Velocidad de golpeo de balón y Kicking Deficit en futbolistas de élite

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CERTIFICA:

Que la tesis doctoral presentada por D. Lois Rodríguez Lorenzo, titulada **"Velocidad de golpeo de balón y Kicking Deficit en futbolistas de élite",** reúne los requisitos formales y científicos para su lectura y defensa públicas.

A Coruña, a 10 de Mayo de 2017

Fdo. D. Rafael Martín Acero.

DEDICATORIA

A mis padres
y a mi hermana.

Por vuestro cariño y apoyo,
por darme fuerzas en los malos momentos,
porque sin vosotros no hubiese podido llegar hasta aquí.

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RESUMEN

El golpeo de balón es una de las habilidades más importantes en el fútbol, y realizarlo con ambas piernas supone una gran ventaja para los futbolistas. Su rendimiento está determinando en gran medida por la velocidad alcanzada por el balón. Existe un déficit de golpeo (KD) con la pierna no dominante, definido como la diferencia, en porcentaje, de la velocidad de balón alcanzada con la pierna no dominante en relación a la dominante.

Esta tesis es un compendio de artículos que estudian el rendimiento del golpeo de balón y el KD en futbolistas de élite. Las dos primeras publicaciones son revisiones bibliográficas sobre el estudio de la velocidad de golpeo de balón, y sobre su relación con la fuerza muscular. Las tres últimas son investigaciones que estudian el KD y la relación entre la velocidad de golpeo con las manifestaciones de la fuerza y en futbolistas adultos y en edades de formación.

Los resultados indican que el KD es un elemento constante y estable en toda la muestra. En futbolistas niños y futbolistas jóvenes los factores de fuerza muscular son determinantes para el golpeo de balón, mientras que en adultos los factores coordinativos se vuelven más importantes.

RESUMO

O golpeo de balón é unha das habilidade máis importante no fútbol, e realizalo con ambas pernas supón unha gran vantaxe para os futbolistas O seu rendemento está determinado en gran medida pola velocidade alcanzada polo balón tras o impacto. Sen embargo, existe un déficit de golpeo (KD) coa perna non dominante, definido como a diferenza, en porcentaxe, da velocidade de balón alcanzada coa perna non dominante en relación a dominante.

Esta tese é un compendio de artigos que estudan o rendemento do golpeo de balón e o KD en futbolistas de elite. As dúas primeiras publicacións son revisións bibliográficas sobre o estudo da velocidade de golpeo de balón e sobre a súa relación coa forza muscular. As tres últimas, son investigacións que estudan o KD, é a relación entre a velocidade de golpeo coas manifestación da forza en futbolistas adultos e en idades de formación.

Os resultados indican que o KD é un elemento constante e estable en toda a mostra. En futbolistas mozos a habilidade de golpeo non está tan consolidada, e os factores de forza son determinantes para o golpeo de balón, mentres que en adultos os factores coordinativos vólvense máis importantes.

ABSTRACT

Kicking ability represents the most important soccer-specific skill. The performance of kicking in soccer mainly depends on the maximum ball velocity. Moreover, achieving maximal kicking performance with both legs leads to an advantage for the soccer player. However, there is a Kicking deficit (KD) with the non-dominant leg, that could be defined as the percentage of the difference between the maximal velocity obtained for each player with the non-dominant leg in relation with the dominant leg.

This thesis is collection of five papers. The first two publications are review articles focused on the study of maximal kicking velocity and its relationship with muscular strength. The last three publications are original researches focused on the study of KD and the relationship between maximal kicking velocity and vertical jump performance in young and adult elite soccer players.

Our results show that Kicking Deficit is a constant element in elite soccer players. Furthermore, in young soccer, players kicking skill is not so consolidated strength and power factors are determinant for kicking performance, while in adult soccer players coordination factors (skilled players) become more important.

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LISTADO DE ABREVIATURAS

3D	3 Dimensiones
ANOVA	Análisis de varianza, del inglés *Analysis Of Variance*
ARS	Sistema de registro mediante audio, *Audio recording system*
C	Video cámaras
cm	Centímetros
CMJ	Salto con contramovimiento, del inglés *Counter Movement Jump.*
CMJA	Salto con contramovimiento con acción de brazos, del inglés *Counter Movement Jump with arm Swing.*
Co.	Compañia
CSIC	Centro superior de investigaciones científicas
CSTS	Entrenamiento de Core en superficies estables
CSTU	Entrenamiento de Core en superficies inestables
CV	Coeficiente de Variación
DL	Pierna dominante, del inglés *Dominant Leg*
DOI	Digital Object Identifier.
e.g.	Por ejemplo, del latín *exempli gratia*
F	Mujeres, del inglés *Female*
FIFA	Fédération Internationale de Football Association
g	Fuerza de la Gravedad
G+14	Grupo de más de 14 años (Artículo Nº3): 14.02–16.39 años, n=46
G-14	Grupo de menos de 14 años(Artículo Nº3): 10.80–13.55 yrs, n=46
GHz	Gigahercio
HG	Entrenamiento pliométrico horizontal
HTML	Lenguaje de marcas de hipertexto, del inglés *Hypertext Markup Language*

i.e.	es decir, del latín *id est*
IL	Illinois
INEF	Instituto Nacional de Educación Física
KD	Déficit de golpeo, del inglés *Kicking Deficit*
kg	Kilogramos
KPI	Incremento en el rendimiento del golpeo, del inglés *kicking performance increase*
KVdomMax	Maximal kick ball velocity achieved with the dominant
KVnodommax	Maximal kick ball velocity achieved with the non-dominant legs
LFP	Liga de Fútbol Profesional
Ltd	Sociedad anónima de responsabilidad limitada, del inglés *Limited*
m	metros
M	Hombres, del inglés *Male*
m/s	Metros por segundo.
MKBV	Velocidad máxima de golpeo, del inglés *Maximal kick ball velocity*
n	Tamaño de la muestra
NA	Datos no disponibles, del inglés *No available data*
NDL	Pierna no dominante, del inglés *Non-Dominant Leg*
Nº	Número
NPPT	Entrenamiento pliométrico sin incremento progresivo en volumen
p	Probabilidad de obtener un resultado al menos tan extremo como el que realmente se ha obtenido
P	Fotocélulas, del inglés *Photocell*
PDF	Archivo de datos, del inglés *Portable Document Format*
PhD	Doctorado, del latín *Philosophiæ doctor*
PPT	Entrenamiento pliométrico con incremento progresivo en volumen

r	Coeficiente de correlación de Pearson
R	Radar
RI	Instrumento de registro, del inglés *Register instrument*
RJA	Salto vertical reactivo con acción de brazos y poca flexión de rodillas, Del inglés *Reaction Jump with arm swing.*
RM	Repetición máxima
SD	Desviación típica, del inglés *Standard deviation*
SJ	Salto vertical desde flexión de rodillas, del inglés *Squat Jump.*
SPSS	Programa informático, del inglés *Statistical Package for the Social Sciences*
SSC	Ciclo de estiramiento acortamiento, del inglés *Stretch shortening cycle*
U-	Menor qué X años, del inglés *under*
UDC	Universidade de A Coruña
UK	United Kingdom
URL	Localizador Uniforme de Recursos, del inglés *Uniform Resource Locator*
USA	United States of America
VB	Velocidad de golpeo de balón, del inglés *ball velocity*
VG	Entrenamiento pliométrico vertical
VHG	Entrenamiento pliométrico combinado vertical y horizontal
yrs	Años, del inglés *years*

INTRODUCCIÓN

1. ANTECEDENTES Y JUSTIFICACIÓN

El fútbol es uno de los deportes más populares en el mundo. Según una encuesta efectuada en 2006 por la FIFA, entre sus 207 asociaciones miembro, hay un total de 265 millones de personas que juegan al fútbol, de forma reglada, en todo el mundo. La cifra se incrementa a 270 millones, si se tiene en cuenta a entrenadores, asesores y empleados de los clubes, lo que significa que el cuatro por ciento de la población mundial participa activamente en el fútbol (Fédération Internationale de Football Association, 2007).

Debido a esta popularidad son muchos los estudios que intentan analizar las habilidades que se desarrollan durante un partido de fútbol (Lees & Nolan, 1998), con el objetivo de proporcionar información científica que pueda ser de valor práctico para los futbolistas y entrenadores (Masuda, Kikuhara, Demura, Katsuta & Yamanaka, 2005). De entre todas estas habilidades, el golpeo al balón es la habilidad más estudiada (Dörge, Andersen, SØrensen & Simonsen, 2002; Anthrakidis, Skoufas, Lazaridis & Zaggelidis, 2008), debido a que es considerada una habilidad fundamental para el rendimiento del futbolista (Masuda et al., 2005; Bacvarevic et al., 2012), por ser una de las más utilizadas durante la competición (Campo et al., 2009), y una de las más determinantes; además de su empleo en los pases, centros y despejes, los golpeos se utilizan para tirar a portería con la intención de marcar gol, el principal objetivo de este deporte. De hecho, en la Copa Mundial de Fútbol de Sudáfrica 2010, un 80.69% de los goles se marcaron a través de un golpeo con el pie (Njororai, 2013).

