17	186.07 ± 9.74	182.73 ± 9.23	185.73 ± 8.71
	3	183.08 ± 11.26	187.58 ± 11.83	184.00 ± 8.63	186.17 ± 8.52
HR peak (% HRmax)	1	93.13 ± 3.62	94.85 ± 3.46	90.96 ± 4.13	93.38 ± 4.01
	2	93.50 ± 3.96	94.15 ± 4.39	92.47 ± 4.38	93.99 ± 4.15
	3	92.52 ± 5.10	94.80 ± 5.49	93.00 ± 4.08	94.10 ± 3.99
HR mean (b.p.m.)	1	159.30 ± 12.59	174.28 ± 11.31*	155.87 ± 9.42	172.12 ± 9.12*
	2	167.48 ± 11.25	175.57 ± 10.78*	164.17 ± 9.30	175.50 ± 9.39*
	3	165.47 ± 12.35	174.36 ± 12.58	167.77 ± 8.94¥	176.17 ± 10.29
HR mean (% HRmax)	1	80.56 ± 5.48	88.15 ± 4.88*	78.86 ± 4.29	87.09 ± 4.17*
	2	84.71 ± 4.91	88.82 ± 4.77*	83.07 ± 4.34	88.80 ± 4.29*
	3	83.61 ± 5.59	88.11 ± 5.86*	84.79 ± 3.98¥	89.04 ± 4.81*
HR high-intensity (% of Total Time)	1	48.31 ± 26.87	75.81 ± 26.41*	36.68 ± 23.01	67.77 ± 27.01*
	2	62.76 ± 26.42	77.66 ± 31.95	52.08 ± 31.18	74.34 ± 27.61*
	3	57.36 ± 32.72	71.29 ± 35.61	60.98 ± 28.21	75.29 ± 28.58

* Significant differences ($p<0.05$) pre–post for both artificial turf and natural grass
\# Significant differences ($p<0.05$) between surfaces for both pre and post
¥ Significant differences ($p<0.05$) among bouts for both pre and post
V: Speed; HR: Heart rate
High intensity = % of total time over 85% of HR max.

Table 2. Total time of each sprint among bouts and between surfaces

Variable	Bout	Artificial Turf	Natural Grass
Sprint 1 (s)	1	2.82 ± 0.21	2.89 ± 0.26
	2	2.90 ± 0.15	2.91 ± 0.19
	3	2.93 ± 0.18	2.92 ± 0.24
Sprint 2 (s)	1	2.79 ± 0.13	2.92 ± 0.33
	2	2.98 ± 0.23	2.94 ± 0.25
	3	2.95 ± 0.21	2.93 ± 0.26
Sprint 3 (s)	1	2.83 ± 0.15	2.86 ± 0.26
	2	2.95 ± 0.17	2.95 ± 0.28
	3	3.01 ± 0.24	2.87 ± 0.25
Sprint 4 (s)	1	2.78 ± 0.10	2.90 ± 0.24
	2	2.94 ± 0.19	2.89 ± 0.24
	3	2.94 ± 0.25	2.92 ± 0.28
Sprint 5 (s)	1	2.77 ± 0.13	2.85 ± 0.24
	2	2.85 ± 0.10	2.88 ± 0.26
	3	2.99 ± 0.31	3.03 ± 0.37
Sprint 6 (s)	1	2.78 ± 0.14	2.81 ± 0.24
	2	2.88 ± 0.12	2.86 ± 0.25
	3	2.88 ± 0.20	2.86 ± 0.24

* Significant differences ($p<0.05$) among bouts; # Significant differences ($p<0.05$) among surfaces
¥ Significant differences ($p<0.05$) among sprints

Table 3. Agility test variables among bouts and between surfaces and pre–post

Variable	Bout	Artificial Turf: Before the repeated sprint	Artificial Turf: After the repeated sprint	Natural Grass: Before the repeated sprint	Natural Grass: After the repeated sprint
Time					
Agility test 1 (s)	1	9.20 ± 0.86	9.14 ± 0.71	9.60 ± 0.67	9.39 ± 0.70
	2	9.29 ± 0.67	9.30 ± 0.71	9.58 ± 0.90	9.60 ± 0.71
	3	9.45 ± 0.83	9.22 ± 0.73	9.54 ± 0.73	9.53 ± 0.52
Agility test 2 (s)	1	9.01 ± 0.61	9.27 ± 0.73	9.61 ± 0.55#	9.55 ± 0.62
	2	9.25 ± 0.72	9.37 ± 0.76	9.52 ± 0.86	9.58 ± 0.65
	3	9.40 ± 0.91	9.52 ± 0.89	9.68 ± 0.85	9.69 ± 0.78
Agility test 3 (s)	1	8.99 ± 0.75	9.35 ± 0.80	9.47 ± 0.62	9.43 ± 0.62
	2	9.22 ± 0.70	9.34 ± 0.86	9.50 ± 0.80	9.51 ± 0.58
	3	9.47 ± 1.07	9.41 ± 1.02	9.61 ± 0.87	9.58 ± 0.78
Agility test 4 (s)	1	9.03 ± 0.73	9.25 ± 0.66	9.51 ± 0.74	9.50 ± 0.73
	2	9.22 ± 0.68	9.41 ± 0.86	9.62 ± 0.78	9.65 ± 0.81
	3	9.41 ± 1.01	9.19 ± 0.71	9.78 ± 0.64	9.50 ± 0.73
S-AR 15 m Sprint Time (s)	1	2.76 ± 0.24	2.80 ± 0.14	2.92 ± 0.47	2.81 ± 0.21
	2	2.81 ± 0.12	2.95 ± 0.47	2.82 ± 0.28	2.80 ± 0.20
	3	2.84 ± 0.15	2.82 ± 0.12	2.85 ± 0.25	2.77 ± 0.17
S-AR Turn Time (s)	1	3.46 ± 0.40	3.56 ± 0.47	3.77 ± 0.21#	3.73 ± 0.20
	2	3.55 ± 0.45	3.59 ± 0.49	3.75 ± 0.23	3.76 ± 0.21
	3	3.58 ± 0.58	3.54 ± 0.54	3.76 ± 0.23	3.76 ± 0.16
S-AR Cut Time (s)	1	2.86 ± 0.25	2.89 ± 0.23	3.05 ± 0.49	3.50 ± 2.21
	2	3.01 ± 0.53	2.95 ± 0.28	3.04 ± 0.44	3.02 ± 0.30
	3	3.02 ± 0.29	2.97 ± 0.23	3.05 ± 0.33	3.03 ± 0.36
Speed					
Maximum Speed (Km/h)	1	24.36 ± 1.59	23.62 ± 1.18	23.75 ± 1.65	23.22 ± 2.49
	2	23.57 ± 1.25	22.98 ± 2.00	23.30 ± 2.06	23.08 ± 1.66
	3	22.97 ± 1.56	23.26 ± 1.40	23.10 ± 1.80	23.28 ± 1.62
Average Speed (Km/h)	1	18.80 ± 1.45#	18.40 ± 1.41	17.63 ± 1.45	17.96 ± 1.23
	2	18.40 ± 1.34	18.21 ± 1.47	17.75 ± 1.58	17.74 ± 1.21
	3	18.11 ± 1.80	18.26 ± 1.60	17.64 ± 1.35	17.40 ± 2.10
Fatigue					
Best Time (s)	1	8.79 ± 0.58	9.04 ± 0.72	9.31 ± 0.62#	9.22 ± 0.61
	2	9.04 ± 0.64	9.16 ± 0.70	9.34 ± 0.78	9.36 ± 0.56
	3	9.21 ± 0.84	9.04 ± 0.71	9.39 ± 0.65	9.34 ± 0.63
Total Time (s)	1	36.22 ± 2.79	37.01 ± 2.82	38.19 ± 2.44	37.87 ± 2.52
	2	36.97 ± 2.66	37.42 ± 3.10	38.23 ± 3.25	38.34 ± 2.61
	3	37.73 ± 3.75	37.34 ± 3.21	38.60 ± 2.96	38.30 ± 2.73
% Best	1	2.93 ± 1.98	2.41 ± 1.11	2.54 ± 1.52	2.71 ± 1.69

	2	2.23 ± 1.30	2.08 ± 1.07	2.36 ± 1.03	2.33 ± 2.09
	3	2.33 ± 1.38	3.21 ± 1.78	2.80 ± 2.49	2.47 ± 1.79
% Diff	1	5.88 ± 4.39	4.73 ± 2.14	5.34 ± 3.62	5.50 ± 3.06
	2	4.87 ± 2.97	4.72 ± 2.53	4.76 ± 2.35	4.63 ± 3.84
	3	4.90 ± 2.61	6.70 ± 3.56	5.60 ± 4.00	4.75 ± 3.05

* Significant differences ($p<0.05$) pre–post for both artificial turf and natural grass
# Significant differences (p<0.05) between surfaces for both pre and post
¥ Significant differences (p<0.05) among bouts for both pre–post and surfaces
S-AR 15 m sprint time: time in first stretch of the agility test; S-AR turn time: time in second stretch of the agility test; S-AR cut time: time in last stretch of the agility test

5.1.5. Estudio 5. Neuromuscular responses and physiological patterns during a soccer simulation protocol

J Sports Med Phys Fitness. 2017 Sep 22. doi: 10.23736/S0022-4707.17.07768-4.

Neuromuscular responses and physiological patterns during a soccer simulation protocol. Artificial turf versus natural grass

Running tittle: Players' responses on various game surfaces

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Supporting Statement

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Conflict of interest

Authors state no conflicts of interest to disclose

J Sports Med Phys Fitness. 2017 Sep 22. doi: 10.23736/S0022-4707.17.07768-4.

Abstract

BACKGROUND: Latest studies suggest similar performance of soccer players either on artificial turf (AT) or natural grass (NG). However, it is not clear if their muscular and physiological responses are also similar on both surfaces. This research aims to assess the influence of game surface on physiological patterns and neuromuscular responses of soccer players during a soccer simulation protocol (SSP) that incorporates repeated sprints and nonlinear actions at maximum speed.

METHODS: Sixteen amateur soccer players completed three bouts of the SSP on both AT and NG. The mechanical behaviour of both surfaces was recorded and the order was randomly established for each player. The physiological responses were measured during the SSP. A contra-movement jump and a tensiomyography analysis of the rectus femoris (RF) and biceps femoris (BF) were assessed right before and right after the SSP.

RESULTS: Both surfaces presented different mechanical properties. No differences among either surfaces or bouts were found for heart rate (HR) peak and HR mean ($p > 0.05$). While the half-relaxation time of the RF on NG decreased after the SSP (right-leg: -44.430 ms; $p = 0.049$; left-leg: -52.131 ms; $p = 0.008$), the sustain time of the BF decreased after the SSP on AT (right-leg: +64.868 ms; $p = 0.007$; left-leg: +87.564 ms; $p < 0.001$). No differences between surfaces were found for the contra-movement jump.

CONCLUSION: The mechanical behaviour of both surfaces does not differ enough to cause different physiological and neuromuscular responses. Playing on AT should cause similar neuromuscular responses to NG.

Keywords: Fatigue; Football; Muscles

J Sports Med Phys Fitness. 2017 Sep 22. doi: 10.23736/S0022-4707.17.07768-4.

1. Introduction

The quality of third generation artificial turf systems has increased in the last few years. This surface offers similar mechanical behaviour to natural grass surfaces so that the Fédération Internationale de Football Association (FIFA) has accepted them for playing soccer.[1, 2] Even, international tournaments like the FIFA Women's World Cup (Canada 2015) was played on artificial turf.[3] Nevertheless, the high diversity in the mechanical properties of artificial turf systems reported by previous studies,[1, 4] suggests that not all of them are suitable for playing soccer.[1, 5, 6] Therefore, to guarantee that the synthetic systems offer similar mechanical behaviour to natural grass surfaces, international organisations such as FIFA or the European Committee for Standardisation (CEN) recommend certifying them according to their standardisation programme.[1, 2, 5]

According to players' perceptions, artificial turf is associated with a greater risk of injury and greater perceived effort than natural grass.[7-9] However, the latest epidemiological studies contradict these perceptions by a reporting similar injury rate when playing soccer either on artificial turf or on natural grass.[10, 11] Comparative studies between artificial turf and natural grass suggest that synthetic fields do not delay players' recovery, cause more fatigue or increase the sprint time when performing a similar exercise or task.[12-14] These findings indicate that artificial turf is as safe as natural grass and players have similar physical and physiological performances on both surfaces. Nonetheless, the higher trauma injury rate found on artificial turf with lower infill surface weight,[15] or the differences in physical performance and physiological responses of soccer players when playing soccer on artificial turf systems with different mechanical properties,[4, 16] testifies to the importance of analysing the mechanical properties of artificial turf systems, and the difficulties determining cause-and-effect relationships.[1, 17]

Although some authors have used small-sided games or 11-a-side for analysing the differences in players responses among different surfaces,[16, 18] most studies have opted for standardised tests in order to avoid the existing variability of physical performance during a soccer match.[13, 14, 19]

The soccer simulation protocol (SSP) has been used for this purpose,[20] as it replicates the physical and physiological demands of soccer matches and includes repeated sprints and nonlinear actions at maximum speed.[13, 14] Nonetheless, other authors have opted for another standardised test such as the soccer-specific aerobic field test (SAFT90) or linear sprint tests.[19, 21]

The faster sprint time and agility actions reported on artificial turf than on natural grass may indicate greater physiological responses of players on the synthetic surface during or after a soccer match.[12, 13, 22] Nevertheless, the lack of differences between surfaces in the heart rate responses and blood lactate reported during and after a SSP or the SAFT 90 seems to contradict this hypothesis.[13, 14, 19] However, in these studies the heart rate responses were exclusively assessed in terms of beats per minute. These authors neither studied the influence of the game surface on the internal load, as they did not establish zones of intensity in their research as in other investigations.[16, 18] Therefore, some interaction effect (surface x time) may be found when analysing the internal load and the heart rate responses as a percentage of the maximum heart rate of participants.[16, 18]

The influence of game surface on muscular fatigue has been assessed through diverse ways such as the levels of creatine kinase, the explosiveness of lower limbs in diverse types of jumps or the perception of muscular stiffness; without finding differences between the natural surfaces and the synthetic ones.[13, 14, 19] However, the neuromuscular responses of soccer players on these two surfaces have not been directly studied. The interaction effect (surface x time) on natural grass reported by Stone et al. in the repeated sprint test existing in the SSP,[14] suggests small differences between surfaces in the amount of eccentric stress and muscle damage experienced during soccer activity.[23] Given that tensiomyography (TMG) has been identified as a useful non-invasive technique to assess the muscular responses of muscles such as the vastus medialis, the vastus lateralis, the rectus femoris and the biceps femoris,[24-26] this tool may provide information about neuromuscular responses of soccer players through variables such as muscular stiffness or contraction time.[27]

The aim of this research was to assess the influence of the game surface on physiological patterns and neuromuscular responses of soccer players during a soccer simulation protocol that incorporates repeated sprints and nonlinear actions at maximum speed. It is expected that this research will provide additional information regarding whether artificial turf systems negatively affect the two factors: physiological responses and neuromuscular pattern; as they play an important role not only in performing high-intensity actions,[13, 14, 16] but also in injury prevention.[15]

The studies that compare soccer surfaces have reported diverse results due to the heterogeneity in the mechanical behaviour of these surfaces.[13, 14, 21, 28] Contrary to these, the current research is the first that controls the mechanical properties of both artificial turf and natural grass following the procedures established in comparative studies of artificial turf systems.[4, 16] Based on previous studies, we hypothesise that the differences in the mechanical properties of both surfaces are not great enough to cause differences in the physiological and neuromuscular responses of soccer players.