Desde un punto de vista biomecánico, tanto si el balón está parado, moviéndose en el suelo o si cae del cielo como sucede en un despeje, la acción de golpeo puede describirse como un “*throw-like*” patrón de movimiento en el cual los segmentos distales se quedan atrás de los proximales y se van moviendo a medida que estos últimos avanzan (Dörge et al, 2002). El golpeo puede explicarse como una sumatorio de fuerzas (Rodano & Tavana, 1993), en el cual el pie de golpeo es el último y más rápido segmento en intervenir en la cadena cinética abierta.

Desde un punto de vista práctico, Csanádi & Kubala (1984) definen el golpeo como el lanzamiento del balón de forma consciente con alguna parte del pie. Es decir, el jugador busca a través del golpeo una trayectoria y velocidad en el balón de acuerdo a una intención previamente determinada.

El rendimiento del golpeo con la intención de conseguir gol en fútbol, depende fundamentalmente de la velocidad alcanzada por el balón tras el impacto y de la precisión en relación al objetivo (Lees & Nolan, 1998; Andersen & Dörge, 2011). Aunque la precisión es un factor importante, el rendimiento del golpeo de balón ha sido evaluado principalmente a través de la medición de la velocidad máxima del balón (Markovic, Dizdar & Jaric, 2006). De hecho, asumiendo que un golpeo es preciso las posibilidades de marcar se incrementan con un incremento en la velocidad del balón, debido a que el portero tiene menos tiempo para reaccionar (Markovic et al., 2006).

Por lo tanto, se sugiere que alcanzar altas velocidades de golpeo, asumiendo que este sea preciso, aumentaría las posibilidades de marcar gol, y alcanzar altas velocidades de golpeo con las dos piernas lo haría aún más. Pero en la práctica esto no es así, existe acuerdo en la literatura en que la mayoría de los jugadores producen significativamente mayor velocidad de balón cuando golpean con su pierna dominante (Barfield, Kirkendall & Yu, 2002; Dörge et al., 2002; Nunome, Ikegami, Kozakai, Apriantono, & Sano 2006), dando lugar a un déficit de golpeo (KD) con la pierna no dominante.

1.1. Estado actual de las investigaciones sobre el rendimiento máximo de golpeo de balón en fútbol

Teóricamente, los principios que determinan la velocidad del balón cuando este sale del pie, son los mismos que gobiernan la velocidad post-impacto de cualquier objeto que es golpeado por otro cuerpo. Estos principios sugieren que se podría incrementar en gran medida la velocidad del balón incrementando el coeficiente de restitución, incrementando la masa de la pierna y el pie de golpeo, e incrementando la velocidad del pie en el momento del contacto (Young & Rath, 2011). Sin embargo, en fútbol, la masa de la pierna o el pie de golpeo no influye significativamente en la velocidad máxima de golpeo (Andersen, 1999). La velocidad de balón está más afectada por la velocidad alcanzada por el pie en el momento del impacto con el balón que cualquiera de las otras variables mencionadas anteriormente (Ishii, Yanagiya, Naito, Katamoto & Maruyama, 2012).

El coeficiente de restitución es una medida de la elasticidad de un impacto (Andersen, 1999), y la transferencia del momento desde el pie al balón (Dörge et al., 2002). El coeficiente de restitución está influenciado por la rigidez del pie en el momento de contacto y por la parte del pie que contacta con el balón (Lees & Nolan, 1998). La rigidez o "*stiffness*" del pie es crucial para el éxito del impacto; un tiempo de contacto breve puede aumentar el coeficiente de restitución y favorecer una mayor velocidad de balón (Asami & Nolte, 1983; Levanon & Dapena, 1998; De Witt & Hinrichs, 2012; Ball, 2013). Contrariamente, una superficie de contacto distal, cerca de los dedos, puede provocar una mayor flexión plantar de tobillo en respuesta a las fuerzas de impacto del golpeo, aumentando el tiempo de duración de la fase de contacto, que daría como consecuencia una reducción del coeficiente de restitución y una menor velocidad del balón (Asami & Nolte, 1983). Además, se ha comprobado que los tibiales anteriores se mostraron muy activos en el momento del golpeo (Bollens, De Proft & Clarys et al., 1987). Las evidencias anteriores nos sugieren que los flexores dorsales del pie juegan un papel importante en el golpeo de balón, principalmente evitando la flexión plantar del pie.

Los factores biomecánicos que influyen en la velocidad del pie en el momento del impacto son muchos y complejos. La coordinación o *"timing"* de activación muscular en la pierna de golpeo, registrado mediante electromiografías, fue descrito como proximal-distal. Con la activación en un primer momento de los flexores de cadera, como el psoas ilíaco seguido del recto femoral, el cual es un flexor de cadera y extensor de rodilla, y finalmente la activación de los extensores de rodilla como el vasto lateral (Dörge et al., 2002). El recto femoral se considera muy importante porque se muestra muy activo en los futbolistas durante el golpeo máximo. De hecho, es uno de los músculos más lesionados durante la realización de esta acción (Orchard, 2001). Además, los flexores de rodilla (isquiotibiales) y los extensores de cadera (glúteos, principalmente glúteo mayor), son significativamente activos durante el golpeo máximo en fútbol (De Proft, Clarys, Cabri & Dufour, 1988). Sin embargo, la cantidad de activación de los isquiostibiales no está clara. Aunque la función de los isquiotibliales como antagonistas es decelerar el movimiento de la pierna *"swing"* después del impacto, este grupo muscular no aparece altamente activo durante el *"follow-through"* (movimiento del cuerpo que sigue al golpeo) (Orchard, Walt, McIntosh, & Garlick, 2002). Lo que puede explicar porque el golpeo no es una de las mayores causas de rotura de isquiotibiales (Orchard, 2001).

En el golpeo de balón en fútbol, cuando el muslo empieza su movimiento hacia delante durante la flexión de cadera, la flexión de rodilla se incrementa, causando una contracción excéntrica del cuádriceps. Cuando la pierna continúa su recorrido, la rodilla se extiende, produciéndose un ciclo de estiramiento acortamiento (SSC) en la acción muscular del cuádriceps. Los SSC, tal y como su propio nombre describe, implican una activación excéntrica seguida por una activación concéntrica. Además, entre ambas fases de activación existe una breve fase isométrica. Los SSC pueden ser un importante mecanismo para generar velocidad del pie. De hecho, se ha demostrado que, en posición sentado, la velocidad de extensión máxima de la rodilla puede ser un 20% mayor durante un ciclo rápido de SSC en comparación con una sola contracción concéntrica (Bober, Putnam, & Woodworth, 1987).

El papel de la pierna de apoyo en la habilidad de golpeo ha recibido menor atención en la literatura. Las electromiografías realizadas en los músculos del glúteo y del cuádriceps de la pierna de apoyo indican que están muy activos durante el golpeo (Rodano & Tavana, 1993; Orchard et al., 2002), el componente vertical de las fuerzas de reacción del suelo es relativamente alto en la pierna de apoyo (Sinclair et al., 2014). Además, muchos futbolistas diestros prefieren realizar saltos verticales con su pierna izquierda (Saliba & Hrysomalis, 2001). Todas estas evidencias nos sugieren que la pierna de apoyo podría ser utilizada para proporcionar "plataforma estable" para que la pierna de golpeo pueda realizar un rápido movimiento de toda la cadena cinética (Young & Rath, 2011; Ball, 2013).

A pesar de que las extremidades inferiores juegan un papel determinante en el golpeo de balón, esta habilidad es resultado de una compleja interacción entre diferentes partes del cuerpo, incluyendo las extremidades superiores y el tronco. Particularmente, estas estructuras podrían tener especial importancia para crear unas condiciones iniciales que permitan una contracción muscular más explosiva (Shan & Westerhof, 2005). Además, el papel de los músculos del tronco o "*core*" cobra especial importancia para garantizar una eficaz transmisión de fuerzas dentro de la cadena cinética (Shan & Westerhof, 2005).

En resumen, los patrones musculares activados durante el golpeo surgieren que una adecuada coordinación intermuscular y unos óptimos niveles de fuerza y potencia de los músculos flexores de cadera, extensores de rodilla y dorsiflexores de tobillo de la pierna de golpeo, son determinantes para generar una alta velocidad del pie de golpeo. Los agonistas requieren una gran fuerza concéntrica (flexores de cadera y extensores de rodilla), mientras que los antagonistas (extensores de cadera y flexores de rodilla) requieren mayor fuerza excéntrica (Young & Rath, 2011). Además, los extensores de rodilla y cadera de la pierna de apoyo y la musculatura del tronco también tienen un papel importante en el rendimiento del golpeo de balón.

Debido a que los patrones musculares activados durante el golpeo sugieren que la fuerza muscular de las extremidades inferiores podría desempeñar un papel importante en el rendimiento máximo del golpeo en fútbol. En los últimos años, ha habido un interés creciente en estudiar la relación entre la velocidad máxima de golpeo y el rendimiento en diferentes test de fuerza, y en comprobar los efectos de diversos programas de entrenamiento de fuerza sobre la velocidad de golpeo de balón. Sin embargo, los resultados de estos estudios son contradictorios y la controversia se mantiene con respecto al papel que puede jugar la fuerza muscular en el rendimiento máximo de golpeo en fútbol.

Por otro lado, en las últimas décadas se han llevado a cabo numerosos estudios que evidencian que diversos factores relacionados con las características de la muestra, las técnicas de golpeo, los protocolos de evaluación y los instrumentos de registro empleados durante las investigaciones pueden afectar a la velocidad máxima de golpeo. La identificación y conocimiento de estos factores resulta imprescindible para emprender cualquier investigación relacionada con el rendimiento máximo de golpeo, o para interpretar y comparar los resultados de las diferentes investigaciones sobre el tema.

1.2. Estudio de las variables velocidad de balón, fuerza muscular y Kicking Déficit

Debido a la importancia del golpeo en futbol, y a que el golpeo está determinado en gran medida por la velocidad alcanzada por el balón tras el impacto. En las últimas décadas, se han llevado a cabo numerosas investigaciones, con diferentes objetivos, que midieron la velocidad del balón tras un golpeo en fútbol (Artículo Nº 1).

Sin embargo, hemos detectado que la relación entre la edad y el rendimiento máximo de golpeo no ha sido extensamente estudiado. Se ha comunicado que la edad afecta positivamente a la velocidad máxima de golpeo (Luhtanen, 1988, Bacvarevic, 2012), pero el rango de edad examinado en estos estudios fue muy limitado. De hecho, no existe información en la literatura con respecto al desarrollo anual de la velocidad máxima de golpeo en un amplio rango de edad, y esta carencia de información es aún mayor con la pierna no dominante.

A pesar de que la importancia de la utilización de la pierna no dominante en el fútbol de alto nivel es conocida por los técnicos y jugadores, los porcentajes de utilización de la pierna dominante con respecto a la no dominante son muy elevados, entorno al 90% para los controles, pases, centros y remates. No obstante, para el golpeo a portería ese porcentaje baja hasta el 72% (Miguel et al., 2005). El motivo de este resultado puede estar relacionado a que el golpeo a portería en muchas ocasiones tiene una limitación temporal añadida, producida por la cercanía de los rivales y la alta presión a la que se ven sometidos los atacantes, lo que provoca que los jugadores no se puedan acomodar a su pierna dominante y tengan que utilizar en mayor medida su pierna no dominante. De hecho, se ha demostrado que los mejores goleadores son capaces de marcar gol con las dos piernas (Starosta, 1988).

Las evidencias expuestas en el párrafo anterior apuntan que la habilidad de golpear con ambas piernas supone una gran ventaja para los futbolistas. Sin embargo, la exhaustiva revisión de la literatura realizada en el Artículo Nº 1 indica que los futbolistas producen velocidades de golpeo significativamente superiores (entre 9.32-18.35%) con la pierna dominante, indicando un déficit de golpeo con la pierna no dominante. El déficit de golpeo (KD) puede ser definido como la diferencia, en porcentaje, de la velocidad de balón alcanzada con la pierna no dominante en relación a la dominante (Artículo Nº3). No obstante, los valores del KD fueron calculados a partir de los valores medios del total de la muestra de cada estudio, por lo que son necesarios nuevas investigaciones que lo hagan partir de los valores individuales de cada jugador.

Por otro lado, la exhaustiva revisión realizada en el Artículo Nº 2 indica que los programas de entrenamiento de fuerza explosiva, en combinación con las sesiones habituales entrenamiento de fútbol, resultaron efectivos a la hora de mejorar la velocidad de golpeo de balón. Estás mejoras en la velocidad de golpeo vinieron acompañadas de mejoras en la capacidad de salto. No obstante, la relaciones entre los test de salto y la velocidad máxima de golpeo no están claras, ya que estos estudios se realizaron exclusivamente con estudiantes y niños, y además solo con la pierna dominante. Por tanto, aún no se conoce la relación entre los niveles de fuerza explosiva y la velocidad máxima de golpeo en futbolistas adultos de élite, y si esa relación es similar tanto para la pierna dominante como para la no dominante. Por lo tanto, se necesitan más investigaciones que aborden esta cuestión. Estos datos pueden ser de vital importancia para conocer la naturaleza del KD y extraer las manifestaciones de fuerza que se requieren para mejorar la velocidad de golpeo de balón.

De manera similar, en la revisión realizada en el Artículo Nº 1 comprobamos que existen varios factores que pueden afectar a la velocidad máxima de balón y que deben ser tenidos en cuenta para su investigación. Será necesario describir lo más detalladamente posible las características de la muestra (edad, género, dominancia lateral, tiempo de práctica motriz, nivel de competición) y los protocolos de evaluación (tipos de golpeo, superficie de contacto del pie con el balón, carrera previa y ángulos de aproximación) ya que son elementos que pueden influir en la velocidad máxima de golpeo. Además, en futbolistas jóvenes se han encontrado correlaciones positivas entre la velocidad de golpeo, la estatura y el índice de masa corporal (Wong, Chamari, Dellal, & Wisløff, 2009). Por lo tanto, estás y otras variables antropométricas deberían de ser tenidas en cuenta para analizar cualquier investigación en la que se mida la velocidad máxima de golpeo en fútbol. Sin embargo, ningún estudio ha comprobado si las variables antropométricas siguen afectando al golpeo de balón en adultos, cuando los futbolistas ya han completado su crecimiento (Luhtanen, 1988; Ré, Cattuzzo, Santos y Monteiro, 2014).

2. OBJETIVOS

La presente Tesis Doctoral persigue alcanzar los siguientes objetivos generales y específicos:

Objetivo General 1

1. Analizar el estado actual de las investigaciones sobre el rendimiento máximo de golpeo de balón en fútbol.

   Objetivos específicos

   1.1. Identificar los factores que afectan a la velocidad máxima de golpeo en fútbol relacionados con las características de la muestra (Artículo Nº 1).

   1.2. Identificar los factores que afectan a la velocidad máxima de golpeo en fútbol relacionados con la ejecución del golpeo y conocer los diversos métodos e instrumentos utilizados para registrar la velocidad del balón (Artículo Nº 1).

   1.3. Identificar la relación entre la velocidad de golpeo de balón y la fuerza muscular (Artículo Nº 2).

   1.4. Conocer los efectos de programas de entrenamiento de fuerza en la velocidad máxima de golpeo (Artículo Nº 2).

Objetivo General 2

2. Estudiar la velocidad máxima de golpeo de balón y el Kicking Deficit (KD) en diferentes grupos de edad de futbolistas de élite, e iniciar la exploración de la naturaleza de ese déficit.

   Objetivos específicos

   2.1. Determinar la velocidad máxima de golpeo de balón con cada una de las piernas y el Kicking Deficit (Artículo Nº 3, Nº 4, Nº 5).

   2.2. Identificar la intensidad y significación estadística de la relación entre los test de salto vertical y la velocidad máxima de golpeo con cada una de las piernas (Artículo Nº 3, Nº 4).

   2.3. Identificar la intensidad y significación estadística de la relación entre las variables antropométricas y la velocidad máxima de golpeo con cada una de las piernas (Artículo Nº 3, Nº 4).

   2.4. Describir la evolución de velocidad máxima de golpeo con cada una de las piernas y el Kicking Deficit, en los grupos de edad de futbolistas de élite (Artículo Nº 5).

3. *METODOLOGÍA*

En esta sección se desarrolla una síntesis combinada de la metodología empleada en cada uno de los tres estudios de campo que forman parte de esta tesis doctoral (Artículos Nº3, Nº4 y Nº5). Por favor, consulte las publicaciones completas en la sección "*Compendio de publicaciones*" para más detalles (pág., 49).

3.1. Muestra

La muestra utilizada está formada por los jugadores integrantes de las categorías inferiores del Real Club Deportivo de la Coruña, que pertenecen al rango de edad analizado en cada artículo (ver tabla 1). Estos jugadores son seleccionados por el club de entre los mejores jugadores de la zona Noroeste de la península ibérica, pasando numerosos filtros, tanto para entrar en el club, como para progresar dentro de él a lo largo de los años. Por lo tanto, podemos considerarlos como jugadores de élite en sus respectivas categorías.