2. Methods

2.1. Selection and Description of Participants

Sixteen amateur soccer players were recruited to participate in the study (22.17 ± 3.43 years old; 177.12 ± 5.24 cm; 74.42 ± 4.87 kg). All of them have been playing soccer for at least 10 years (13.57 ±1.85 years). All of them played soccer three days a week including the match day. Participants did not present any cardiopulmonary disease nor were they taking any sort of medicine during the study. Moreover, they had passed the medical examination required to play soccer.

Participants were informed about the benefits and possible risks associated with this study who signed an informed consent. This research was approved by the local institutional ethics committee based on the latest version of the Declaration of Helsinki.

2.2. Experimental design

One system of 3rd generation artificial turf (fibre: monofilament of polyethylene of 60 mm in height; infill: 20 kg/m2 of SBR and quartz sand with 0.3–0.8 granulometry) and one surface of natural grass (height of grass: 25 mm; high quality for soccer practice: certified by two independent gardeners) were selected for this study.

2.2.1. Mechanical properties of the surfaces

The mechanical properties of each surface were assessed in situ following the protocols and specifications presented in previous work.[4, 16, 21] Thus, through an Advanced Artificial Athlete (AAA; Labosport, Le Mans, France) it was recorded the force reduction (FR-%), standard vertical deformation (StV-mm) and energy restitution (ER-%) of each surface.[2] The assessment consists of measuring, through a load cell, the maximum force applied to the surface when a mass of 20 Kg is dropped from a prearranged height. Inside the five zones specified by the standards EN 15330-1:2014 (Figure 1) three points separated by more than 100 mm were selected for the analyses of these variables. Three tests were carried out at each point, but only the mean of the two last tests was recorded for the statistical analysis.

******Figure 1 near here******

2.2.1.1. *Force reduction (FR):* This variable calculates the shock absorption of a surface through the following formula, FR (%) = [1 – (F_{max} / Fref)] * 100. Where FR is the force reduction in %; F_{max} is the maximum force measured on the sports surface in N, and the F_{ref} is the reference force fixed to 6760 N (theoretical value for the concrete pavement).

2.2.1.2. Standard vertical deformation (StV): For calculating the StV it is considered the time interval from when the 20 Kg mass makes the initial contact with the surface (T_1) until the time when the maximum absolute velocity of the mass is obtained after the impact (T_2). This variable is calculated by the formula, StV (mm) = D_{mass} - D_{spring}.

Where D_{mass} is the maximum displacement of the falling mass and D_{spring} is the displacement of the spring during that interval.[2]

2.2.1.3. Energy restitution (ER): This variable is the energy that the system returns to the 20 Kg mass and it is calculated through the formula, ER (%) = E_2 / E_1 * 100. Where E_1 is the energy before impact ($E_1 = 0.5 * mV_{max}^2$); and E_2 is the energy after impact ($E_2 = 0.5 * mV_{min}^2$). V_{max} is the velocity before impact at T_1 and V_{min} is the velocity before impact at T_2; m is the 20 Kg mass that includes the spring, base plate and load cell, expressed in Kg; T_1 is the time when the 20 Kg mas makes the initial contact with the surface, while T_2 is the time of the maximum absolute velocity of the mass during its rebounds after the impact on the surface.

2.2.2.Study protocol

Each player selected two consecutive weeks between March and May to participated in the study. In the first week, players completed a yo-yo test of intermittent recovery level 1 to establish their maximum heart rate (HR max) through a heart rate monitor (Polar Team System, Kempele, Finland) attached to their chest.[16] Moreover, they also completed a training session to get used to both the test used in this investigation and the technology employed. On the other hand, the main test (3 bouts of the SSP) was performed on two separate days within the second week. A period of 72-h of rest was established before each test day.

In the main test, all players completed the first three bouts of the SSP (first half of the SSP) on each selected surface.[14, 20] The surface order was randomly established for each player so that eight participants completed the first test on natural grass and the remaining eight on artificial turf. Players only performed the first three bouts of the SSP due to several authors have demonstrated that 45 minutes of game are enough to get differences among surfaces.[16, 18] Each bout last 16 minutes with 3 minutes of rest between bouts. Each bout consisted of 8 cycles and one repeated sprint (RS: 6 × 15 m sprints departing every 18 s) block between cycles 4 and 5 (Figure 2) structured as follows:[20]

- 3 × 20 m at a walking pace of 1.43 m·s−1
- 1 × sprint-agility run (S-AR) at maximal intensity (20 s for sprint and recovery)
- 3 × 20 m at a running speed of 2.5 m·s−1
- 3 × 20 m at a running speed of 4.0 m·s−1

****Figure 2 near here****

Tests were performed under similar conditions (dry; temperature of 18 ± 3˚C; relative humidity of 25 ± 5%; wind speed between 0.0 m/s–0.5 m/s) and coincided with the training time of players to avoid the influence of circadian rhythms. Participants agreed to keep the 72-h recovery period before each test day without any sort of exhausting or moderate physical activity. Moreover, they committed to using the same boots during all tests and to maintain similar eating habits.

2.3. Technical Information

Fifteen minutes before the beginning of each test, players attached a heart rate monitor on their chest (Polar Team System, Kempele, Finland). Each participant used the same instrument during the entire investigation to avoid possible variation in data.

Basal conditions were recorded for each test day, right before the standardised warm-up that players completed before the SSP. The warm up consisted of 5 minutes of running, 5 minutes of articulation mobility and three sprints of 30 m at increasing speed.[16, 18]

2.3.1. Physiological responses and internal physiological load.

The maximum value for heart rate (HR) was established based on the results collected in the yo-yo test of intermittent recovery level 1. Taking this value as a reference, the peak heart rate (HR peak) was recorded and the average heart rate (HR mean) in both beats per minute (bpm) and as a percentage of the individual maximum heart rate (% HR max.). Six zones of intensity in the form of % of HR max. were established to quantify the internal physiological load (<75%; 75%–80%; 80%–85%; 85%–90%; 90%–95%; +95%) and measure the relative time that players were in each zone in relation to the total time of test.[29] Moreover, actions over 85% of HR max. were recorded as HR high intensity. These variables were also recorded for the warm up to provide further information about its intensity (HR_{peak}: 177.5 ± 9.91 b.p.m; HR_{mean}: 148.84 ± 9.63 b.p.m.; Time in Zone 1 [<75% HR_{max}]: 39.64 ± 16.80%; Time in Zone 2 [75%-80% HR_{max}]: 20.93 ± 12.38%; Time in Zone 3 [80%-85% HR_{max}]: 20.25 ± 10.75%; Time in Zone 4 [85%-90% HR_{max}]: 11.33 ± 13.29%; Time in Zone 5 [90%-95% HR_{max}]: 6.47 ± 3.76%; Time in Zone 6 [90%-95% HR_{max}]: 0.35 ± 0.14%).

2.3.2. Muscular responses.

Through TMG equipment (TMG–BMC Ltd., Ljubljana), the contractile ability of the muscles biceps femoris and rectus femoris of both legs were assessed right before the warm up and the vertical jump (basal conditions) and immediately after the SSP and the vertical jumping. Measures were taken on muscles under relaxed conditions, applying stimuli of 1 ms of duration with varied amplitude and one minute of recovery between stimuli. All measurements were carried out by the same technician who was an expert in the use of tensiomyography. This test started with a stimulus of 20 mAp which was increased by 10 mAp each time until reaching 110 mAp or until finding the maximal muscular displacement of the muscle. A 15s rest was established between consecutive measurements to minimize the effects of fatigue and potentiation. No participant reported nonconformity during this test. In this study, the following variables were recorded: maximal muscular displacement (Dm); contraction time (Tc); sustain time (Ts); delay time (Td); half-relaxation time (Tr).[24-26] Krizaj et al. reported a low error level (0,5 a 2,0 %) and a high reproductivity (ICC: 0.85 – 0.98) in these five parameters (Dm: 0,98; Tc: 0,97; Td: 0,94; Ts: 0,89; Tr: 0,86).[30]

The participant was in supine position with a knee flexion of 120° when the rectus femoris was measured. A triangular-shaped foam cushion was used to obtain the desired knee flexion.[24] The biceps femoris was measured with the participant lying face down and his knee flexed at 5° with the aid of a foam pad.[25] A digital transducer Dc–Dc Trans-Tek® (GK 40, Panoptik d.o.o., Ljubliana, Slovenia) was placed according to the instructions of Rey et al. [24] The self-adhesive electrodes (TMG electrodes, TMG-BMC d.o.o. Ljubljana, Slovenia) were positioned symmetrically to the sensor at a distance of 50–60 mm.[24] The position of both the transducer and the electrodes was marked with a permanent marker to ensure that all measurements made in this study were carried out at the same point.[24]

2.3.3. Vertical jumping.

Right before the warm up and immediately after the SSP players performed three countermovement jumps (CMJ). The height of each jump was measured through an infrared system (Optojump Next, Microgate, Bolzano, Italy), but only the best jump height was collected for the subsequent statistical analysis.

2.4. Statistics

Results are presented as means and standard deviations (±SD). The verification of the normality and homogeneity of the variance was performed by means of the Kolmogorov-Smirnov test and Leven's statistic. All variables presented a normal distribution in each of the samples and groups of analysis. Comparisons between heart rate results were analysed through a two-way ANOVA test (surface x bout). The results collected in the jump variables and TMG before and after the SSP on all surfaces were analysed by the same method (surface x moment). Confidence interval (CI of 95%) was included to identify the magnitude of changes. Effect sizes were also calculated and defined as follows: null, <0.3; mild, 0.3–0.5; moderate, 0.5–0.7; strong, 0.7–0.9; and very strong, 0.9–1.0.[31] Data were analysed with the statistics software SPSS v 20.0. The level of significance was established as $p < 0.05$.

J Sports Med Phys Fitness. 2017 Sep 22. doi: 10.23736/S0022-4707.17.07768-4.

3. Results

3.1. Mechanical properties

Table 1 displays the mechanical properties of both surfaces selected for the tests of FR, StV and ER. Results show that whereas natural grass is softer (higher FR) (+6.10%; $p = 0.07$; ES: 0.543; CI: 1.81–10.40), artificial turf presents greater deformation (+1.48 mm; $p < 0.01$; ES: 2.07; CI: 0.94–2.02) and is more rigid (greater ER) (+14.62%; $p < 0.01$; ES: 3.253; CI: 10.85–18.38).

****Table 1 near here****

3.2. Physiological responses and internal load

The physiological responses of the three bouts of SSP and both surfaces are displayed in Table 2. No significant differences were found among bouts or between surfaces ($p > 0.05$). However, a strong effect size was found in the variable of HR mean bpm (ES: 0.775) and HR mean % HR max. (ES: 0.852) when comparing bout 1 with bout 3 on natural grass.

****Table 2 near here****

Figure 3 displays the internal physiological load of soccer players as the percentage of time that they spent in each of the six zones of intensity previously established. The only significant difference is found on natural grass in zone 1 as players spent more time under their 75% of HR max in bout 1 than in bout 3 (+4.19%; $p = 0.034$; ES: 1.593; IC: -1.608–5.860).

****Figure 3 near here****

3.3. Muscular responses

Table 3 displays the differences in TMG variables of the rectus femoris between surfaces before and after the SSP. Outputs of Tr show higher values after the SSP on natural grass in both the right leg (+44.430 ms; p = 0.049; ES: 0.859; IC: 0.099–88.761) and the left leg (+52.131 ms; p = 0.008; ES: 1.371; IC: 14.609–89.652). Ts of the right leg is also greater after the SSP with respect to the basal measure on artificial turf (+58.39 ms; p = 0.022; ES: 0.93; IC: 8.893–107.850).

****Table 3 near here****

Differences among the TMG variables of the biceps femoris are displayed in Table 4, dividing the outputs between surfaces before and after the SSP. The main significant differences are found for artificial turf since greater values were found before the SSP than after it with respect to Ts variables of both the right leg (+64 .868 ms; p = 0.007; ES: 1.128; IC: 18.570–111.165) and left leg (+87.564 ms; p < 0.001; ES: 1.847; IC: 45.145–129.984). Moreover, the Ts in basal conditions of the left leg is also significantly greater on artificial turf than on natural grass (+53.964 ms; p = .014; ES: 0.899; IC: 11.545–96.384). Lastly, the basal outputs of the left leg presented lower values for Tc (-12.793 ms; p = .025; ES: -1.097; IC: -3.929–-1.165) and bigger outputs for Tr (+34.687; p = 0.036; ES: 1.096; IC: 2.403–66.970) than after the SSP on artificial turf.

****Table 4 near here****

3.4. Vertical jumping

When comparing the height of vertical jumping and the percentage of difference, no significant differences were found between surfaces or between the basal values with the outputs following the SSP (p > 0.05).

4. Discussion

The main result of this research is that no significant differences were found between the surfaces of natural grass and artificial turf in both the physiological responses and acute muscular fatigue after completing the three bouts of the SSP. Although previous authors have demonstrated a similar influence of both of these surfaces on players' responses during the SSP,[13, 14, 19] this study is the first one that evaluates the mechanical properties of the artificial turf system and the natural grass surface to compare the physiological and muscular responses in amateur soccer.

The use of artificial turf fields certified by FIFA is common in previous studies,[14, 28] but only Sassi et al. assessed the mechanical properties of this surface as well as those of natural grass.[21] Sánchez-Sánchez et al. found faster sprint performance on the artificial turf systems more rigid; while the physiological responses tend to increase in systems with greater force reduction.[6, 16] Therefore, each system, especially those with artificial turf, should be assessed individually instead of as a uniform group.[32] Indeed, in analysing data reported by previous studies, we found large differences among artificial turf systems with values from 31.45 ± 6.24% to 70.30 ± 61.47% for FR;[6, 33] from 3.43 ± 0.43mm to 7.34 ± 60.43mm for StV;[6, 16] and from 32.66 ± 3.17 to 50.50 ± 2.19% for ER.[16, 34]

Outputs collected from the HR mean (surpassing 80% of the HR max in all bouts) and HR peak (exceeding 90% of the HR max) indicate that the SSP has a similar physiological effect to playing a small-sided game or 11-a-side matches.[16, 18] The lack of significant differences in the physiological variables between surfaces suggests that the differences between the mechanical properties of both surfaces, FR, StV and ER are not high enough to affect the physiological responses of soccer players.[4, 16] Thus, similar energy costs may be expected when playing on both surfaces.[16, 18] These outcomes also strengthen the results of previous studies that did not report differences in heart rate responses and blood lactate levels during a soccer match simulation either in elite or sub-elite players.[13, 14, 19] However, the lack of mechanical properties reported in those studies makes it necessary to be cautious when comparing these results with previous ones. The existing diversity in the mechanical properties of artificial turf systems may explain the greater heart rate peaks and lactate levels found on artificial turf than on natural grass in a multistage running test.[1, 5, 28] Consequently, more research that includes the mechanical properties of the surfaces is required to determine cause-and-effect evidence when comparing the physiological responses of players on artificial turf and on natural grass.