Ante las características de la muestra y de su selección, se optó por un muestreo no probabilístico de muestras de conveniencia, o muestreo intencional (Sarriá & Brioso, 2001). Los criterios de inclusión para la selección de la muestra fueron: 1) Poseer ficha federativa con el Real Club Deportivo de la Coruña en las temporadas 2012/2013 (Artículos Nº3 y Nº4) y 2013/2014 (Artículo Nº 5); 2) No haber sufrido ninguna lesión, durante las 4 semanas previas a la recogida de datos, que hayan impedido al jugador participar en 2 o más entrenamiento.

Tabla 1. Distribución de la muestra utilizada en cada artículo en función de la categoría deportiva y el año de registro de datos.

Categoría	Temporada 2012/2013				Temporada 2013/2014	
	Artículo Nº 3		Artículo Nº 4		Artículo Nº 5	
	Grupo	Edad	Grupo	Edad	Grupo	Edad
Pre- Benj 1º					U-9 (n=12)	9.13 ± 0.23
Pre- Benj º					U-10 (n=12)	10.14 ± 0.26
Benjamín 1º					U-11 (n=15)	11.08 ± 0.21
Benjamín 2º			G-14 (n=46)	12.18 ± 0.94	U-12 (n=15)	12.00 ± 0.28
Infantil 1º					U-13 (n=15)	13.05 ± 0.22
Infantil 2º					U-14 (n=19)	14.04 ± 0.32
Cadete 1º			G+14 (n=46)	15.04 ± 0.80	U-15 (n=16)	15.12 ± 0.25
Cadete 2º					U-16 (n=15)	16.21 ± 0.13
Juvenil 1º					U-17 (n=13)	17.11 ± 0.26
Juvenil 2º					U-18 (n=12)	17.91 ± 0.23
Juvenil 3º					U-19 (n=11)	18.98 ± 0.30
Filial	U-23 (n=23)	21.12 ± 2.42			U-23 (n=20)	22.11 ± 1.89
Total	n=23		n=92		n=175	

3.2. Consentimiento informado

Las pruebas realizadas fueron llevadas a cabo dentro del programa de valoración morfo-funcional de los *Servicios de Apoyo al Rendimiento Físico* del Real Club Deportivo de la Coruña.

Atendiendo a las recomendaciones establecidas en el Código de buenas prácticas científicas del CSIC (Comité de Ética del CSIC, 2015). Después de recibir una explicación detallada de las pruebas a realizar y de ser informados de que los datos del estudio serían utilizados como parte de una tesis doctoral en la Universidade da Coruña. Todos los participantes firmaron voluntariamente una hoja de consentimiento informado (Anexo A). En el caso de ser menor de edad, además, fueron firmadas por el tutor legal del deportista. El estudio fue aprobado por el departamento médico del Real Club Deportivo de la Coruña y cumplió los requisitos de la Declaración de Helsinki para la investigación con seres humanos. Además, cada participante en el estudio tenía la libertad de rescindir el consentimiento e interrumpir su participación en el proyecto o en la actividad en cualquier momento.

3.3. Protección de datos

Se garantizó en todo momento la confidencialidad de los datos de cada uno de los participantes, según la Ley orgánica 15/1999, de 13 de diciembre, de protección de datos de carácter personal, y Real Decreto 1720/2007, de 21 de diciembre, por el que se aprueba el reglamento de desarrollo de la Ley Orgánica 15/1999, de 13 de diciembre, de Protección de Datos de Carácter Personal.

3.4. Conflictos de interés

Siguiendo el Manual de Conflictos de Intereses del CSIC (Comité de Ética del CSIC, 2011) establecemos que no hubo ningún conflicto de interés en el presente estudio. Además, no se recibió ninguna financiación para realizar este estudio.

3.5. Materiales y protocolos

Para llevar a cabo las evaluaciones a lo largo de esta investigación se utilizaron los protocolos y materiales descritos en la siguiente tabla:

Tabla 2. Materiales y protocolos.

TEST DE GOLPEO DE BALÓN		
Test	**Protocolo**	**Material**
Velocidad máxima de golpeo	Versión modificada de Markovic et al. (2006)	• Stalker Radar (Stalker Sport 2, Plano, Texas, USA) • Balón (FIFA, standard) • Portería fútbol 11
TEST DE SALTO VERTICAL		
Test	**Protocolo**	**Material**
SJ y CMJ	Bosco et al. (1983)	• Plataforma de fuerza (Quattro Jump, Kisler, Winterhur, CH)
CMJA y 1RJA	Acero et al. (2012)	
VALORACIÓN ANTROPOMÉTRICA		
Test	**Protocolo**	**Material**
Masa Corporal	Marfell-Jones et al. (2006)	• BFW300 Platform scale (Adam Equipment Co. Ltd., UK.)
Estatura		• Harpenden stadiometer (Holtain Limited, UK.)
Diámetros y alturas		• Siber - Hegner Anthropometer (Zurich, Switzerland)
Perímetros		• Lufkin W606PM flexible steel tape (Cooper Industries, USA)

3.6. Procedimientos

Para garantizar la calidad de los datos en las pruebas motoras, un mismo técnico especializado condujo 4 sesiones de familiarización, el mes previo a la toma de datos, con el objetivo de objetivo de conocer y dominar la técnica de los test de salto y golpeo. En ellas, se explicaron y practicaron los test a realizar en las sesiones de recogida de datos.

Los test se llevaron a cabo en dos sesiones de entrenamiento separadas entre ellas por 48 horas de descanso, siempre dentro de la misma semana y en las horas habituales de entrenamiento de cada categoría. Todos los equipos fueron testados, dentro del mismo mes, al final del período competitivo.

En la primera sesión de recogida de datos se llevaron a cabo las mediciones antropométricas y los test de salto vertical. Se comenzó con el registro de las medidas antropométricas de los jugadores, en la clínica médica de club. Cuando los jugadores fueron terminando, pasaron a realizar un calentamiento dirigido por el mismo técnico especializado (Protocolo A, Anexo B). Posteriormente los jugadores realizaron 1 salto de prueba dentro de la plataforma, los dos siguientes intentos fueron utilizados para la recogida de datos. Para evitar la fatiga muscular, se concedió un mínimo de 3 minutos de descanso y un máximo de 4 entre dos intentos consecutivos.

En la segunda sesión de recogida de datos los jugadores cubrieron el cuestionario de valoración de los antecedentes deportivos (Anexo E), y realizaron los test de golpeo de balón. Los equipos cubrieron el cuestionario de valoración de antecedentes deportivos en la sala de reuniones. Cuando los jugadores fueron terminando se calzaron las botas de fútbol y fueron al campo de hierba artificial, realizaron un calentamiento individual dirigido por un técnico especialista (Protocolo B, Anexo B). Posteriormente los jugadores realizaron 1 golpeo de prueba con cada pierna, los dos siguientes intentos fueron utilizados para la recogida de datos. Para evitar la fatiga muscular, se concedió un mínimo de 1 minuto de descanso entre dos intentos consecutivos. En el Artículo Nº 5 solo se llevaron a cabo los test de golpeo de balón en una única sesión.

Todos los tests se realizaron con la vestimenta deportiva que utilizan habitualmente los jugadores para entrenar, formada por una camiseta de manga corta y un pantalón corto. Entre cada prueba los jugadores se podían poner una sudadera con el objetivo de que no enfriarse. Además, los deportistas debían calzar unos tenis deportivos antideslizantes en las pruebas de salto, y de preferencia funcional. En los test de golpeo de balón debían de calzar botas de tacos, al ser realizadas sobre una superficie de hierba artificial.

Por último, se les solicitó a los jugadores evitar cualquier tipo de actividad física extenuante dos días antes de empezar el estudio y durante la realización del mismo. Además, se les pidió mantener sus hábitos dietéticos habituales durante la duración de los test.

3.7. Variables de los estudios

En las tablas 3, 4, y 5 se presenta un resumen de las variables utilizadas en los Artículo Nº3 y Nº4. Debido a los diferentes objetivos perseguidos en el Artículo Nº5, en este, solo se analizaron las siguientes variables de golpeo: *KVdomMax, Kvnodommax* y KD (Tabla 3).

Tabla 3. Variables analizadas en los test de golpeo de balón.

TEST GOLPEO DE BALÓN		
Abreviatura	**Descripción**	**Unidad**
KVdomMax	Velocidad máxima de golpeo con la pierna dominante	m/s
KVnodommax	Velocidad máxima de golpeo con la pierna no dominante	m/s
CV Average velocity Dominant leg	Coeficiente de variación de los tres intentos con la pierna dominante	-
CV Average velocity Non-Dominant leg	Coeficiente de variación de los tres intentos con la pierna no dominante	-
KD	Kicking Deficit	%

Tabla 4. Variables analizadas en la valoración antropométrica.

VALORACIÓN ANTROPOMÉTRICA		
Variable	**Descripción**	**Unidad**
Age	Edad decimal	Años
Bodymass	Peso corporal	kg
Stature	Estatura	cm
Body mass index	Índice de masa corporal	kg/m^2
Trochanterion height	Distancia entre punto trocantéreo y el plano de sustentación	cm
Tibiale laterale height	Distancia entre el punto acromial y el plano de sustentación	cm
Arm flexed and tensed girth	Perímetro del brazo contraído voluntariamente	cm
Thigh girth	Perímetro situado en el punto medio trocantéreo tibial	cm
Calf girth	Perímetro medido a nivel de la máxima circunferencia de la pierna	cm
Biiliocristal breadth	Distancia entre las entre las partes más laterales de las crestas ilíacas	cm
Biepicondylar femur breadth	Distancia entre el cóndilo medial y lateral del fémur	cm
Ankle breadth	Distancia entre maléolo peronéo y el maléolo tibial del tobillo	cm

Tabla 5. Variables analizadas en los test de salto vertical.

TEST DE SALTO VERTICAL		
Variable	**Descripción**	**Unidad**
SJ	Altura máxima calculada en base al tiempo de vuelo tras un SJ	cm
CMJ	Altura máxima calculada en base al tiempo de vuelo tras un CMJ	cm
CMJA	Altura máxima calculada en base al tiempo de vuelo tras un CMJA	cm
1RJA	Altura máxima calculada en base al mayor tiempo de vuelo tras un RJA	cm

4. RESULTADOS Y DISCUSIÓN

En esta sección se desarrolla una síntesis combinada de la discusión de los cinco artículos que componen esta tesis doctoral. Por favor, consulte las publicaciones completas en la sección "*Compendio de publicaciones*", para más detalles (pág., 49).

Para facilitar la lectura y comprensión de los resultados y su discusión, vamos a presentar esta sección de tal forma que vayamos dando respuesta a cada uno de los objetivos generales y específicos que se encuentran desarrollados en el punto 2 del presente documento (pág., 9).

La Subsección 4.1 está relacionada con las dos primeras publicaciones de esta tesis (Artículo Nº 1 y Artículo Nº 2). Ambos artículos son revisiones bibliográficas que tienen como finalidad alcanzar el Objetivo General 1 *"Analizar el estado actual de las investigaciones sobre el rendimiento máximo de golpeo de balón en fútbol"*, y sus correspondientes objetivos específicos.

La Subsección 4.2 está relacionada con las investigaciones de campo (Artículo Nº 3, Artículo Nº 4 y Artículo Nº 5) que tienen como finalidad alcanzar el Objetivo General 2: *Estudiar la velocidad máxima de golpeo de balón y el Kicking Deficit (KD) en diferentes grupos de edad de futbolistas de élite, e iniciar la exploración de la naturaleza de ese déficit,* y sus correspondientes objetivos específicos. En los siguientes apartados se exponen los resultados obtenidos:

4.1. Estado actual de las investigaciones sobre el rendimiento máximo de golpeo de balón en fútbol

4.1.1. Factores relacionados con las características de la muestra

Esta sección se encarga de exponer y discutir los resultados relacionados con el objetivo específico 1.1 "*Identificar los factores que afectan a la velocidad máxima de golpeo en fútbol relacionados con las características de la muestra*". Por favor, consulte el Artículo Nº 1 para más detalles (pág., 51).

Edad

Los estudios que exploraron la contribución de la edad en el golpeo máximo de balón, indican que la máxima velocidad de golpeo incrementa con la edad en futbolistas jóvenes (Luhtanen, 1988; Bacvarevic et al., 2012). Estás mejoras en la velocidad de golpeo asociadas con la edad son probablemente debidas a una combinación de mejoras en el patrón de golpeo y cambios biológicos asociados con la maduración y el crecimiento (Poulmedis et al., 1988;

Rodano & Tavana, 1993, Trolle, Aagaard, Simonsen, Bangsbo, & Klausen, 1993; Tol, Slim, van Soest & van Dijk, 2002).

No obstante, los estudios que exploraron la influencia de la edad en la velocidad de golpeo fueron de carácter transversal, los rangos de edad utilizados fueron muy reducidos y analizando principalmente el golpeo solo con la pierna dominante. Por lo tanto, estudios longitudinales que registren la velocidad de balón con ambas piernas, en un rango de edad completo de la vida deportiva de los futbolistas y en ambos géneros, son necesarios para comprender mejor el efecto de la edad en el rendimiento máximo de golpeo.

Género

Los estudios que comparan la velocidad máxima de golpeo entre géneros han sido llevados a cabo principalmente con adultos. La velocidad de balón alcanzada por los jugadores de género masculino, con ambas piernas, es significativamente superior a la de las jugadores de género femenino, tanto en jugadores expertos como en novatos (Barfield et al., 2002; Izquierdo et al,. 2008; Shan, 2009), aunque pueden presentarse excepciones individuales (Barfield et al., 2002). Estas diferencias entre jugadores y jugadoras pueden ser atribuidas al uso de diferentes técnicas, que desarrollan diferentes parámetros cinemáticos y dinámicos. (Barfield et al., 2002; Shan, 2009; González-Jurado, Amate, & Martín, 2016). Después de un golpeo máximo, los hombres mostraron la tendencia de continuar el movimiento con un salto para disipar el momento residual de la pierna. Las mujeres evitaban esta fase aérea contrarrestando el momento con una flexión del tronco. Estás diferencias en la mecánica de golpeo entre ambos géneros, son debidas a que los hombres utilizan un patrón muscular más explosivo, y a que en las mujeres la desaceleración de las articulaciones más proximales (cadera y rodilla) es menos eficaz (Shan, 2009; González-Jurado et al., 2016).

Tiempo de práctica acumulado y nivel de competición

El tiempo de práctica acumulado es claramente un factor que afecta a la velocidad de golpeo (Anthrakidis et al., 2008; Shan, 2009), probablemente debido a la influencia de la experiencia. Esta experiencia proporciona a los futbolistas una mayor capacidad para ajustar diferentes formas de coordinación intermuscular (Shan, 2009). Se ha comprobado que los jugadores expertos alcanzaban mayores velocidades de balón que los inexpertos (De Proft et al., 1988a; Shan, 2009), lo mismo ocurría con los entrenados en comparación con los no entrenados y con los de élite respecto a los de no élite. Sin embargo, el nivel de competición no mostró diferencias entre diferentes grupos de futbolistas de categorías profesionales (1ª División, 2ª División y 3ª División).

Debido a que no existe una definición clara de la cantidad de entrenamiento, experiencia o nivel deportivo de los jugadores examinados, resulta muy complicado realizar comparaciones entre diferentes estudios. Por lo tanto, llegar a un consenso sobre la definición de estos términos y realizar una exhaustiva descripción de la muestra en las investigaciones es de vital importancia para que los resultados obtenidos entre diferentes estudios puedan ser interpretados y comparados con mayor fiabilidad.

Puesto específico

El puesto específico que desempeñan los jugadores en el terreno de juego no parece afectar la velocidad máxima de golpeo en fútbol. La mayoría de los estudios que abordaron este tópico no reportaron diferencias estadísticamente significativas en la velocidad de golpeo de balón con ambas piernas entre porteros, defensas, medios o delanteros (Taiana et al., 1993; Sousa, Garganta & Garganta, 2003; Izquierdo et al., 2008; Khorasani, Osman & Yusof, 2009).

Dominancia lateral

La dominancia lateral en las investigaciones publicadas sobre el golpeo en fútbol ha sido entendida como la preferencia de uso de uno de los pies. La dominancia lateral afecta de forma significativa al rendimiento del golpeo de balón. Los futbolistas producen velocidades de golpeo significativamente superiores con la pierna dominante en comparación con la no dominante. Esto ha sido comprobado tanto en jugadores amateurs (Narici et al., 1988; McLean & Tumilty, 1993; Mognoni et al., 1994; Nunome, 2006), como en jugadores expertos (Barfield, 1995; Dörge et al., 2002; Barfield, 2002), también en jóvenes (Barbieri, Santiago, Gobbi & Cunha, 2008), en hombres y mujeres (Barfield, 2002; Campo et al., 2009), con y sin intención de precisión hacia el objetivo del golpeo (Bacvarevic et al., 2012), y en varios tipos de golpeo (McLean & Tumilty, 1993; Marques et al., 2011). Las diferencias de rendimiento entre ambas piernas pueden ser causadas por una mejor coordinación intersegmental en el patrón de movimiento de la pierna dominante, y por una mejor transferencia de la velocidad del pie al balón en comparación con la no dominante (Dörge et al., 2002; Nunome, 2006).

4.1.2. Factores relacionados con la ejecución del golpeo

Esta sección se encarga de exponer y discutir los resultados relacionados con el objetivo específico 1.2 "*Identificar los factores que afectan a la velocidad máxima de golpeo en fútbol relacionados con la ejecución del golpeo y conocer los diversos métodos e instrumentos utilizados para registrar la velocidad del balón.*". Por favor, consulte el Artículo Nº 1 para más detalles (pág., 51).