Muscular fatigue is a decrease in muscle performance as a result of muscle activity which can vary according to the type and duration of exercise.[35] As a non-invasive evaluation technique to measure the contractile properties of muscles, the TMG has recently been incorporated in the rehabilitation and sport training fields;[26] increasing the studies that used this technique in soccer.[24, 27] Although Wiewelhove et al. suggest that TMG is not sensitive enough to detect muscular performance changes in elite youth athletes,[36] it has been validated and evaluated by various authors. TMG has demonstrated a greater short-term reliability and a high sensitivity for detecting changes in the characteristics of the leg muscles.[24, 27, 30] Moreover, various studies have supported the use of TMG in detecting muscle damage and recovery;[35] with greater reliability in exercised or fatigued state, compared to rested.[37] Therefore, although it is necessary to be cautious when analysing the findings coming from this technique, it seems to be valid for analysing the surface-effect in neuromuscular responses after the SSP.[35, 38] On the other hand, the reliability studies agree that the most stable parameters are the Dm (ICC: 0.98) and Tc (ICC: 0.97), as the coactivation of neighbouring muscle can affect the values of Td (ICC: 0.94), Ts (ICC: 0.89), Tr (ICC: 0.86) and therefore, their reliability.[30, 38] Consequently, the differences in these parameters reported in this study might be due to the coactivation of neighbouring muscle instead of the influence of the surface.

In TMG, fatigue is manifested by changes in electric muscle activity; the incapacity to reach an initial strength level in repeated contractions or by a reduction in the capacity to sustain a determined level of strength during the contraction.[39] The increase in the Tr and Ts values has been associated with the presence of fatigue of the neural and morpho-functional mechanisms.[35] The decrease of these variables after the SSP might indicate a greater neuromuscular activation in the rectus femoris on natural grass and in the biceps femoris on artificial turf at the end of the SSP;[30, 40] and therefore, that some surface-specific performance response may exist over time.[14]

The lack of significant differences in the variables of Tc, Td and Dm suggest a low acute fatigue, which agrees with the findings of Rey et al. in soccer players measured after a training.[24] Consequently, the hypothesis that the differences in the mechanical properties of both surfaces are not great enough to cause different muscle fatigue in soccer players is accepted. These outcomes were expected as Stone et al. did not find significant differences in creatine kinase and the perception of muscle soreness between surfaces after players complete the SSP.[14] Finally, coinciding with previous works, there was no surface interaction in the CMJ variables;[13] what indicates a similar explosive capacity of players' lower limbs on both surfaces after the SSP. These outcomes reinforce the findings of TMG as no surface interaction was found in Dm and Tc values. Nonetheless, Encarnación-Martínez et al. reported differences in the impact attenuation among various artificial turf systems certified by the UNE-EN 15330-1:2014, but with different structural components.[33] Therefore, as the structural components of artificial turf like fibre or infill affect the final FR, StV and ER values of artificial turf systems,[1, 33] it is not possible to generalise the findings presented in this work.

The outputs of this study, as well as the findings of previous investigations, suggest a small difference in the physiological response and muscular fatigue of players when playing soccer on both of these surfaces.[13, 19, 21] Nonetheless, the lack of standardisation of most artificial turf systems,[1] together with the absence of a certification standard for natural fields,[2] prevents the generalisability of the findings of this research. One must consider that players who took part in this study were amateurs and that they only completed the first three bouts of the SSP instead of the six bouts that compose the entire test.[20] For these reasons, it is advisable for future research to analyse whether a game surface can have a different influence on players' responses with regard to different physical, technical and tactical levels, and to assess if high-quality game surfaces cause different player responses. Finally, some authors have reported that TMG is not sensitive enough to detect changes in neuromuscular responses due to fatigue.[36] Therefore, caution is required when considering the findings reported by this technique. Moreover, the assessment of neuromuscular responses at 48 and 72 hours after the test would provide further information about the recovery of players on different surfaces.

J Sports Med Phys Fitness. 2017 Sep 22. doi: 10.23736/S0022-4707.17.07768-4.

5. Conclusion

The lack of differences between surfaces on both physiological and neuromuscular responses suggest that coaches do not have to modify the training programmes based on standardised test when players train on artificial systems. Indeed, it is expected players to have the same physiological and neuromuscular effects as when playing on natural grass. On the other hand, these results also suggest that playing soccer on artificial turf does not cause greater muscular fatigue in players. Thus, leaving aside the technical and tactical differences of footballers when playing on artificial turf, it may be likely that players will achieve similar performance regardless of the surface where they play. However, the high variability existing in the mechanical responses of artificial turf systems makes necessary further evidence to confirm this statement.

Disclosure statement

The authors report no conflicts of interest

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Figure legends

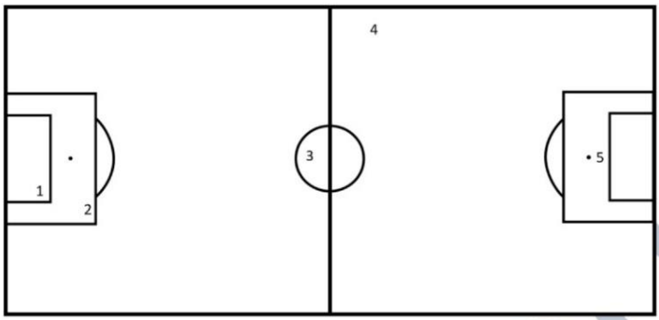

Figure 1. Zones to assess the sport surfaces

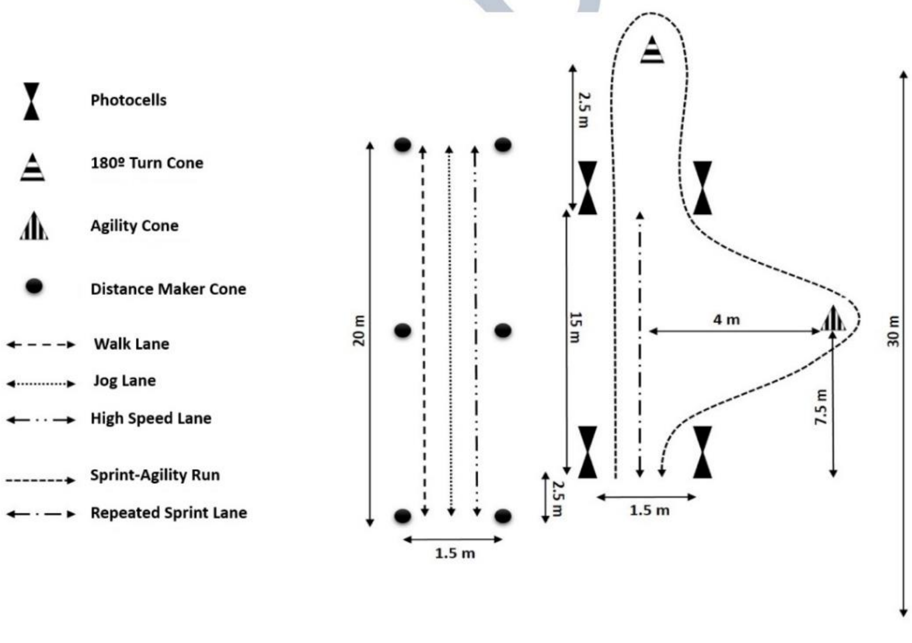

Figure 2. Soccer simulation protocol

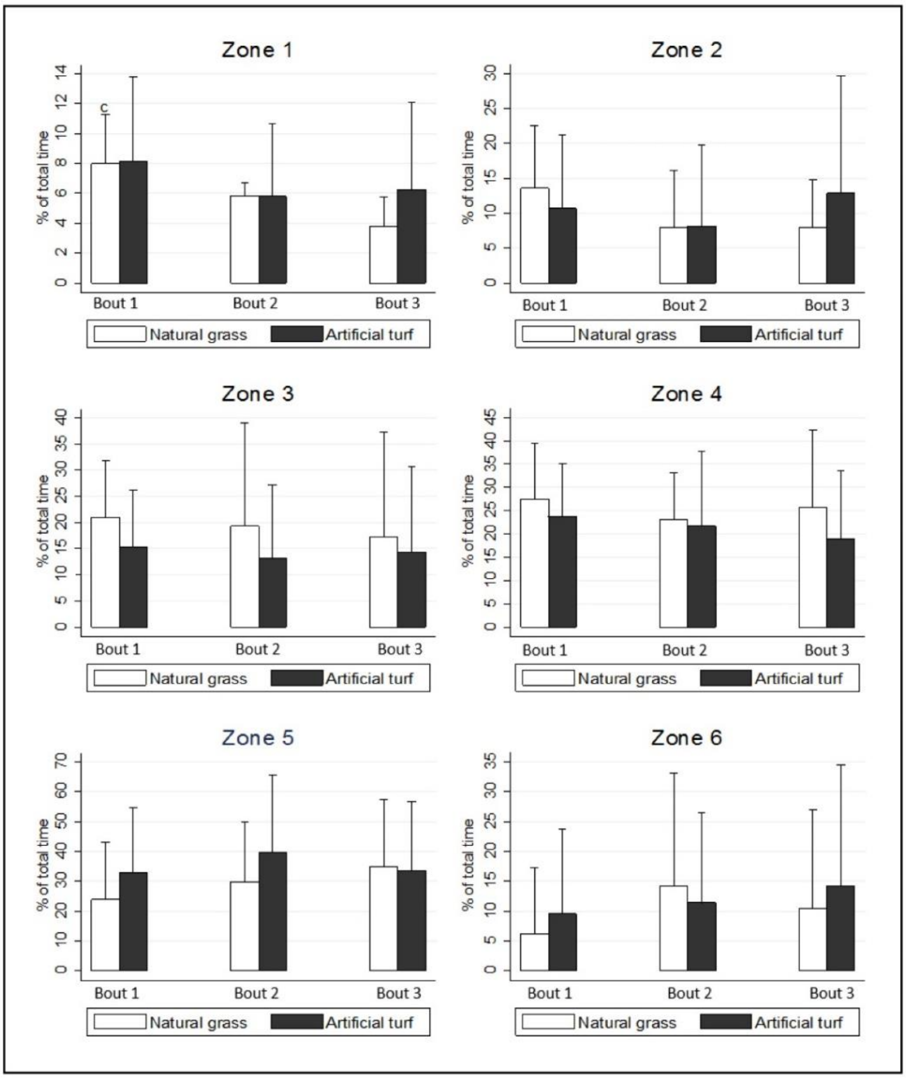

Figure 3. Internal load in the three bouts for both surfaces of artificial turf and natural grass.

C: Significant differences between bout 1 and bout 3

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Title of tables

Table 1. Mechanical properties of both selected surfaces

	Artificial	Natural	*p* value
FR	43.59 ± 5.09*	49.69 ± 6.33	$p = 0.07$
StV	6.77 ± 0.60	5.29 ± 0.83	$p < 0.01$
ER	53.84 ± 2.23	39.22 ± 6.76	$p < 0.01$

* Non-compliance with the specifications of the standard EN 15330-1:2014
FR = force reduction; StV = standard vertical deformation; ER = energy restitution

Table 2. Physiological responses in the three bouts for both the surfaces of artificial turf and natural grass

Variables	Bouts	Artificial	Natural
HR peak (bpm)	1	189.53 ± 8.06	185.73 ± 8.01
	2	188.20 ± 8.80	186.73 ± 9.04
	3	188.42 ± 11.64	187.25 ± 8.56
HR peak (% HR max.)	1	95.89 ± 3.00	93.99 ± 3.77
	2	95.22 ± 3.70	94.50 ± 4.29
	3	95.23 ± 5.46	94.65 ± 4.14
HR mean (bpm)	1	169.01 ± 11.54	165.91 ± 8.98
	2	172.74 ± 10.69	171.35 ± 9.23
	3	171.30 ± 12.11	172.80 ± 8.80
HR mean (% HR max.)	1	85.48 ± 4.91	83.94 ± 4.05
	2	87.38 ± 4.66	86.70 ± 4.24
	3	86.56 ± 5.53	87.33 ± 3.90
HR high intensity (t [%]) > 85% HR max.)	1	66.00 ± 24.29	57.53 ± 21.72
	2	72.87 ± 26.30	66.90 ± 26.72
	3	66.62 ± 33.61	70.95 ± 26.99

* Significant differences ($p < 0.05$) between surfaces for each bout
\# Significant differences ($p < 0.05$) among bouts for both artificial turf and natural grass
HR: Heart Rate

J Sports Med Phys Fitness. 2017 Sep 22. doi: 10.23736/S0022-4707.17.07768-4.