Precisión

La precisión de golpeo es un componente importante dentro del rendimiento en fútbol, y puede ser definida como la habilidad para golpear el balón hacia un espacio concreto (Finnoff, Newcomer & Laskowski, 2002), de la portería, del campo o de otro jugador. La intención de precisión en un golpeo máximo en fútbol reduce significativamente la velocidad máxima de balón, si lo comparamos con golpeos donde precisión no es requerida (Lees & Nolan, 1998; Teixeira, 1999; Andersen & Dörge, 2011; Juárez & Navarro, 2010), probablemente debido a que el control del movimiento es menos estable cuando la intención de precisión es incorporada (Sterzing, Lange, Wächtler, Müller & Milani, 2009). Por otra parte, se ha comprobado que los jugadores que alcanzan mayores velocidades de balón en golpeos máximos, también son los que alcanzan mayores velocidades de balón cuando la intención de precisión es requerida (Juárez & Navarro, 2006; Juárez & Navarro, 2010).

A pesar de su importancia, el análisis del golpeo de precisión ha recibido menos atención en la literatura que los golpeos máximos (Kellis & Katis, 2007). Probablemente debido a la dificultad de desarrollar una prueba factible, fiable y operativa para medir la precisión de golpeo. De hecho, pese a que ha habido varios intentos para validar protocolos o test que midan la precisión de golpeo (Finnoff et al., 2002; Russell, Benton & Kingsley, 2008; Bacvarevic et al., 2012), ninguno de ellos se ha consolidado como protocolo estándar. Otra dificultad añadida es que para realizar un test de precisión de golpeo el número de intentos necesarios es muy elevado (11-41), mientras que para medir la velocidad máxima de golpeo se necesitan pocos intentos (1-2) (Bacvarevic et al., 2012).

Técnicas de golpeo

En el fútbol existen una gran variedad de técnicas de golpeo (Sterzing & Hennig, 2008). Bisanz y Gerish (1988) distinguen entre el golpeo de interior y tres variedades de golpeo de empeine: interior, exterior y total (Sterzing, 2010). El golpeo de interior, qué es el más preciso (Sterzing et al., 2009), se usa principalmente en pases cortos y golpeos de precisión. El golpeo de empeine total se emplea en pases largos y en el golpeo a portería, mientras que los golpeos de empeine interior y exterior se utilizan para imprimirle un efecto al balón (Sterzing & Hennig, 2008). Los golpeos de empeine alcanzan mayores velocidades de balón que los de interior (Levanon & Dapena, 1998; Sterzing et al., 2009; Katis & Kellis, 2010), y entre los tres tipos de golpeo de empeine, el golpeo de empeine total logró velocidades de balón significativamente superiores, seguidos del empeine interior y el empeine exterior (Neilson & Jones, 2005; Sterzing & Hennig, 2008; Sterzing et al., 2009). Curiosamente, los golpeos realizados descalzos produjeron mayores velocidades de balón que los realizaron con calzado (Sterzing, Kroiher & Hennig, 2008).

Además de considerar las distintas superficies con las que el pie contacta con el balón, existen otras variables relacionadas con la técnica de golpeo que pueden condicionar el rendimiento del mismo. La velocidad máxima de golpeo tiende a ser menor tras un golpeo a balón parado, si lo comparamos con un golpeo en el que el balón va rodando a 2.2 m/s hacia el jugador (Tol et al., 2002). La realización de una finta previa al golpeo también redujo la velocidad de balón (Katis & Kellis, 2011). Por otro lado, los golpeos precedidos de una carrera previa, obtuvieron mayores velocidades de balón que los realizados sin carrera previa (Markovic et al., 2006; Opavsky, 2011). Por último, los diferentes ángulos utilizados en la carrera de aproximación al balón no produjeron diferencias significativas en las velocidades de golpeo. No obstante, se comprobó que los futbolistas prefieren un ángulo de aproximación de entre 30° y 60° (Isokawa y Lees 1988; Masuda et al., 2005).

Fatiga muscular

A pesar de que este tema está relacionado con el Artículo Nº 2, para la elaboración de este documento hemos decido incluirlo antes de los protocolos de evaluación. El motivo es debido a que existe acuerdo en la literatura en que, tras la aplicación de diferentes protocolos de fatiga, la velocidad máxima de golpeo se ve reducida (Asami & Nolte, 1983; Katis & Kellis, 2011). Por lo tanto, para evitar la influencia de la fatiga a la hora de medir la velocidad máxima de golpeo deben utilizarse menos de 5 intentos consecutivos (Kellis & Katis, 2007).

Protocolos de evaluación

Existen varias investigaciones que validaron protocolos para registrar la velocidad máxima de golpeo de balón en fútbol (Markovic et al., 2006; Russell, Benton & Kingsley, 2008; Bacvarevic et al., 2012). Sin embargo, como ocurre con los protocolos para medir la precisión de golpeo, ninguno de ellos se ha consolidado como protocolo estándar, y no existe consenso en la literatura como deben ser estos protocolos.

En los párrafos anteriores hemos comprobado que existen una gran variedad de técnicas y factores relacionados con la ejecución de golpeo que condicionan la velocidad de golpeo de balón en fútbol, por lo que deben ser tenidos en cuenta para su medición. A continuación, exponemos unas pautas que a nuestro entender deben de cumplir los protocolos diseñados para evaluar el rendimiento máximo de golpeo en fútbol.

- La influencia de la intención de precisión debe ser reducida al máximo debido a que reduce significativamente la velocidad máxima de balón.
- Los golpeos realizados de “empeine total” alcanzaron velocidades de balón significativamente superiores, por lo que parece el tipo de golpeo más adecuado para medir la velocidad máxima de golpeo.
- La complejidad para homogeneizar las condiciones iniciales, a todos los participantes en un golpeo en el que el balón está en movimiento, hace recomendable evaluar el golpeo con el balón parado.
- La carrera de aproximación del jugador hacia el balón debe ser acotada, ya que influye significativamente en la velocidad del pie en el momento del contacto.
- Para evitar la influencia de la fatiga, deben utilizarse menos de 5 intentos consecutivos.

Teniendo en cuenta todas estas recomendaciones consideramos que el protocolo validado por Markovic et al. (2006) es el más adecuado para medir la velocidad máxima de golpeo. Sin embargo, proponemos una pequeña modificación, ya que este autor acota la carrera de aproximación del jugador al balón limitando el número de metros. A nuestro entender, acotar el número de pasos es la mejor opción, ya que permite un ajuste individual de la distancia de aproximación y produce técnicas más homogéneas intra e intersujeto.

Instrumentos de registro

Los instrumentos utilizados en la medición de velocidad del balón han sido muy diversos. Las primeras investigaciones realizadas registraban la velocidad del balón mediante el empleo de una videocámara (Isokawa & Lees, 1988; Luhtanen, 1988; Poulmedis, Rondoyannis, Mitsou & Tsarouchas 1988). Posteriormente, en los análisis biomecánicos en el laboratorio, se utilizaron sistemas de captura y análisis de movimiento en tres dimensiones, que empleaban múltiples videocámaras sincronizadas entre sí (Shan, 2009; Katis & Kellis, 2011). Otros instrumentos, menos populares, que han sido utilizados para medir la velocidad del balón son los sensores de sonido (Narici, Sirtori & Mognoni, 1988; Taiana, Grehaigne & Cometti, 1993; Mognoni, Narici, Sirtori, & Lorenzelli, 1994) y las células fotoeléctricas (Kristensen, Andersen & Sørensen, 2005). Sin embargo, en los últimos años se está imponiendo el uso del radar como principal instrumento de medida de la velocidad del balón, cuantificando la velocidad máxima del mismo (Masuda et al., 2005; Markovic et al., 2006; Bacvarevic et al., 2012), debido a que aporta numerosas ventajas, como la obtención de datos en tiempo real y su fácil transporte y utilización.

4.1.3. Relación entre la velocidad de golpeo de balón y la fuerza muscular

Esta sección se encarga de exponer y discutir los resultados relacionados con el objetivo específico 1.3 *"Identificar la relación entre la velocidad de golpeo de balón y la fuerza muscular*". Por favor, consulte el Artículo Nº 2 para más detalles (pág., 67).

Existen diversas clasificaciones de las manifestaciones de la fuerza muscular. En el entorno europeo, es posible que la propuesta que define las manifestaciones de la fuerza en base a las manifestaciones estáticas, activas y reactivas (figura 1), sea la que tiene una mayor aplicación (Bosco & Vila, 1991; Vittori, 1993).

La práctica del fútbol de alto nivel, requiere de casi todas las manifestaciones de la fuerza para la realización eficaz de las acciones, así como de las diferentes tensiones que pueden realizar los músculos en una acción determinada, por lo que las manifestaciones de la fuerza se presentarán de forma compleja y combinada.

Al analizar las diferentes acciones que se producen en el fútbol, podemos dividirlas en cuatro grandes grupos: saltos, desplazamientos, golpeos y luchas. De esta manera, es posible distinguir entre varias formas de expresión de la fuerza en el fútbol: Fuerza de Desplazamiento, Fuerza de Salto, Fuerza de Golpeo y Fuerza de Lucha (Seiru-lo, 1993; Domínguez, 2003). La fuerza de golpeo puede cuantificarse mediante el registro de la velocidad del balón, que es la consecuencia de la interacción entre la fuerza de los músculos que ejecutan el golpeo y de la coordinación motriz de dichos músculos (Too, 1984).

En las dos últimas décadas se han realizado numerosos estudios que han intentado aclarar la relación entre los niveles de fuerza muscular y la velocidad máxima de golpeo, con el objetivo de extraer las manifestaciones de fuerza que se requieren en su entrenamiento.

Figura 1. Manifestaciones de la fuerza (A partir de Vittori, 1990 elaboración propia).

Fuerza estática y dinámica máxima

La relación entre los valores de fuerza máxima, y el rendimiento máximo del golpeo de balón, no está clara. Algunas investigaciones reportaron correlaciones significativas entre la fuerza dinámica máxima, medida mediante dinámometros isocinéticos a diferentes velocidades angulares, de los flexores y extensores de cadera y rodilla (Cabri, De Proft, Dufour & Clarys, 1988; Poulmedis et al., 1988; Masuda et al., 2005; Anthrakidis et al., 2008), mientras que otros no encontraron relaciones significativas (Narici et al., 1988; McLean & Tumilty, 1993; Mognoni et al., 1994; Cometti, Maffiuletti, Pousson, Chatard, & Maffulli, 2001; Saliba & Hrysomallis, 2001). Juárez et al. (2008) tampoco encontraron correlaciones significativas entre la fuerza máxima dinámica en squat: 1RM(kg), y la velocidad de golpeo de balón. Los resultados de las mediciones de la fuerza isométrica (estática) máxima también son contradictorios; Luhtanen (1988) encontró correlaciones significativas entre la fuerza isométrica máxima de los flexores y extensores de rodilla y tobillo y la velocidad del balón, mientras que Dörge et al. (2002) no las encontró con los flexores de cadera y extensores de rodilla.

No ha sido posible establecer una relación de causa-efecto entre la fuerza máxima y el rendimiento máximo de golpeo (Shan, 2009). Por lo tanto, ni las mediciones de tipo isocinético, isométrico, ni los "*full squat test*" son buenos predictores de la velocidad del balón. Probablemente porque no reproducen las demandas musculares involucradas en el golpeo de balón.

Manifestaciones de la Fuerza: explosiva, explosiva-elástica y explosiva-elástica-reactiva

En este apartado se discuten los resultados encontrados en la revisión bibliográfica publicada Artículo Nº 2. La discusión de los datos de las investigaciones originales correspondientes a los Artículos Nº 3 y Nº 4 se encuentran en el punto 4.2.2 (pág., 30).

Es razonable suponer que los test que impliquen acciones musculares más explosivas podrían ser más apropiados para explorar la relación entre las manifestaciones de la fuerza muscular y el rendimiento máximo del golpeo de balón. Para la valoración de la fuerza explosiva han sido muy representativos los test de salto vertical, destacando una gran variedad y modificaciones para distinguir la fuerza explosiva (test de salto SJ) y la fuerza explosiva-elástica (test de salto CMJ), explosiva-elástica-reactiva predominantemente de la musculatura de la rodilla (test de salto CMJA) y predominantemente de la musculatura del tobillo (test de salto 1RJA). Sin embargo, el reducido número de estudios y sus resultados contradictorios dificultan establecer una conclusión definitiva sobre esta relación. Algunos estudios reportaron relaciones significativas entre las mediciones de fuerza explosiva y fuerza explosiva-elástica y la velocidad de golpeo de balón (Sousa et al., 2003 Mercé, González, Mayo, Pardo & Sorli, 2004), mientras que otros reportaron correlaciones débiles pero estadísticamente significativas (Juárez et al., 2008). No obstante, ninguno estudió la contribución de la fuerza explosiva-elástica-reactiva. Además, estos estudios han sido realizados con futbolistas jóvenes y son necesarias investigaciones con jugadores adultos, y en todos los casos es definitivo el asegurar la calidad del dato a través de la estabilidad en la ejecución de los saltos de los sujetos.

4.1.4. Programas de entrenamiento de fuerza y velocidad máxima de golpeo

Esta sección se encarga de exponer y discutir los resultados relacionados con el objetivo específico 1.4 *"Conocer los efectos de programas de entrenamiento de fuerza en la velocidad máxima de golpeo*". Por favor, consulte el Artículo Nº 2 para más detalles (pág., 67).

Existen evidencias en la literatura que, tras la aplicación de diferentes programas de entrenamientos de fuerza, en combinación con las sesiones de entrenamiento de fútbol, pueden incrementar de forma significativa la velocidad máxima de golpeo (de Villarreal et al. 2015; Ramírez-Campillo et al., 2015). Estos estudios han sido realizados principalmente en futbolistas jóvenes tanto de nivel amateur como de élite, y en futbolistas amateur adultos. Sin embargo, existe escasez de información con futbolistas adultos de élite, probablemente debido a la dificultad del acceso a este tipo de muestra. Los estudios conducidos en adultos no lograron obtener mejoras significativas en la velocidad máxima de balón (Trolle et al., 1993; Aagaard, Simonsen, Trolle, Bangsbo & Klausen, 1996), probablemente porque los ejercicios de fuerza isocinética utilizados en esos estudios no son los más apropiados para mejorar el rendimiento en el golpeo de balón. Por lo tanto, son necesarios más estudios que comprueben los efectos de otros tipos en entrenamiento de fuerza con futbolistas de élite adultos.

La efectividad de los programas de entrenamiento de fuerza en la velocidad de golpeo de balón con la pierna dominante y no dominante ha sido examinada solo en tres estudios (Bloomfield, Elliott, & Davies, 1979; Csanádi & Kubala 1984; González-Jurado et al., 2016). Los resultados de estos estudios muestran mejoras significativas en la velocidad de balón con ambas piernas, siendo mayores en la no dominante (García-Pinillos et al, 2014; de Villarreal et al, 2015).

Los programas de entrenamiento de fuerza que resultaron más efectivos a la hora de mejorar la velocidad de golpeo de balón, fueron aquellos que utilizaron ejercicios de fuerza explosiva en combinación con las sesiones habituales de entrenamiento de fútbol. Estos estudios reportaron mejoras simultáneas en la capacidad de salto y la velocidad de golpeo de balón (Taiana et al., 1993; Campo et al., 2009; Manolopoulos, Katis, Manolopoulos, Kalapotharakos, Kellis, 2013; Marques et al., 2013; Ramírez- Campillo et al., 2014; de Villarreal et al. 2015; Ramírez-Campillo et al., 2015), en contraposición con lo expuesto en los estudios recogidos en el apartado 4.1.3. Esto puede ser debido a que tanto los saltos como los lanzamientos están formados por una combinación de activaciones musculares que se conocen como el ciclo estiramiento-acortamiento (SSC), que son determinantes para su rendimiento. En esta línea, es razonable pensar que, las mejoras en los niveles de fuerza y de coordinación intermuscular producidas por los programas de fuerza puedan manifestarse en los SSC del salto y del golpeo. Por lo tanto, son necesarias más investigaciones que aclaren la relación entre las manifestaciones de la fuerza y velocidad máxima de golpeo, para extraer las manifestaciones de fuerza que se requieren en el entrenamiento del rendimiento máximo de golpeo.

4.2. Estudio de las variables velocidad de balón, fuerza muscular y Kicking Déficit

En este apartado se presenta una síntesis combinada de la discusión de los resultados de las investigaciones de campo que componen esta tesis doctoral (Artículo Nº 3, Artículo Nº 4 y Artículo Nº 5) y que tienen como finalidad alcanzar el Objetivo General 2: "*Estudiar la velocidad máxima de golpeo de balón y el Kicking Deficit (KD) en diferentes grupos de edad de futbolistas de élite, e iniciar la exploración de la naturaleza de ese déficit*", y sus correspondientes objetivos específicos.

Los Artículos Nº 3 y Nº 4 se han llevado a cabo con la misma metodología, persiguiendo los mismos objetivos en diferentes tipos de muestra. El Articulo Nº 3 fue realizado en futbolistas adultos (Grupo Senior = 20.27 ± 4.49 años), y el Artículo Nº 4 con dos grupos de futbolistas jóvenes (G-14 = 12.18 ± 0.94 años; G+14 = 15,04 ± 0.80 años). En ambos artículos se ha registrado la velocidad de golpeo con la pierna dominante y no dominante, y se ha calculado el KD. Se ha explorado la naturaleza del KD estudiando la relación entre los test de salto vertical y la velocidad máxima de golpeo con cada una de las piernas. Además, se ha comprobado la influencia de las variables antropométricas de los sujetos en la velocidad máxima de golpeo.