Table 3. Muscular responses of the rectus femoris between pre-post and between surfac*es*

	Artificial Turf		Natural Grass	
	Pre	Post	Pre	Post
Tc Right leg (ms)	33.22 ± 9.58	31.47 ± 5.95	34.40 ± 8.90	33.13 ± 7.18
Td Right leg (ms)	25.72 ± 5.11	23.40 ± 2.98	25.31 ± 1.93	24.11 ± 3.27
Tr Right leg (ms)	69.37 ± 59.33	48.81 ± 43.86	101.65 ± 66.83#	57.22 ± 36.56
Dm Right leg (mm)	9.33 ± 3.61	9.54 ± 2.16	9.74 ± 2.10	9.92 ± 2.22
Ts Right leg (ms)	146.14 ± 76.80#	87.75 ± 48.76	146.30 ± 67.34	101.88 ± 41.06
Tc Left leg (ms)	34.85 ± 8.51	33.84 ± 9.58	33.75 ± 10.12	33.29 ± 7.96
Td Left leg (ms)	28.78 ± 14.36	23.39 ± 2.82	25.57 ± 2.01	23.84 ± 2.38
Tr Left leg (ms)	49.70 ± 41.39	46.87 ± 27.23	90.35 ± 58.30#	38.22 ± 17.76
Dm Left leg (mm)	8.47 ± 3.68	8.97 ± 2.62	9.74 ± 2.16	9.13 ± 2.87
Ts Left leg (ms)	118.17 ± 74.73	109.35 ± 56.36	145.05 ± 90.31	98.21 ± 48.29

* Significant differences ($p < 0.05$) between surfaces for pre-post
# Significant differences ($p < 0.05$) pre-post for both artificial turf and natural grass
Tc = contraction time; Td = delay time; Tr = half-relaxation time; Dm = maximal muscular displacement; Ts = sustain time

Table 4. Muscular responses of the biceps femoris between pre-post and between surfaces

	Artificial Turf		Natural Grass	
	Pre	Post	Pre	Post
Tc Right leg (ms)	40.22 ± 12.75	41.40 ± 13.28	43.16 ± 18.70	42.22 ± 15.77
Td Right leg (ms)	24.66 ± 2.06	24.00 ± 2.70	25.27 ± 2.96	24.14 ± 3.73
Tr Right leg (ms)	84.72 ± 64.65	51.80 ± 29.58	61.73 ± 65.80	30.28 ± 34.31
Dm Right leg (mm)	7.62 ± 2.79	7.68 ± 2.67	7.29 ± 3.12	7.90 ± 2.97
Ts Right leg (ms)	216.04 ± 83.03#	151.17 ± 32.01	179.93 ± 48.42	140.66 ± 49.01
Tc Left leg (ms)	34.54 ± 10.51	47.34 ± 12.82#	40.80 ± 17.58	45.73 ± 12.20
Td Left leg (ms)	25.94 ± 4.29	27.61 ± 3.95	24.60 ± 5.66	26.43 ± 4.47
Tr Left leg (ms)	82.39 ± 48.82#	47.70 ± 14.50	62.97 ± 45.62	58.84 ± 38.52
Dm Left leg (mm)	7.16 ± 3.81	8.64 ± 2.34	7.67 ± 3.27	7.82 ± 3.05
Ts Left leg (ms)	226.80 ± 78.87*#	139.23 ± 15.93	172.83 ± 41.26	158.73 ± 49.56

* Significant differences ($p < 0.05$) between surfaces for pre-post
# Significant differences ($p < 0.05$) pre-post for both artificial turf and natural grass
Tc = contraction time; Td = delay time; Tr = half-relaxation time; Dm = maximal muscular displacement; Ts = sustain time

5.1.6. Estudio 6. Muscle contractile properties on different sport surfaces using tensiomyography

Original Article

Muscle contractile properties on different sport surfaces using tensiomyography

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ABSTRACT

Propose: the propose of this study was to discover the influence of sand and natural grass on muscle overuse in female rugby players after an induced fatigue test. Methods: the participants of this study were 15 female amateur rugby players (23.4 ± 4.42 years). RSA Test consisted of six-sprints of 40 m (20 + 20 m) and was performed in two different surfaces (natural grass and sand). Before and immediately after completing the RSA, the contractile capacity of the biceps femoris and the rectus femoris of both legs was evaluated through Tensiomyography (TMG). Results: players also did 2 CMJ jumps before and after the RSA to assess the muscle fatigue. CMJ jump high decreased (-2.89 cm; ES= 0.67; IC: to -4.59 to -1.18) after having performed the RSA Test on sand versus natural grass. Rectus femoris presented higher values of Tc (11.66 ms; ES= 1.00; IC: 4.03 to 9.29; p≤0.01) and Dm (1.20 mm; ES= 0.80; IC: 0.21 to 2.61; p<0.05) on sand than on natural grass after finishing the RSA while the biceps femoris do not display any differences regarding surfaces. Conclusion: therefore, muscular response on rectus femoris after repetitive-sprint-actions differ between different surfaces (sand and natural grass). **Key words:** FATIGUE, EXERCISE, MUSCLE, PERFORMANCE

Cite this article as:
Ubago-Guisado, E., Rodríguez-Cañamero, S., López-Fernández, J., Colino, E., Sánchez-Sánchez, J., & Gallardo, L. (2017). Muscle contractile properties on different sport surfaces using tensiomyography. *Journal of Human Sport and Exercise, 12*(1), 167-179. doi:10.14198/jhse.2017.121.14

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Submitted for publication March 2017
Accepted for publication May 2017
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

doi:10.14198/jhse.2017.121.14

INTRODUCTION

Overuse or fatigue injuries are caused by repeated micro-trauma, without any actual moment causing the injury (Fuller et al., 2006). Overuse injuries are responsible for 63% of relapse injuries, with 75% occurring during training and 51% during the preseason (Walden et al., 2005). According to Petibois et al. (2002) fatigue plays an important role in the risk of injury. Acute fatigue generates a reduction in strength and motor control of the implicated muscle groups, making them more susceptible to injury, especially during high-intensity exercises at the end of a training session or a competition (Hawkins et al., 2001).

Sport injuries can be caused by intrinsic factors of the player and by extrinsic factors of the environment (Orchard, 2001). Among the extrinsic factors, the game surface represents one of the main causes of sport injuries. To date, research has been conducted on artificial turf, natural grass, and rigid surfaces to determine their influence on performance and sport injuries through injury registration (Hughes et al., 2013; Iacovelli et al., 2013; Sánchez-Sánchez et al., 2014).

Tensiomyography (TMG) is a non-invasive method developed to evaluate the mechanical properties and muscle contractility in response to electric stimulation. This method provides information on muscle stiffness, contraction speed, predominant muscle fibre types, and muscle fatigue (Rey et al., 2012). TMG has been demonstrated as a reliable method that can predict the risk of injury during sport practice (Alentorn-Geli et al., 2015).

This study is the first to analyse the differences in the muscle response after induced fatigue on sand and grass. Research conducted on sand and grass is related with other parameters. Alcaraz et al. (2011) studied the kinematics of sprint running between sand and an athletic track, finding differences in the players' biomechanical use. Binnie, Dawson, Arnot et al. (2014) demonstrated that sport practice on sand significantly increases the heart rate and involves a higher-intensity load compared to natural grass. In volleyball, the difference in the height of a vertical jump between sand and a firm surface was studied (Giatsis et al., 2004), noting that less jump height was reached on sand.

On the other hand, Brito et al. (2012) analysed the differences in football players' performance during simulated game situations on sand, grass, and concrete. Sand was the most demanding surface during the match, with higher levels of lactate, higher perceived exertion, and an elevated heart rate of the players. Finally, there is research on plyometric intervention training on sand, resulting in a recommended surface for improving neuromuscular adaptations and in analysing running economy on sand (Impellizzeri et al., 2008; Mirzaei et al., 2013; Pinnington et al., 2005).

There is a lot of controversy regarding the relationship between the game surface and injuries. Previous research has shown that playing on sand increases the risk of injury (Knobloch et al., 2008). In contrast, another study has shown a decrease in injury incidence compared to firm surfaces (Impellizzeri et al., 2008). Ekstrand et al. (2006) associate firmer surfaces (natural grass) with a higher musculoskeletal impact on the player, and Inklaar (1994) with overuse injuries. Therefore, during the formation period of the athlete in the preseason, training on a surface like sand could be more recommended compared to a firmer surface like natural grass, as there is a higher incidence of overuse injuries during this period of time (Woods et al., 2002). Also, sand can be more useful to improve the aerobic capacity of athletes who have suffered an injury (Impellizzeri et al., 2008).

Despite these studies, no scientific evidence exists on the risk or injury incidence according to the sport surface (Binnie, Dawson, Pinnington et al., 2014). The differences in fatigue produced on different game surfaces could be an indicator of the risk of muscle injury for the athlete. For this reason, the aim of this s tudy was to discover the influence of sand and natural grass on muscle parameters in female rugby players after an induced fatigue test.

MATERIALS AND METHODS

Participants

A total of 15 healthy female amateur rugby players between 18 and 28 years old (23.4 ± 4.42) from the province of Toledo participated in the study. All of the participants signed a consent form to take part in the study, which detailed the tests and the possible risks. The study protocol was approved by the local ethics committee (Toledo Hospital) and was done according to the ethical code of the World Medical Association (Helsinki Declaration). The general characteristics of the participants are described in Table 1.

Table 1. Descriptive characteristics of the participants.

	Average	SD
Age (years)	23.40	3.36
Weight (kg)	65.21	12.08
Height (cm)	165.08	7.53
Fat (%)	27.25	6.11
Fat (g)	17987.66	1286.95
Muscle (g)	43705.20	1056.67
BMC (g)	2231.19	293.39
BMD (g/cm^2)	1.15	0.07

BMC: bone mineral content; BMD: bone mineral density.
SD= Standard Deviation

Study design

Previous to the start of the study, the players carried out an initial pilot test on a neutral surface to familiarize with all of the tests included in the study protocol. These tests were repeated on the rugby pitch of natural grass and on a beach sand surface in two different days during the same week, with a separation between them of 48h. The tests were developed in October between 16:00h and 20:00h in the same city and at the same altitude (529 m above sea level), under dry conditions, at a temperature between 18-22.5ºC and with a relative humidity of 20-30%.

The study was performed during a non-competitive week so that the players had not made any intense physical exertion before the tests. The players were asked not to do any exhausting activities for 72h before each test and to maintain the same food habits. They were also asked to use the same footwear on both surfaces. Before the start of the study, a global positioning system was attached to each player's back (GPS, HPU, GPSports, Australia) together with a monitoring heart rate band (Polar Team System, Kempele, Finland), which were proven to be valid and reliable (Barbero-Álvarez et al., 2010).

Prior to the different tests, the participants completed a standardised warm-up that consisted of 5 minutes of continuous running, 5 minutes of joint mobility, and three 30-m sprints, increasing the intensity with a 2-minute recovery between each sprint (Sánchez-Sánchez et al. 2014). No stretching was done either during or after the warm-up. In baseline, the contractile capacities of participants were measured and the participants performed a countermovement jump (CMJ). After, the players completed an RSA test in the specific surface (artificial turf and sand). Straight after, the contractile capacities of participants and CMJ were measured again.

Repeated-Sprint ability (RSA) shuttle test

The players completed an RSA test that consisted of six sprints of 40 m (20 + 20 m) with 20 s of passive recovery (Sánchez-Sánchez et al. 2014). The players began on the start line and ran 20 m, turning 180º and returning to the start line as quickly as possible.

Prior to the RSA test, each participant completed a preliminary maximum sprint that was used as a score criterion to validate the RSA test, resting for 5 minutes after this sprint before starting the RSA test. This way, if the performance of the first sprint of the RSA test was worse than the preliminary sprint, the test was not considered valid and the participant had to immediately stop and repeat the RSA test at a maximum exertion after a 5-minute recovery (Chaouachi et al., 2010).

The total time (RSATT) and the decrease percentage (%BEST) were calculated. The %BEST ([mean time/best time*100] –100) has been identified as the most valid and reliable method to evaluate fatigue in this type of test (Chaouachi et al. 2010). These data were collected using four pairs of photocells (Microgate, Bolzano, Italy) placed at the start line, at 5 m, at 10 m, at 30m, and at 40 m with a 0.001 s sensibility. The maximum speed (V_{MAX}) and maximum heart rate (HRmax) of players during the RSA test were monitored with GPS at 10 Hz and heart rate bands (Polar Team System, Kempele, Finland).

Vertical jumping

A CMJ was done before and after the RSA test using an infrared system (Optojump Next, Microgate, Bolzano, Italy) in a neutral surface (smooth concrete). The participants had to keep their hands on their hips to avoid the influence of arm movement on the jump performance. Each player did two CMJ jumps before and after the RSA test (2-minute recovery between jumps). The best jump was selected for the statistical analysis.

Tensiomyograpy (TMG)

The following procedures have already been described by other authors (Rey et al. 2012; Tous-Fajardo et al., 2010). The contractile capacity of the biceps femoris and the rectus femoris of both legs was evaluated using TMG (BMC Ltd., Ljubljana, Slovenia) before (resting state) and immediately after doing the RSA test and the CMJ with the aim of evaluating muscle fatigue. TMG is a non-invasive technique that measures maximal displacement (Dm) given by the radial movement of the muscle belly expressed in mm and depends on the muscle tone or stiffness; contraction time (Tc), the time between 10 and 90% of Dm; sustain time (Ts), the time in which the muscle response remains >50% of Dm; delay time (Td), also known as reaction or activation time, the time between the initiation and 10% of Dm; and half-relaxation time (TR), the time in which the muscle response decreases from 90 to 50% of Dm muscle (Figure 1).

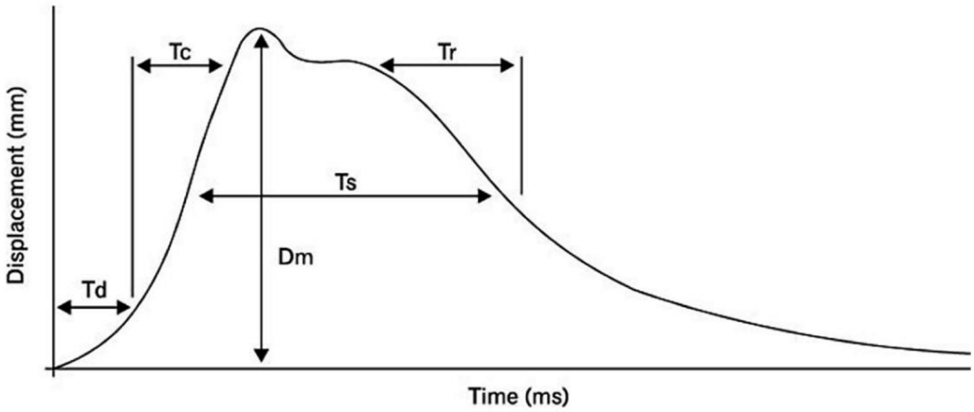

Figure 1. TMG parameters definition (Carrasco et al., 2011)

A small electric stimulation is produced on the required muscle. This stimulus is measured by placing a digital transducer perpendicular to the muscle belly Dc-Dc Trans –Tek® (GK 40, Panoptik d.o.o., Ljubljana, Slovenia). The stimulation of the selected muscle is made using two self-adhesive electrodes (TMG electrodes, TMG-BMC d.o.o. Ljubljana, Slovenia) placed equidistant to the point where the measurement will be made. The proximal electrode corresponds to the anode and the distal to the cathode. The stimulus is produced by a TMG-100 system electrostimulator (TMG-BMC d.o.o., Ljubljana, Slovenia) of 1 ms duration. The amplitude range of the electrical stimulus can be from 0 to 110 mA.

The rectus femoris was measured with the individual in a supine position with a 60º knee flexion with the help of a foam triangular-shaped cushion. The biceps femoris was measured with the individual lying face down and with the knee flexed at 5º with the help of a foam cushion. The digital transducer was placed following Delagi et al. (1975) indications. The electrodes were placed symmetrically from the sensor at the same distance of 50–60 mm. Both the sensor and electrode positions were marked with a permanent marker to guarantee that the measurements in the research were made at the same point. Ultimately, the stimulation was of 1 ms, giving four stimulations to each muscle, varying the amplitude (25, 50, 75, and 100 mAp). All of the measurements were done by the same technical expert in this type of measurement.

Statistical analysis
The reliability of the TMG parameters was calculated through intraclass correlation coefficient reliabilities (ICCRs). Results are presented as mean and standard deviation (SD). The verification of the normality and homogeneity of the variances was assumed by means of the Kolmogorov–Smirnov test and the Leven's statistic. The comparison between results collected in the RSA test on different surfaces and TMG assessment before and after the RSA test on both surfaces (natural grass and sand) was analysed using a T-Student test. Data were analysed with the statistic software SPSS v 20.0. The level of significance was established at $p<0.05$. The effect size (ES; Cohen's d) was evaluated according to the following criteria: 0–0.2 = trivial, 0.2–0.5 = small, 0.5–0.8 = moderate, and 0.8 = significant (Cohen, 1992). In addition, the confidence interval (CI of 95%) was calculated to identify the magnitude of changes. Statistical significance level was set at $p<0.05$.

RESULTS

In relation to the RSA test results, the RSATT (grass 10.04 ± 0.68 s and sand 10.65 ± 0.93 s; -0.61 s; ES= 0.75; IC: -0.87 to -0.34) and the VMAX (grass 4.00 ± 0.26 m/s and sand 3.78 ± 0.32 m/s; 0.22 m/s; ES= 0.76; IC: 0.12 to 0.31) showed significant differences between the surfaces ($p<0.01$). The %BEST of the RSA test were significant in the fifth and sixth sprint when comparing natural grass and sand (Figure 2). In this context, HRmax during the RSA test was higher on the sand (192.15 ± 11.82 b.p.m.) with respect to natural grass (189.46 ± 11.82 b.p.m.), but significant differences were not found ($p=0.54$). On the other hand, CMJ height decreased (-2.89 cm; ES= 0.67; IC: to -4.59 to -1.18) after performing the RSA test on sand versus natural grass.

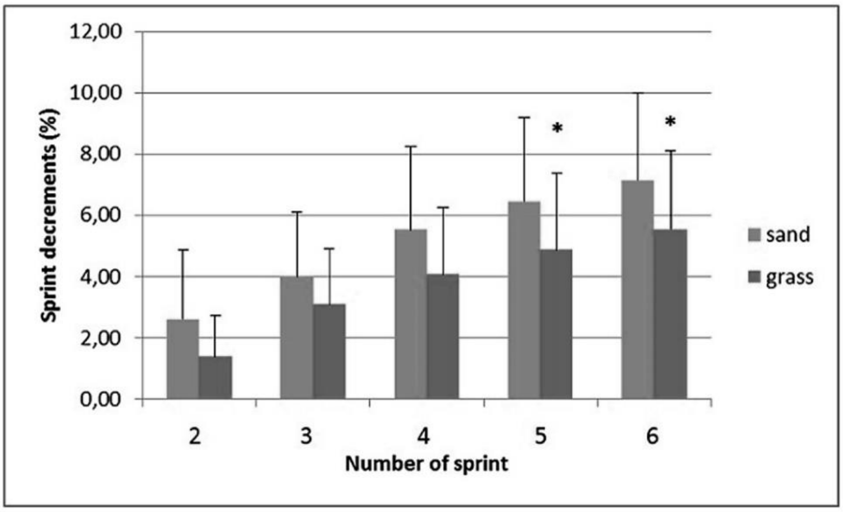

Figure 2. Profile of mean sprint decrements (%Best) compared to the first sprint of the 6 x 40-m test RSA. *Significantly different from the 6 x 40-m sprint decrement between surfaces $p<0.05$.

Table 2 shows the results between pre- and post-variables on natural grass and sand of Tc, Tr, Td, and Ts of the rectus femoris and the biceps femoris after completing the RSA test. When comparing the pre- and post-variables of the same surface, the female rugby players showed significant differences in the rectus femoris in the Tr (8.15 ms; ES= 0.81; IC: 5.90 to 10.40; $p<0.05$) and Ts (31.88 ms; ES= 0.70; IC: 17.87 to 45.89; $p<0.05$) variables on natural grass and in the Tr variable (11.21 ms; ES= 1.30; IC: 1.72 to 20.70; $p<0.01$) on sand. The biceps femoris results showed significant differences in the Tr (54.04; ES= 1.28; IC: 37.32 to 75.40; $p<0.01$) and Td variables (7.13 ms; ES= 0.68; IC: 5.90 to 20.16; $p<0.01$) on natural grass and in the Tr variable (40.17 ms; ES= 1.07; IC: 31.68 to 112.02; $p<0.01$) on sand. Once the RSA test was completed on both surfaces, the results revealed significantly higher values on the sand for the rectus femoris for the Tc variable (11.66 ms; ES= 1.00; IC: 4.03 to 9.29; $p\leq0.01$).

Table 2. Comparison of the Tc, Tr, Td and Ts variables of the rectus and biceps femoris.

		Natural grass			**Sand**			***P***
Variable		Pre	Post	Dif. (%)	Pre	Post	Dif. (%)	Post
RF								
	Tc (ms)	37.43 ± 10.86	39.31 ± 12.22	8.22 ± 11.25	39.76 ± 6.17	50.97 ± 11.01**	30.77 ± 14.11	0.010†
	Tr (ms)	28.46 ± 9.45	36.61 ± 10.60*	41.47 ± 12.43	31.69 ± 7.39	33.39 ± 12.46	6.91 ± 2.03	0.388
	Td (ms)	27.10 ± 3.14	30.43 ± 9.60	12.39 ± 8.64	25.30 ± 3.18	29.05 ± 9.75	16.96 ± 6.72	0.601
	Ts (ms)	118.07 ± 20.03	149.95 ± 12.88*	38.70 ± 10.19	118.16 ± 29.21	132.46 ± 25.06	17.37 ± 12.95	0.221
BF								
	Tc (ms)	31.36 ± 7.30	31.54 ± 6.79	3.75 ± 8.14	28.87 ± 8.18	28.49 ± 8.42	0.64 ± 1.05	0.284
	Tr (ms)	49.19 ± 18.92	103.23 ± 65.53**	35.22 ± 15.55	58.75 ± 19.12	98.92 ± 55.78**	45.98 ± 27.81	0.794
	Td (ms)	29.08 ± 7.16	36.21 ± 13.81**	26.05 ± 8.99	28.45 ± 7.01	29.52 ± 7.82	5.44 ± 4.11	0.056

	Ts (ms)	204.19 ± 75.62	203.95 ± 96.18	15.51 ± 11.67	217.53 ± 77.83	219.98 ± 91.42	8.11 ± 2.84	0.616

*Significant differences between pre and post on the same surface (*p*<0.05).

** Significant differences between pre and post on the same surface (*p*≤0.01).

† Significant differences between surfaces (*p*<0.05).

Dif. (%): difference of percentage between pre and post.

RF: rectus femoris; BF: biceps femoris; Tc: contraction time; Td: delay time; Tr: half-relaxation time; Ts: sustain time.

In Table 3 we can observe the differences in the Dm variable. Between TMG pre- and post- after the RSA test, the results showed significant differences on grass and sand in the rectus femoris (grass: 0.94 mm; ES= 0.64; IC: 0.57 to 2.45; p<0.05; sand: 1.76 mm; ES= 1.77; IC: 1.19 to 2.33; p<0.01) and biceps femoris (grass: 0.78 mm; ES= 0.42; IC: 0.25 to 1.31; p<0.05; sand: 2.14 mm; ES= 1.66; IC: 0.65 to 3.63; p<0.01). When the post-tests between the two surfaces were compared, significantly higher values in the Dm of the rectus femoris on the sand were obtained (1.20 mm; ES= 0.80; IC: 0.21 to 2.61; p<0.05).

Table 3. Comparison of maximal displacement (Dm) between natural grass and sand in post-test

		Natural Grass			**Sand**			***P***
Variable		Pre	Post	Dif. (%)	Pre	Post	Dif. (%)	Post
RF								
	Dm (mm)	2.46 ± 1.09	3.40 ± 1.86*	55.03 ± 13.11	2.84 ± 0.85	4.60 ± 1.14**	75.44 ± 5.66	0.042†
BF								
	Dm (mm)	3.87 ± 2.01	4.65 ± 1.74*	57.63 ± 8.48	3.36 ± 1.67	5.50 ± 0.91**	62.61 ± 11.73	0.162

*Significant differences between pre and post on the same surface (*p*<0.05). ** Significant differences between pre and post on the same surface (*p*≤0.01). † Significant differences between surfaces (*p*<0.05).

Dif. (%): difference of percentage between pre and post.

RF: rectus femoris; BF: biceps femoris; Dm: maximal displacement.

DISCUSSION

The main findings of this study were that the RSA test done on the sand produces a different muscle response compared to physical exercise done on natural grass. In recent years, there has been an increase of studies that use TMG in their investigations of diverse topics, such as sport and rehabilitation (García-Manso, Rodríguez-Ruiz et al., 2011; García-Manso, Rodríguez-Matoso et al., 2011), among others.

This technique has been validated and evaluated by various authors, proving to be reliable for collecting this type of data (Tous-Fajardo et al., 2010), with a high sensitivity for detecting changes in the characteristics of the leg muscles (Rodríguez-Ruiz et al., 2011). Various studies have proven their use for professionals and researchers for detecting muscle damage and recovery (García-Manso, Rodríguez-Matoso et al., 2011). Because it is a non-invasive evaluation technique and is independent of motivation, TMG has recently been incorporated in the rehabilitation and sport training fields (Tous-Fajardo et al., 2010). However, it has never been used to measure the contractile capacity of the muscles after an induced fatigue test on different sport surfaces.

In relation to performance parameters during the RSA test, players reached higher speed peaks on natural grass. In this way, the total times of the test are lower on this surface compared to on the sand, and the differences in fatigue start to be more evident between the two surfaces at the fifth sprint. Our results coincide with studies like that of Alcaraz et al. (2011) who concluded that sand reduces running speed due to a higher overuse of the athlete. Studies on runners using electromyography prove high energy expenditure associated with higher muscle activity during running on sand compared to a firm surface (Pinnington et al., 2005). Also, when comparing an eight-week training session on grass and sand, a higher fatigue is perceived on sand compared to natural grass (Binnie, Dawson, Arnot et al., 2014). Other studies using reduced game situations in football players have proven that players have a higher fatigue perception when they play on sand compared to asphalt (Brito et al., 2012).

In TMG, fatigue is manifested by a reduction in the capacity to maintain a determined level of strength during a sustained contraction or the inability to reach an initial strength level in repeated contractions, along with changes in electric muscle activity (Rodríguez-Matoso et al., 2012). Using TMG, fatigue is detected by increments in Dm (García-Manso, Rodríguez-Ruiz, Rodríguez-Matoso et al., 2011), in Td (Šimunič et al., 2005), in Tc (Smith et al., 2006), in Ts (García-Manso, Rodríguez-Matoso, Sarmiento et al., 2012), and in Tr (García-Manso, Rodríguez-Ruiz, Rodríguez-Matoso et al., 2011). The results that we obtained in each surface between TGM pre- and post- are of a higher Tr and Ts in the RF and a higher Tr and Td in the BF on natural grass, and a higher Tc and Dm in the RF and a higher Tr and Dm in the BF on sand. When we compare between surfaces, sand provokes higher muscle fatigue in the RF with 29.66% more contraction time and 35.29% more muscle belly deformation.

These findings coincide with studies like that of García-Manso, Rodríguez-Ruiz, Rodríguez-Matoso et al. (2011) who evaluated the state of the muscle immediately after an ultra-resistance triathlon and found an increase in the BF in the Tc, Tr, and Dm once the race was finished. The effect of muscle fatigue generates a loss in contractile capacity shown by changes in neuromuscular response and muscle contractile capacity (García-Manso, Rodríguez-Matoso, Sarmiento et al., 2012). Wiewelhove et al. (2015) observed a significant increase in Tc in the RF and BF after high-intensity interval training during six days, which is a potential marker for fatigue and recovery control. A reduction of stiffness (increasing Dm) causes a loss of strength and explosive power, decreasing the ability to generate force rapidly (Wiewelhove et al., 2015).

In contrast, authors like López-Rovira and Amorrich-del Fresno (2014) revealed a statistically significant decrease in Dm after exercise (p<0.01). However, after a recovery muscle massage, they detected a significant maximum deformation increment (p<0.01) due to a decrease in muscle stiffness and tone. In short-to medium-duration resistance events with an elevated intensity (2 minutes on a cycle ergometer), the participants showed statistically significant decreases in Dm values (Carrasco et al., 2011). These results highlight the importance of controlling parameters like the intensity of the exercise, the duration, the type of activity practiced, and the magnitude of the stimulation, as very short stimulations will not fatigue type I fibres (García-Manso, Rodríguez-Matoso, Sarmiento et al., 2012).

Resistance to fatigue and muscle stiffness can be a risk factor for injury. Alentorn-Geli et al. (2015) analysed the risk of anterior cruciate ligament injury in male football players. Their results were that the players with an injury at the time of the test had higher values in Tc, Tr, and Ts in the RF and in Dm in the BF compared to those players without injuries. These results must be taken into account when choosing athletes with a high anterior cruciate ligament injury risk and also for designing adequate prevention programmes for anterior cruciate ligament injuries in female rugby players. As an alternative use, sand can also be used as an effective rehabilitation surface, as it reduces force impact due to its ability to absorb impact, which is useful for adequate injury rehabilitation (Impellizzeri et al., 2008). However, the higher fatigue on the sand surface demonstrated in this study requires a higher control of training load. This control would allow the use of sand for sport training due to the benefits in the athlete's performance, incorporating exercises on sand during their firm surface training (Mirzaei et al., 2013).

Although TMG is a reliable method, various methodological factors exist that can affect its reliability, such as the position of the sensor in relation to the muscle belly, the pressure point of the sensor, and the placement of the electrodes (Tous-Fajardo et al., 2010). To minimise these factors, the zone where the electrodes were placed were marked with a felt-tip pen so that they were always put in the same place; the measure of the sensor point was also marked, and the tests were always measured by the same person. One of the limitations of this study was the evaluation of only two muscle groups. It is possible to evaluate other lower trunk muscle groups, as well as increase the number and intensity of the stimulations in each muscle group. In future research, the measurement of serum concentrations of creatine kinase (CK), C-reactive protein (CRP), and urea, as well as of delayed onset muscle soreness (DOMS) at the end and after 72h, could provide information on the evolution and correlation of these parameters with the TMG variables.

CONCLUSION

Information on skeletal muscle structure is very important for observing changes in the muscles and improving training processes of athletes (Dahmane et al., 2001). Also, the follow up and control with TMG helps training, as it allows an adequate monitoring and improves injury prevention programmes, decreasing their incidence (Vasilescu et al., 2008). Nonetheless, its use in the sport field is still incipient. Therefore, the main conclusion of this research is that repetitive-sprint-actions on sand regarding the natural grass produces higher levels of muscle fatigue on rectus femoris but not on biceps femoris. Hence, this research can help technical and medical personnel for predicting and orientating future prescription of training load and avoid muscle injury risk.

ACKNOWLEDGEMENTS

We appreciate the collaboration of the participants and families who were part of the study and we would like to thank all the sports clubs who supported this research.

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5.2. Discusión general de la Tesis Doctoral

El principal propósito de la Presente Tesis Doctoral fue analizar la influencia de la superficie de juego en el rendimiento físico y en la respuesta fisiológica y muscular de los deportistas. Para ello, se realizaron 6 estudios cuyos objetivos específicos fueron: **1)** evaluar la influencia de la superficie de juego y las dimensiones del espacio en el perfil de movimiento de las mujeres futbolistas sub-élite durante varios juegos reducidos de cuatro jugadores por equipo; **2)** evaluar la influencia de la superficie de juego y las dimensiones del espacio en la respuesta fisiológica, la fatiga y la percepción de las jugadoras de fútbol sub-élite en diferentes juegos reducidos de cuatro jugadores por equipo; **3)** analizar las demandas de potencia metabólica de varios juegos reducidos de posesión y sin portero jugados sobre tres superficies de juego diferentes; **4)** analizar la influencia de la superficie de juego sobre la respuesta física y fisiológica de los jugadores de fútbol amateur a través de un protocolo de partido simulado; **5)** evaluar la influencia de la superficie de juego sobre los patrones fisiológicos y la respuesta muscular de los jugadores de fútbol mediante un protocolo de partido simulado que incorpora esprines repetidos y acciones no lineales a máxima velocidad; **6)** descubrir la influencia de la arena y el césped natural sobre los parámetros musculares en jugadoras de rugby tras un test que induce a la fatiga.

5.2.1. Influencia de la superficie de juego y las dimensiones del espacio en el rendimiento físico, las respuestas fisiológicas y metabólicas, la fatiga y la percepción de jugadoras de fútbol sub-élite durante la realización de diferentes tipos de juegos reducidos.

El principal resultado de los estudios 1, 2 y 3 fue que tanto la superficie de juego como las dimensiones del espacio juegan un papel determinante en las acciones de alta intensidad de las jugadoras de fútbol sub-élite. Por ello, es recomendable tener en cuenta estos dos factores a la hora de diseñar los juegos reducidos. Los juegos reducidos utilizados en estudios no incluyeron portero ni porterías, siendo el objetivo principal de la tarea el mantener la posesión de balón el máximo tiempo posible. Esto se debe a que los juegos reducidos de posesión han evidenciado una mayor intensidad que aquellos que incorporan porteros (Gaudino, Alberti, &

Iaia, 2014). No obstante, la mayoría de los trabajos presentes en la literatura incluyen o porteros o porterías pequeñas de diferente índole (Brito et al., 2012; Casamichana & Castellano, 2010; Hodgson et al., 2014). Por otro lado, la carga interna durante la práctica del fútbol parece similar tanto en hombres como en mujeres, ya que la FC_{pico} y la FC_{media} fueron equivalentes a otros estudios que analizaron tanto juegos reducidos, como partidos (Casamichana & Castellano, 2010; Castellano, Casamichana, & Dellal, 2013; Köklü, Alemdaroğlu, Dellal, & Wong, 2015). Sin embargo, al comparar los resultados del estudio 3 con el estudio de Gaudino et al. (2014), encontramos que la carga metabólica durante los juegos reducidos en mujeres es distinta a la de los hombres. Por estas razones, hay que ser cuidadoso a la hora de comparar los resultados de los estudios 1, 2 y 3 con otros trabajos previos centrados en hombres.

En línea con autores como Brito et al. (2012), aunque utilizando otras superficies (tierra, césped artificial y hierba natural), la intensidad de los juegos reducidos varía de una superficie a otra, probablemente debido a que cada superficie cuenta con unas propiedades mecánicas distintas (Sánchez-Sánchez et al., 2016; Sánchez-Sánchez et al., 2014b). En este sentido, nuestros hallazgos sugieren que la tierra es el pavimento menos recomendado para la práctica deportiva, pues sobre ella, las jugadoras presentaron un perfil físico y fisiológico más bajo. Además, jugar al fútbol sobre tierra requirió una menor demanda energética tanto relativa (carga metabólica relativa) como absoluta (carga metabólica absoluta). Estos resultados probablemente se deban a una menor estabilidad sobre este pavimento, lo que explica el menor número de acciones explosivas y la baja satisfacción de las participantes con la tierra (Sánchez-Sánchez et al., 2016; Sánchez-Sánchez et al., 2014b).

Desde un punto de vista del rendimiento físico, la hierba natural favoreció una mayor intensidad de juego. Por eso, es probable que la práctica del deporte sobre esta superficie requiera de una mayor tasa de descomposición de fosfato de creatina y glucólisis debido a mayores tasas de rotación de energía anaeróbica (Bangsbo et al., 2006; Brito et al., 2012; Sánchez-Sánchez et al., 2016). No obstante, es preciso señalar que dichas diferencias sólo se encontraron en los juegos reducidos que causaron una mayor carga externa (SSG 600). Estos resultados, contradicen los hallazgos de estudios previos que destacan un rendimiento físico similar sobre césped artificial y hierba natural, no encontrando diferencias ni en los tiempos de esprín ni en las acciones de alta intensidad (Hughes et al., 2013; Nédélec et al., 2013). Esto puede ser debido a que el comportamiento técnico-táctico es diferente sobre cada una de estas dos superficies (Andersson et al., 2008). Sin embargo, consideramos que probablemente sea debido a diferencias en las propiedades mecánicas de ambos pavimentos, ya que varios estudios sugieren que propiedades mecánicas como la absorción de impactos o la tracción rotacional juegan un papel decisivo en el número y duración de las acciones de alta intensidad (Sánchez-Sánchez et al., 2016; Sánchez-Sánchez et al., 2014b).

Algo similar ocurre al analizar la respuesta fisiológica de las deportistas en estas dos superficies. Los últimos estudios comparativos entre césped artificial y hierba natural indican que la práctica deportiva sobre estas dos superficies no causa diferencias ni en la frecuencia cardiaca media y pico ni en la concentración de lactato (Hughes et al., 2013; Nédélec et al., 2013). Por el contrario, los resultados obtenidos en el estudio 2 de esta Tesis Doctoral, muestran una mayor carga fisiológica sobre el césped natural que sobre el césped artificial, aunque sólo en el SSG 600, que fue donde las jugadoras obtuvieron una mayor carga interna. Al igual que con los patrones físicos, esto probablemente se deba a una gran diferencia entre las propiedades mecánicas de las dos superficies seleccionadas en este estudio (Sánchez-Sánchez et al., 2016; Sánchez-Sánchez et al., 2014b), y a la gran diversidad existente en las respuestas mecánicas de los pavimentos sintéticos (Sánchez-Sánchez et al., 2014a). En este sentido, los pavimentos con mayor absorción de impactos parecen inducir a una mayor carga fisiológica en los futbolistas que aquellos pavimentos con una menor absorción de impactos (Sánchez-Sánchez et al., 2016).

Por otro lado, coincidiendo con Brito et al. (2012), la superficie de juego no parece alterar el deterioro del rendimiento en un salto con contramovimiento. Sin embargo, al contrario que varios trabajos previos, los resultados presentes en el estudio 2, mostraron un aumento de rendimiento después de la tarea principal, en lugar de sufrir un decrecimiento con motivo de la fatiga acumulada (Brito et al., 2012; Sánchez-Sánchez et al., 2016; Sánchez-Sánchez et al., 2014b). Esto, probablemente se deba a que los juegos reducidos analizados en este estudio duraron 4 minutos. La ausencia de diferencias en esta variable puede explicar por qué las jugadoras percibieran un nivel de fatiga similar en ambas superficies. Por último, aunque la satisfacción general de las participantes con ambas superficies fue similar, éstas indicaron una mayor facilidad para regatear sobre césped artificial, lo que indica una mayor estabilidad sobre dicha superficie para realizar cambios de dirección (Gains, Swedenhjelm, Mayhew, Bird, & Houser, 2010). En contraposición a lo anterior, las jugadoras destacaron una mayor dificultad para hacer tacles sobre el pavimento artificial, demostrando la existencia de pequeñas diferencias en el estilo de juego sobre cada superficie (Andersson et al., 2008). De hecho, este factor puede ser uno de los causantes de las pequeñas diferencias en la respuesta física y fisiológica de las jugadoras encontradas entre ambos pavimentos, teniendo que ser tenido en cuenta en futuros estudios.

En cuanto a las dimensiones de espacio, varios estudios en hombres han concluido que aumentar el tamaño del espacio de los juegos reducidos aumenta la intensidad de juego, viéndose reflejado en variables como distancia total, metros por minuto, ratio trabajo descanso, velocidad máxima o velocidad media (Casamichana & Castellano, 2010; Hodgson et al., 2014). Los resultados de los estudios 1 y 3 están en línea con estos trabajos previos dado que las jugadoras mostraron una intensidad de juego y una carga metabólica mayor en los juegos reducidos de mayores dimensiones. Estos resultados demuestran que los entrenadores pueden usar el tamaño del espacio para controlar la intensidad de sus juegos reducidos.

Uno de los principales hallazgos obtenidos en esta tesis doctoral es que los resultados de los indicadores globales de rendimiento y de la carga interna del juego reducido mediano fueron similares y en algunos casos superiores a los resultados del juego reducido de mayores dimensiones. Esto demuestra que, si las dimensiones del espacio del juego reducido son demasiado grandes, el rendimiento de los futbolistas puede verse afectado negativamente; resaltando la importancia de utilizar las dimensiones de los juegos reducidos como medio para controlar la intensidad del ejercicio. Aunque es la primera vez que un estudio reporta este tipo de resultados, en la literatura científica existen varios trabajos que no encontraron diferencias en el rendimiento físico de los deportistas al aumentar las dimensiones del espacio (Kelly & Drust, 2009). Por esta razón, a la hora de optar por un espacio u otro hay que tener en cuenta las características y habilidades de los deportistas. En cuanto a la respuesta fisiológica de los deportistas, el efecto que tienen los juegos reducidos de mayor tamaño sobre la carga interna de los deportistas no está del todo claro. Así, mientras este estudio y trabajos previos como el de Köklü et al. (2015) y Rampinini et al. (2007) sugieren una mayor carga fisiológica en los juegos reducidos de mayores dimensiones, Kelly y Drust (2009) no encontraron dichas diferencias. El estudio 2 de esta Tesis Doctoral muestra un descenso de la respuesta fisiológica en el juego reducido con las dimensiones del espacio más grande con respecto al mediano. Por ello, los entrenadores tienen que tener cuidado al elegir el tamaño del espacio, ya que si seleccionan unas dimensiones demasiado grandes es probable que la carga fisiológica de los deportistas sea menor a lo esperado.

5.2.2. Respuesta física y fisiológica entre el césped artificial y césped natural en jugadores amateur de fútbol

Una de las principales limitaciones de los estudios 1, 2 y 3, es que no analizaron las propiedades mecánicas de las superficies seleccionadas. Esta limitación, puede hacerse extensible a otros trabajos presentes en la literatura científica, pues la mayoría de los estudios que comparan entre superficies, no incluyen ninguna información sobre las propiedades mecánicas de las superficies utilizadas. Esta información es necesaria para poder comprender el efecto de las superficies en el rendimiento deportivo, ya que varios estudios han reportado una gran variabilidad entre la respuesta mecánica de los sistemas de césped artificial (McGhie & Ettema, 2013; Sánchez-Sánchez et al., 2014a). Así, esta diversidad se aprecia al revisar trabajos previos sobre césped artificial; encontrando valores desde 31,45 ± 6,24% hasta 70,30 ± 61,47% en la absorción de impactos (Encarnación-Martínez et al., 2017; Sánchez-Sánchez et al., 2014a); desde 3,43 ± 0,43 mm hasta 7,34 ± 60,43 mm en la deformación vertical (Sánchez-Sánchez et al., 2014a; Sánchez-Sánchez et al., 2016) y desde 32,66 ± 3,17 hasta 50,50 ± 2,19% en la energía de restitución (Sánchez-Sánchez et al., 2016; Ubago-Guisado, 2017). Por esta razón, uno de los principales valores añadidos de los estudios 4 y 5, es que se incorporan las propiedades mecánicas tanto del césped artificial como de la hierba natural utilizados en dichos trabajos.

A pesar de que las dos superficies utilizadas en estos estudios presentaron diferencias significativas en las tres variables mecánicas analizadas, los jugadores presentaron resultados parejos en ambas superficies; exceptuando algunas acciones del test de agilidad. Estos hallazgos van en línea con los estudios previos, de forma que los nuevos sistemas de césped artificial parecen haber alcanzado las prestaciones de las superficies de hierba natural (Hughes et al., 2013; Nédélec et al., 2013; Stone et al., 2014). Si analizamos la respuesta fisiológica de los deportistas, los resultados del estudio 4 y 5 sugieren que entrenar sobre césped artificial no causa una respuesta cardiovascular diferente (misma frecuencia cardiaca tanto en latidos por minuto como en $\%FC_{max}$) que la hierba natural. Esta ausencia de diferencias coincide con los resultados de Hughes et al. (2013) y Nédélec et al. (2013) quienes no encontraron diferentes concentraciones de lactato ni diferente frecuencia cardiaca media y pico en función de la superficie utilizada. En un estudio previo realizado solo con sistemas de césped artificial, se evidenció una mayor respuesta fisiológica en los sistemas con mayor absorción de impacto (Sánchez-Sánchez et al., 2016). Sin embargo, en dicho trabajo se hallaron diferencias de hasta el

20% entre los sistemas utilizados. Por ello, la diferencia del 6,10% existente entre las dos superficies utilizadas en los estudios 4 y 5 parece ser demasiado baja como para alterar significativamente la respuesta fisiológica de los deportistas. No obstante, futuros estudios deberían analizar la respuesta fisiológica de los deportistas en base a su frecuencia cardiaca de reserva en lugar de utilizar la frecuencia cardiaca máxima, ya que, el método empleado tanto en estos estudios, como en trabajos previos (Brito et al., 2012; Nédélec et al., 2013; Sánchez-Sánchez et al., 2016) puede verse afectado por la propia variabilidad cardiaca de los deportistas (Dellal, Jannault, Lopez-Segovia, & Pialoux, 2011).

Cabe señalar que, varios autores han reflejado en sus estudios menores tiempos de esprín en las superficies con una menor capacidad de absorber los impactos y mayores valores de energía de restitución (Sánchez-Sánchez et al., 2016; Sánchez-Sánchez et al., 2014b); probablemente debido a un menor tiempo de contacto con el pavimento (McGhie & Ettema, 2013). A pesar de que la respuesta mecánica de las dos superficies utilizadas fue distinta, en el estudio 4 no se encontraron diferencias entre superficies en los tiempos de esprín, coincidiendo además con los últimos trabajos comparativos entre el césped artificial y la hierba natural (Hughes et al., 2013; Nédélec et al., 2013). Esto probablemente se deba a que las diferencias mecánicas entre ambas superficies no son lo suficientemente altas como para alterar la técnica de carrera de los deportistas. Por esa razón, aunque los jugadores pueden percibir que jugar sobre césped artificial es más complicado (Andersson et al., 2008), estos hallazgos sugieren un rendimiento físico similar sobre ambas superficies.

Por otro lado, en el estudio 4 sí se encontraron ligeras diferencias entre estas dos superficies en el rendimiento de los deportistas durante las acciones de agilidad a máxima intensidad que se realizaron en el primer bloque del protocolo de partido simulado. En este caso, los futbolistas mostraron un menor tiempo de carrera y una mayor velocidad sobre césped artificial que sobre la hierba natural. Esto sugiere la existencia de diferencias en la respuesta biomecánica de los jugadores ante los giros y los cambios de dirección en función de la superficie de juego (McGhie & Ettema, 2013; Stone et al., 2014; Villwock, Meyer, Powell, Fouty, & Haut, 2009). Por ello, es posible que las diferencias en la absorción de impactos y la energía de restitución no sean suficientemente altas para modificar los patrones de carrera en esprines lineales, pero si para afectar a los giros y cambios de dirección (Encarnación-Martínez et al., 2017; Sánchez-Sánchez et al., 2016). En cualquier caso, contrariamente a los hallazgos de Hughes et al. (2013) y, coincidiendo con Gains et al. (2010), las acciones que requieren cambio de dirección no son más lentas sobre césped artificial que sobre hierba natural; pudiendo ser, incluso, más rápidas en el sistema sintético. Esta disparidad en los resultados señalados en sendos trabajos probablemente se deba a una gran diferencia en las propiedades mecánicas de las superficies utilizadas (Sánchez-Sánchez et al., 2016; Sánchez-Sánchez et al., 2014b). De hecho, Sánchez-Sánchez et al. (2014b) demostraron que el rendimiento en acciones con cambios de dirección sobre césped artificial está ligado a las propiedades mecánicas de absorción de impacto y tracción rotacional.

Los resultados obtenidos tanto en el CMJ como en la TMG dentro del estudio 5, sugieren que la superficie de césped artificial no causa un estímulo diferente sobre el sistema neuromuscular de los futbolistas que el césped natural (Brito et al., 2012; Sánchez-Sánchez et al., 2014b). No obstante, futuros estudios deberían analizar estas dos variables a las 24 h y 48 h posteriores al ejercicio, ya que aportarían información relevante sobre si la superficie de césped artificial influye de forma diferente en el tiempo de recuperación muscular de los deportistas (Stone et al., 2014). Dentro de la prueba de TGM, es preciso señalar que varios autores han puesto en duda la fiabilidad de esta herramienta para detectar cambios en las propiedades mecánicas de los músculos como consecuencia de la fatiga (Wiewelhove et al., 2017). Aunque Krizaj et al. (2008) indicarin un error bajo de entre 0,5 y 2,0% y una alta reproductibilidad (ICC: 0,85 – 0,98) en los cinco parámetros (Dm: 0,98; Tc: 0,97; Td: 0,94; Ts: 0,89; Tr: 0,86).

Si analizamos los resultados obtenidos con la TMG de forma pormenorizada, la ausencia de diferencias en los variables Tc, Td y Dm refuerzan la hipótesis de que la superficie de juego no altera la fatiga muscular de los deportistas. Estos resultados eran esperables, dado que Stone et al. (2014) no encontraron diferencias entre estas dos superficies en los valores de creatina quinasa ni en la percepción del dolor muscular. Por el contrario, las diferencias encontradas en las variables de Tr y Ts en los dos grupos musculares estudiados, indicarían pequeñas diferencias en la activación de los músculos recto femoral y bíceps femoral en función de la superficie de juego. Sin embargo, debido a la baja fiabilidad de estas dos variables en comparación con el Dm, Tc y Td, es probable que estas diferencias sean debidas a la coactivación de los grupos musculares contiguos (Krizaj et al., 2008), en vez de a la influencia del pavimento.

En base a estos resultados, los estudios 4 y 5 destacan la importancia de controlar las propiedades mecánicas de las superficies de juego en los estudios comparativos. Por ello, a pesar de que los indicios sugieren que los sistemas artificiales se han equiparado a las superficies naturales, no se puede establecer una relación de causa-efecto si no se define la respuesta mecánica de ambas superficies (Sánchez-Sánchez et al., 2016; Sánchez-Sánchez et al., 2014b).

5.2.3. Respuesta física y fisiológica entre el césped natural y la arena de playa en jugadoras amateur de rugby

La continua búsqueda por encontrar un mejor método de preparación para los deportistas ha hecho que varios autores comiencen a explorar el uso de la arena de playa en los entrenamientos deportivos, debido a su alta absorción de impactos (Binnie et al., 2014; Pinnington et al., 2005). Los principales hallazgos obtenidos en el estudio 6 indican que el test RSA sobre arena produce un estímulo diferente sobre la musculatura del tren inferior que el césped natural.

Al analizar el rendimiento durante el RSA se comprueba que las deportistas alcanzaron mayores picos de velocidad media sobre la superficie de césped natural, causando por lo tanto menores tiempos de esprín. Estos resultados eran claramente esperados, ya que varios investigadores han obtenido velocidades más bajas al correr sobre la arena de playa debido a la alta absorción de impactos de esta superficie (Brito et al., 2012). A pesar de los menores picos de velocidad en dicho test sobre arena, las jugadoras de rugby mostraron un incremento en los valores de TC y Dm sobre el recto femoral y de Tr y Dm sobre los de bíceps femoral. Esto indica una mayor fatiga muscular sobre dicha superficie en comparación con la hierba natural (García-Manso et al., 2009; Smith & Hunter, 2006). Estos resultados son importantes, ya que indican una diferencia en la técnica de carrera sobre esta superficie (Binnie et al., 2014), de forma que ejercitarse sobre arena, puede causar un mayor estímulo muscular (Miyama & Nosaka, 2004). Por ello, en caso de incorporar esta superficie al entrenamiento o a la readaptación deportiva en el fútbol o el rugby es preciso un buen control de la carga (Mirzaei, Norasteh, & Asadi, 2013).

Capítulo 6

CONCLUSIONES Y APORTACIONES PRINCIPALES DE LA TESIS DOCTORAL [CONCLUSIONS AND MAIN CONTRIBUTIONS OF THE DOCTORAL THESIS]

6.1. Conclusiones

A continuación, se enumeran las conclusiones de cada uno de los seis estudios presentes en esta Tesis Doctoral:

6.1.1. <u>Estudio 1:</u>

La respuesta física de las mujeres futbolistas es mayor sobre césped artificial que sobre tierra. En los juegos reducidos más intensos, el césped natural genera una carga externa más elevada que su homónimo el césped artificial. Las dimensiones del espacio en los juegos reducidos afectan a la respuesta física de las mujeres futbolistas sub-élite, aumentando en los juegos reducidos de mayor tamaño. No obstante, si se incrementa en exceso las dimensiones del juego reducido, la respuesta física de las futbolistas no aumenta.

6.1.2. <u>Estudio 2:</u>

Las dimensiones del campo pueden ser usadas para controlar la intensidad del juego reducido dado que los juegos reducidos de mayor tamaño causan una mayor respuesta fisiológica que los de menor tamaño. Sin embargo, si se aumentan en exceso las dimensiones, la respuesta fisiológica decrece. Por otro lado, es recomendable no utilizar la tierra para la práctica del fútbol dado que la interacción superficie-jugador y superficie-balón es negativamente percibida por las mujeres futbolistas, además de causar una frecuencia cardiaca más baja. Finalmente, aunque las jugadoras mostraron una satisfacción similar con el césped artificial y la hierba natural, la segunda, produjo una mayor frecuencia cardiaca en los juegos reducidos, por lo que el césped natural causa una mayor carga interna en las jugadoras de fútbol que el césped artificial.

6.1.3. <u>Estudio 3:</u>

La realización de un juego reducido sobre tierra causa una menor respuesta metabólica que sobre las otras dos superficies. Además, los resultados de este estudio muestran una mayor demanda metabólica sobre la hierba natural que sobre el césped artificial. Por otro lado, las dimensiones del juego reducido tienen un efecto directo en la carga metabólica de dicha tarea. No obstante, dichas demandas metabólicas dejan de incrementarse cuando las dimensiones del juego reducido son demasiado altas.

6.1.4. <u>Estudio 4:</u>

La variabilidad mecánica entre el césped natural y el césped artificial no es suficientemente alta como para alterar el rendimiento en esprín y la respuesta fisiológica de los futbolistas amateur ante un mismo estímulo. No obstante, estas diferencias sí afectan ligeramente al rendimiento en los giros y cambios de dirección. Las propiedades mecánicas de las superficies deportivas son más importantes que la propia tipología del pavimento, por lo que futuros estudios deben incluir información sobre las propiedades mecánicas de las superficies deportivas.

6.1.5. <u>Estudio 5:</u>

La respuesta mecánica del césped artificial difiere de la del césped natural. No obstante, dicha variabilidad mecánica no afecta a la respuesta fisiológica y muscular de los futbolistas amateur ante un mismo estímulo. Por ello, dejando de lado las acciones técnicas y tácticas, los resultados de este estudio sugieren que los entrenadores no tienen que modificar sus programas de entrenamiento en función de la superficie de juego utilizada. No obstante, la baja absorción de impactos de la superficie de césped artificial utilizada en este estudio no permite hacer extensible estos resultados a otros sistemas de césped artificial con una mayor absorción de impactos.

6.1.6. <u>Estudio 6:</u>

El rendimiento de las jugadoras de rugby en el test de esprines repetidos es menor sobre arena (mayor tiempo de esprín) que sobre césped natural. Sin embargo, la respuesta fisiológica pico es similar en ambas superficies. Así mismo, estas acciones de esprines repetidos sobre arena causan un mayor Tc y Dm en el recto femoral que sobre césped natural. Esto evidencia que correr sobre arena causa diferentes estímulos musculares, por lo que los entrenadores deberían considerar estos hallazgos cuando prescriban entrenamientos en arena.

6.2. Conclusions

Below, the conclusion of the six studies presented into this Doctoral Dissertation is presented:

6.2.1. <u>Study 1:</u>

Physical responses of female soccer players are higher on artificial turf than dirt. Natural grass provides higher external load than artificial turf in the most intense small-sided games. The intensity of game is affected by the pitch size, increasing in larger small-sided games. However, if pitch size increases too much the physical responses of players do not improve.

6.2.2. <u>Study 2:</u>

Pitch size can be used to manipulate the internal load of SSGs as big pitches provoke greater heart rate responses than the smaller ones. However, coaches should bear in mind that playing on very large pitches may reduce the internal load on female soccer players. On the other hand, it is recommended not playing soccer on dirt surfaces because surface-player and surface-ball interactions on this surface are rated poorly by soccer players. Moreover, playing on dirt also elicits smaller heart rate responses than playing on other surfaces. Finally, female players reported similar satisfaction with the artificial turf systems and the natural grass surfaces. However, playing on natural grass surface elicited greater heart rate responses in the SSGs, suggesting that a higher internal load can be achieved on natural grass than on artificial turf.

6.2.3. <u>Study 3:</u>

Playing on dirt reduces the metabolic power of small-sided games in comparison with the other two surfaces. Moreover, this study shows that natural grass required higher metabolic load than artificial turf. On the other hand, pitch size has a direct effect on the metabolic load of small-sided games. Nevertheless, the metabolic demands stop increasing when the pitch size of the small-sided game is too high.

6.2.4. <u>Study 4:</u>

The mechanical variability between natural turf and artificial turf does not alter the physical and physiological responses of amateur football players to the same stimulus. However, these differences do slightly affect the performance in turns and changes in direction. The mechanical properties of sports surfaces are more important than their typology, so future studies should include information about the mechanical properties of sports surfaces.

6.2.5. <u>Study 5:</u>

The mechanical response of artificial grass differs from that of natural grass. However, the physiological and muscular response of amateur soccer players to the same stimulus are not affected by such mechanical variability. Therefore, living aside the technical and tactical actions, the results of this study suggest that coaches not have to modify the training programmes regardless the playing surface. Nonetheless, the low impact reduction of the artificial turf surface selected in this study do not allow to generalise the findings of this work to other artificial turf systems with higher impact reduction.

6.2.6. <u>Study 6:</u>

The performance of rugby players during the repetitive-sprint-actions is lower on sand (higher sprint time) than on natural grass. However, the peak physiological response is similar in both surfaces. Furthermore, repetitive-sprint-actions on sand produces higher Tc and Dm in the rectus femoris than on natural grass. This evidences that running on sand cause different muscular stimulus, so coaches should consider these findings when prescribing training in sand.

6.3. Aportaciones principales de la Tesis Doctoral

A continuación, se exponen las aportaciones de esta Tesis Doctoral:

6.3.1. Estudios 1, 2 y 3:

Estos resultados sugieren que la tierra no debería ser utilizada para la práctica deportiva, ya que limita la respuesta física y fisiológica de los deportistas. Así mismo, es la superficie peor valorada, de forma que los deportistas prefieren optar por superficies de hierba natural o de césped artificial. Al comparar la respuesta de las futbolistas en los juegos reducidos sobre estas dos superficies, estos tres estudios mostraron una mayor respuesta física y fisiológica en las superficies naturales que en las de césped artificial, aunque sólo en los juegos reducidos más intensos. Estos resultados sugieren, por lo tanto, que entrenar en hierba natural genera una mayor carga interna que el césped artificial probablemente debido a unos mayores niveles de absorción de impactos.

Por otro lado, a la hora de diseñar un juego reducido, la intensidad del ejercicio puede controlarse por medio de las dimensiones elegidas para dicha tarea, ya que la respuesta física y fisiológica de los deportistas aumenta a medida que se incrementan las dimensiones del terreno de juego. Sin embargo, estos tres trabajos evidencian que la carga interna y externa de los juegos reducidos puede decrecer cuando las dimensiones del campo son demasiado grandes. Por lo que los entrenadores tienen que tener cuidado a la hora diseñar los espacios de los juegos reducidos.

6.3.2. **Estudios 4 y 5:**

Las propiedades mecánicas de las superficies parecen jugar un papel clave en el rendimiento, por ello, para poder establecer relaciones causa-efecto, los estudios que comparan entre superficies deben añadir las propiedades mecánicas de los pavimentos incluidos en sus estudios. En este caso, las diferencias en las propiedades mecánicas mostradas por las dos superficies seleccionadas parecen ser demasiado pequeñas como para causar diferencias en la respuesta de los deportistas. Así, la práctica deportiva sobre césped artificial no tiene un efecto negativo en el rendimiento, en la respuesta fisiológica o en la respuesta neuromuscular (respuesta explosiva en salto y respuesta de los músculos recto femoral y bíceps femoral ante un estímulo eléctrico determinado). En definitiva, los entrenamientos y programas de recuperación que utilicen tareas estandarizadas no tendrían que modificarse en base a la superficie de juego.

6.3.3. **Estudio 6:**

Dado que el objetivo del entrenamiento es preparar a los jugadores para las competiciones, el uso de la arena puede ser útil para este propósito. Este trabajo muestra que correr sobre la arena causa un menor rendimiento en esprín (menor velocidad pico) que correr sobre la hierba natural, pero correr sobre arena no causa una frecuencia cardiaca media diferente. Por otra parte, la superficie de juego sí causó una respuesta diferente en el recto femoral ante un mismo estímulo eléctrico, lo que sugiere que el correr sobre arena requiere de una técnica de carrera diferente. Por esa razón, los entrenadores pueden utilizar entrenamientos en la arena cuando quieran aumentar la carga fisiológica de los jugadores, pero no la intensidad física.

6.4. Main contributions of the Doctoral Dissertation

The main contributions of the present Doctoral Dissertation are shown below:

6.4.1. <u>Studies 1, 2 and 3:</u>

These outcomes suggest that dirt pitches should not be used in sports as it limits the physical and physiological responses of players. Furthermore, players affirm that playing on this surface is more challenging than in grass or turf. When comparing the soccer players' responses between artificial turf and natural grass, these three studies showed a higher physical and physiological response on natural surfaces than on artificial turf, but only in the most intense small-sided games. These findings suggest that playing on natural grass cause higher internal load than artificial turf probably due to higher impact reduction.

On the other hand, coaches can use the pitch size to control the intensity of the exercise when designing a SSG; as players' responses seem to increase in bigger pitches. Nonetheless, these three studies expose that the internal and external load of small-sided games can decrease when the pitch dimensions are too big. Therefore, coaches should take care when designing the pitch size of small-sided games.

6.4.2. <u>Studies 4 y 5:</u>

The mechanical properties of surfaces seem to play a key role in the players' performance. Thus, to establish cause-effect relationships, studies that compare surfaces should include the mechanical properties of these pavements. These two studies indicate that the differences between the two selected surfaces are not high enough to cause differences in players' responses. Thus, playing on artificial turf may not have a negative effect on players' performance or on their neuromuscular and physiological responses. For that reason, there is no need to modify the training and recovery programs based on the sports surface.

6.4.3. <u>Study 6:</u>

As the objective in training is to prepare players for competitions, the use of sand may be useful for this purpose. This study shows that running on sand cause lower sprint performance (lower peak speed) than on natural grass but running on sand do not provoke a different mean heart rate response. On the other hand, the playing surface evidenced to cause different responses on rectus femoris to the same electrical stimulus, what suggests that running on sand requires different running technique. For that reason, coaches may use sand in training when they want to increase the physiological load of players but not the physical intensity.

Capítulo 7

LIMITACIONES Y FUTURAS LÍNEAS DE INVESTIGACIÓN [LIMITATIONS AND FUTURE RESEARCH LINES]

7.1. Limitaciones y futuras líneas de investigación

Los seis estudios incluidos en la presente Tesis Doctoral tienen una serie de limitaciones importantes que deben ser consideradas.

7.1.1. Estudios 1, 2 y 3:

Estos trabajos analizaron juegos reducidos de posesión de 4 contra 4, por lo que la comparación con otras investigaciones que utilizan una metodología diferente debe hacerse con cuidado. Por otra parte, no hay muchos estudios que analicen la influencia de las dimensiones del espacio y la superficie del juego en las jugadoras de fútbol, por lo que se requiere más investigación para entender el efecto de estas dos variables en las mujeres futbolistas. Varios estudios han demostrado una alta variabilidad existente entre los sistemas de césped artificial, evidenciando que los resultados de estos estudios no pueden ser generalizados (Sánchez-Sánchez et al., 2014a). Los estudios futuros deben incluir las propiedades mecánicas de las superficies seleccionadas. Por otro lado, los juegos reducidos de estas investigaciones duraron 4 minutos, de forma que los trabajos venideros deberían aumentar la duración de sus juegos reducidos. Por último, existen dudas sobre la fiabilidad de la tecnología GPS de 10 Hz para medir la potencia metabólica (Buchheit, Manouvrier, Cassirame, & Morin, 2015). Por ello, es necesario ser cauteloso al considerar los resultados del estudio 3.

7.1.2. Estudios 4 y 5:

El césped artificial incluido en estos estudios no cumplió con los criterios establecidos por las organizaciones internacionales como FIFA o CEN, al tener una baja capacidad de absorción de impactos. Por esta razón, las conclusiones de este trabajo no pueden extenderse a aquellos sistemas de césped artificial con mayor capacidad de absorción de impactos. Los trabajos futuros deben incluir sistemas de césped artificial cuyas propiedades mecánicas cumplan estos criterios. La muestra utilizada en estas dos investigaciones estuvo compuesta por jugadores de futbol amateur, que tienen una menor capacidad para realizar esprines repetidos y acciones de agilidad a máxima velocidad. Por ello, la influencia de la superficie de juego en los jugadores profesionales podría ser diferente. Además, los participantes sólo completaron los tres primeros bloques del SSP, en lugar de seis bloques que lo conforman. Por último, el protocolo de partido simulado no se ve afectado por las características del juego existentes en los partidos reales (ej. menos tacles y más pases cortos sobre césped artificial) (Andersson et al., 2008), siendo posible que en los partidos existan algunas diferencias entre estas superficies. En el estudio 5, las respuestas neuromusculares de los jugadores después del protocolo de partido simulado se evaluaron a través de un TMG. Algunos autores han cuestionado la fiabilidad de esta tecnología para detectar cambios en las respuestas neuromusculares debido a la fatiga (Wiewelhove et al., 2017). Por ello, se requiere precaución al considerar los hallazgos obtenidos por esta técnica. Por otra parte, la evaluación de las respuestas neuromusculares de más grupos musculares y a las 48 y 72 horas después de la prueba, proporcionarían más información sobre la recuperación de los jugadores en diferentes superficies.

7.1.3. Estudio 6:

Al igual que en el estudio 5, las respuestas neuromusculares de los participantes se registraron a través de un TMG. Dado que existen dudas sobre la fiabilidad de este instrumento para detectar los cambios causados por la fatiga en el perfil neuromuscular de los jugadores, es preciso ser cuidadosos a la hora de analizar estos resultados. De hecho, trabajos previos han informado de que la posición del sensor en relación con el vientre muscular, el punto de presión del sensor o la colocación de los electrodos puede afectar los resultados recogidos por el TMG (Tous-Fajardo et al., 2010). Otra limitación es que este trabajo sólo evaluó dos grupos musculares. Futuras investigaciones deberían estudiar otros parámetros relacionados con la medida de la fatiga muscular como la creatina quinasa (CK), la proteína C reactiva (PCR), la urea o el retraso en el inicio dolor muscular (DOMS) para correlacionarlos con los hallazgos recogidos a través del TMG. Además, si evalúan estos datos a las 48 h o 72 h después de la prueba, pueden proporcionar información relevante sobre el proceso de recuperación entre la arena y el césped natural.

7.2. Limitations and future research lines

The six studies included in the current Doctoral Dissertation have a few important limitations that must be considered:

7.2.1. Studies 1, 2 and 3:

These studies used SSG in possession of four-a-side, so comparison with other research that used a different methodology must be done carefully. Moreover, there are not many studies that analyse the influence of both pitch size and the game surface on female football players. For that reason, more research is required to understand the effect of these two variables in women. Several studies have demonstrated a high variability existing among artificial turf systems, therefore, the findings of these studies cannot be widespread (Sánchez-Sánchez et al., 2014a). For that reason, future studies should include the mechanical properties of the selected surfaces. On the other hand, the SSG included on these research only last 4 minutes, so upcoming research should use SSGs that last longer. Finally, there are several doubts about the reliability of 10 Hz GPS for measuring the metabolic power (Buchheit et al., 2015). Therefore, it is required to be cautious when considering the findings of study 3.

7.2.2. <u>Studies 4 and 5:</u>

The artificial turf included in these studies had a lower shock absorption capacity, so it did not meet the criteria established by the international organizations like FIFA or CEN. For that reason, the findings of this work cannot be widespread to those artificial turf systems with greater shock absorption capacity. Future works should include artificial turf systems whose mechanical properties meet these criteria. The sample used in these two researches was made of amateur football players who have a lower ability to perform the repetitive sprint actions and the sprint agility run. Therefore, the influence of the game surface in professional players could be different. Also, participants only completed the first three bouts of the SSP, instead of six bouts. Finally, the SSP is not affected by the game characteristics existing in the real fixtures (i.e. fewer sliding tackles and more short passes on artificial turf) (Andersson et al., 2008); thus, some differences between these surfaces may occur in matches. In study 5, the neuromuscular responses of players after the SSP were assessed through a TMG. Some authors have questioned the reliability of this technology for detecting changes in neuromuscular responses due to fatigue (Wiewelhove et al., 2017). Therefore, caution is advised when considering the findings reported by this technique. Moreover, the assessment of neuromuscular responses of more muscular groups and at 48 and 72 hours after the test would provide further information about the recovery of players on different surfaces.

7.2.3. Study 6:

As in the study 5, the neuromuscular responses of participants were recorded through a TMG, so caution is advised, as there are some doubts about the reliability of this instrument for detecting changes caused by fatigue in the neuromuscular profile of players. Indeed, previous work has reported that the position of the sensor in relation to the muscle belly, the sensor' pressure point, or the placement of the electrodes may affect the data collected by the TMG (Tous-Fajardo et al., 2010). Another limitation is that this work only assessed two muscle groups. Future works may study other parameters related to muscular fatigue measure as the creatine kinase (CK), C-reactive protein (CRP), urea, or delayed onset muscle soreness (DOMS) to correlate them with the findings collected through the TMG. Moreover, data assessed after 48 h or 72 h may provide relevant information about the recovery process between sand and natural grass.

Capítulo 8

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Capítulo 9

Apéndice [Appendix]

9.1. Apéndice 1. Comité de Ética

COMPLEJO HOSPITALARIO DE TOLEDO
HOSPITAL VIRGEN DE LA SALUD
Avda. Barber, 30. 45004. Toledo. Teléfono 925 269200

C.E.I.C. SALIDA
FECHA: 10/06/2015
N.º 61

sescam

DICTAMEN DEL COMITE ETICO DE INVESTIGACION CLINICA DEL AREA SANITARIA DE TOLEDO

D. Fernando Jiménez Torres, Secretario del Comité Ético de Investigación clínica del "Complejo Hospitalario de Toledo".

CERTIFICA:

Que este Comité, en su reunión del día 27 de mayo de 2015, ha evaluado el Proyecto de Investigación: "ANALISIS DE LA INFLUENCIA DE LA SUPERFICIE DE JUEGO SOBRE LOS PATRONES DE RENDIMIENTO, LA INCIDENCIA EN LA FATIGA Y LA PREVENCION DE LESIONES EN JUGADORAS DE FUTBOL AMATEUR". In. Principal: **Dr. Jorge Lopez Fernandez**. Facultad Ciencias del Deporte. Toledo. Universidad Castilla-La Mancha, y considera que:

Este CEIC emite Dictamen Favorable para la realización de dicho proyecto.

Se recomienda tener seguro de responsabilidad contratado.

Lo que firmo en Toledo, 27 de mayo de 2015.

COMPLEJO HOSPITALARIO DE TOLEDO
COMITE ETICO DE INVESTIGACION CLINICA

Fdo: Fernando Jiménez Torres

9.2. Apéndice 2. Estancia de investigación en la Universidad de Coventry

CENTRE FOR APPLIED BIOLOGICAL & EXERCISE SCIENCES

Professor Alfonso Jimenez
PhD, CSCS, NSCA-CPT, FLF
Professor of Exercise Science & Health
Executive Director
Centre for Applied Biological & Exercise Sciences
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Coventry University
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Coventry, 21st of July 2017

Reference: Confirmation of International Research Training of Jorge Lopez Fernandez as Visiting Research PhD student at Coventry University

Dear Sir/Madam,

As Executive Director of the Centre for Applied Biological & Exercise Sciences, Faculty of Health & Life Sciences at Coventry University, I confirm that **Jorge Lopez Fernandez** has spent 6 months (from 19th September 2016 to 20th December 2016 and from 17th April 2017 to 26Th July 2017) as a full-time visiting postgraduate research PhD student at our Centre for Applied Biological & Exercise Sciences.

During his time with us Jorge has worked on four different manuscripts in relation to football players' responses on different game surfaces that are going to be published in JCR Journals; has improved some critical skills regarding academic writing, specific programmes such as EndNote and RefWorks. He has also attended several workshops and seminars linked to his area of research as part of the visiting research training PGR Programme (scientific oral and communication skills, posters design and development or critical analysis).

Jorge has integrated himself and worked very well within our team and we have enjoyed his visiting training with us.

Please feel free to contact me if you need further information.

Best wishes,

Professor Alfonso Jimenez
PhD, CSCS, NSCA-CPT, FLF
Professor of Exercise Science & Health
Executive Director
Centre for Applied Biological & Exercise Sciences

EXCELLENCE WITH IMPACT

Coventry University

UNIVERSIDAD DE CASTILLA-LA MANCHA

Facultad de Ciencias del Deporte

Departamento de Actividad Física y Ciencias del Deporte

En este documento se presenta una Tesis Doctoral donde se han llevado a cabo seis estudios distintos que analizan la respuesta física y fisiológica de los deportistas sobre diferentes superficies. Los tres primeros estudios se centran en mujeres futbolistas sub-elite, mientras que los trabajos 4 y 5 utilizaron una muestra de hombres futbolistas de nivel amateur. Por último, el estudio 6 incluye mujeres de rugby también de nivel amateur.

Los resultados que se presentan en este trabajo tienen un enfoque claro hacia el mundo científico y la preparación física. En ese sentido, los estudios 1, 2 y 3, muestran que la superficie de tierra no debería ser utilizada para la práctica deportiva ya que limita la respuesta física y fisiológica de las mujeres futbolistas. Además, este pavimento es el peor valorado de todos, de forma que las jugadoras prefieren optar por los sistemas de césped artificial o la hierba natural. Por otro lado, el césped natural parece ser la mejor superficie para la práctica deportiva en mujeres futbolistas sub-elite, aunque la satisfacción de las jugadoras con el césped artificial fue similar que con la hierba natural.

En segundo lugar, los estudios 4 y 5 destacan la importancia que tiene el estudio de las propiedades mecánicas de los pavimentos, en los estudios comparativos entre césped artificial y hierba natural. Entre los principales resultados destaca que, aunque el sistema de césped artificial presentó una menor absorción de impactos, una mayor energía de restitución, no se encontraron diferencias en la respuesta física y fisiológica en jugadores de fútbol amateur. Por ello, los entrenadores no deben modificar sus entrenamientos y programas de recuperación en base a la superficie de juego utilizada

Por último, varios autores sugieren el uso de la arena en el entrenamiento debido a su menor absorción de impactos. Los resultados del estudio 6, muestran que la práctica deportiva sobre arena causa un mayor estímulo muscular que sobre hierba natural; a pesar de que las jugadoras de rugby alcanzaron velocidades más bajas sobre la arena. Por ello, en caso de incorporar esta superficie al entrenamiento o a la readaptación deportiva es preciso un buen control de la carga.

Tesis Doctoral Internacional Desarrollada por:

JORGE LÓPEZ FERNÁNDEZ

Dirigida por:

Dra. Dª. LEONOR GALLARDO GUERRERO
Dr. D. JAVIER SÁNCHEZ SÁNCHEZ