El Artículo Nº 5 se ha llevado a cabo con una muestra mucho más amplia, formada por todos los jugadores de las categorías inferiores de Real Club Deportivo de la Coruña. Los jugadores fueron agrupados de acuerdo con sus categorías en 10 grupos de edad (U-9 hasta U-19), además del segundo equipo del club (U-23). Se ha registrado la velocidad de golpeo con cada una de las piernas y se ha calculado el KD, buscando describir la evolución de estas variables a lo largo de los grupos de edad en futbolistas de élite.

En los siguientes apartados se exponen los resultados obtenidos:

4.2.1. *Velocidad máxima de golpeo y Kicking Deficit*

Esta sección se encarga de exponer y discutir los resultados relacionados con el objetivo específico 2.1 *"Determinar la velocidad máxima de golpeo de balón con cada una de las piernas y el Kicking Deficit (KD)*". Por favor, consulte los Artículos Nº 3, Nº 4 y Nº 5 para más detalles (pág., 49).

Nuestros resultados muestran que los jugadores producen significativamente mayores velocidades de balón con la pierna dominante, confirmando la existencia de un déficit de golpeo (KD) con la no dominante en toda la muestra analizada.

Por la información de la que disponemos, nuestros estudios fueron los primeros en calcular el KD a través de los valores individuales del KD de cada jugador.

Los valores del KD obtenidos en los Artículos Nº 3 y Nº 4, no presentaron diferencias significativas entre grupos de edad (15.31 ± 7.32 % para G-14; 15.83 ± 7.88 % para G+14; 12.49 ± 3.24 % para el Grupo Senior). Sin embargo, la velocidad de golpeo si mostró diferencias significativas entre grupos $p < 0.01$. Lo mismo ocurre con los grupos de edad analizados en el Artículo Nº 5. Por lo tanto, podemos afirmar que el KD es un elemento constante en los futbolistas de élite, y sus valores permanecen estables sin cambios significativos en los diferentes grupos de edad. Sin embargo, existen pequeños cambios de tendencia que se comentarán con más detalle en el apartado 4.2.4.

Finalmente, nuestros resultados muestran que el KD es independiente de la velocidad máxima de golpeo con la pierna dominante (Artículo Nº 3). Además, el KD es más útil para comparar el rendimiento máximo de golpeo entre piernas, que la diferencia entre valores absolutos de velocidad de golpeo con cada una de ellas, permitiendo realizar comparaciones intra e inter sujeto. Por lo tanto, el KD debería de incorporarse para evaluar y monitorizar la evolución de cada jugador para alcanzar niveles similares de rendimiento con ambas piernas.

4.2.2. *Relación entre las manifestaciones de la fuerza y velocidad máxima de golpeo*

Esta sección se encarga de exponer y discutir los resultados relacionados con el objetivo específico 2.2 *"Identificar la intensidad y significación estadística de la relación entre los test de salto vertical y la velocidad máxima de golpeo con cada una de las piernas*". Por favor, consulte los Artículos Nº 3 y Nº 4 para más detalles (pág., 81; pág.,95).

Para explorar la naturaleza del KD se llevó a cabo un análisis correlacional para cada grupo de edad, entre los test saltos verticales y velocidad máxima de golpeo. Encontramos correlaciones significativas entre la altura alcanzada en los 4 saltos verticales y la velocidad de golpeo con las dos piernas en los futbolistas jóvenes (G-14, G+14). Sin embargo, con futbolistas adultos está asociación fue significativa solo con la pierna dominante. Esta falta de relación encontrada en los futbolistas adultos, puede ser debida a la dificultad de expresar con la pierna no dominante, las mismas habilidades neuromusculares que son capaces de expresar con la dominante. Los futbolistas desarrollan una alta especificidad muscular con cada pierna. Mientras la pierna no dominante es entrenada de forma isométrica, proporcionando una plataforma estable para poder realizar el “swing” con la pierna de golpeo, la acción de la pierna de golpeo (dominante) se caracteriza por ser estimulada por una acción explosiva (Dörge et al., 2002; Young & Rath, 2011). Esta especificidad de la estimulación podría descompensar la eficiencia de la acción muscular de la pierna no dominante, lo que puede explicar la falta de correlación entre los saltos verticales y la velocidad de golpeo con la pierna no dominante en futbolistas adultos. Sin embargo, en jugadores jóvenes las relaciones encontradas entre los saltos verticales y la velocidad de golpeo con ambas piernas sugieren que los niveles de fuerza muscular podrían ser más determinantes para el golpeo (Artículo Nº 3). Esto puede ser debido a que la habilidad de golpeo no está tan consolidada. De hecho, los valores individuales del CV de la velocidad de golpeo de los futbolistas jóvenes (Artículo Nº 4) fueron significativamente más altos que los encontrados en futbolistas adultos (Artículo Nº 3), mientras que el rendimiento del golpeo fue significativamente más bajo en futbolistas jóvenes. Esta idea se ve reforzada al analizar las correlaciones entre la edad y la velocidad de golpeo con ambas piernas; estas fueron altas en el G-14, ligeramente inferiores en G+14, e inexistentes en el grupo senior.

Teniendo en cuenta los resultados mencionados anteriormente, parece que el KD tiene un origen multifactorial, y que puede ser resultado de la influencia e interacción de diferentes factores, en función de la experiencia de los jugadores. Esto es de especial importancia para diseñar estrategias y programas eficaces para reducir el KD. Nuestros resultados apoyan la idea de que los programas de entrenamiento de fuerza explosiva (saltos, sprints y ejercicios pliométricos adaptados a la edad del jugador), en combinación con ejercicios que impliquen patrones musculares más complejos (ejercicios de simulación, o reales de golpeo) y con las sesiones habituales de entrenamiento de fútbol, son efectivos para mejorar la velocidad máxima de golpeo. Sin embargo, incorporar tareas analíticas para mejorar el rendimiento con la pierna no-dominante, no garantiza una estimulación adecuada y/o suficiente durante las sesiones de entrenamiento y competición. Por lo tanto, los entrenadores deberán de reforzar positivamente a sus jugadores para continuar usando la pierna no dominante durante las otras partes de los entrenamientos y en los partidos, evitando el uso del feedback negativo cuando los jugadores fallan con la pierna no dominante.

Estos comportamientos deberían ser determinantes para la consolidación de la mejora del rendimiento con la pierna no dominante y reducir gradualmente el KD, hasta llegar a un punto en el que los jugadores tienen un buen rendimiento con las dos piernas y no tienen que recurrir constantemente a situaciones de seguridad, usando su pierna dominante e incrementando su KD. Estas observaciones deben ser registradas para analizar los efectos de las intervenciones prácticas.

4.2.3. Variables cineantropométricas y velocidad máxima de golpeo

Esta sección se encarga de exponer y discutir los resultados relacionados con el objetivo específico 2.3 *"Identificar la intensidad y significación estadística de la relación entre las variables antropométricas y la velocidad máxima de golpeo con cada una de las piernas*". Por favor, consulte los Artículos Nº 3 y Nº 4 para más detalles (pág., 81; pág., 95).

En futbolistas jóvenes (G-14,G+14), la mayoría de variables antropométricas analizadas correlacionaron con la velocidad de balón alcanzada con las piernas dominante y no dominante. Sin embargo, con futbolistas adultos no se encontraron asociación entre ambos parámetros. Una posible explicación es que durante los periodos pre-puberal y puberal, los cambios que se producen en las variables antropométricas asociados con el proceso de maduración, como el peso, la altura y la fuerza muscular (Malina, et al., 2000; Malina et al., 2005; Figueiredo, Gonçalves, Coelho, Silva, & Malina, 2009; Ré et al., 2014) pueden tener una gran influencia en la velocidad máxima de golpeo. Sin embargo, después de la pubertad, cuando finalizan los cambios asociados con la maduración, las medidas antropométricas tienen menos influencia en su rendimiento. Por lo tanto, seleccionar a los jugadores en función de sus características antropométricas, puede aportar a los equipos beneficios solo a corto plazo. Cuando los jugadores completan su crecimiento, las ventajas antropométricas se reducen y los factores técnicos y tácticos pasan a tener mayor importancia (Ré et al., 2014). Por lo tanto, debido a que las ventajas antropométricas desaparecen con la edad, los criterios técnicos y tácticos son los que se deben priorizar en los procesos de detección, selección y seguimiento de talentos.

4.2.4. Tendencias en la velocidad de balón a lo largo de la edad.

Esta sección se encarga de exponer y discutir los resultados relacionados con el objetivo específico 2.4 *"Describir la evolución de velocidad máxima de golpeo con cada una de las piernas* *y el Kicking Deficit (KD), en los grupos de edad de futbolistas de élite*". Por favor, consulte el Artículo Nº 5 para más detalles (pág., 125).

La velocidad máxima de golpeo con la pierna dominante incrementa significativamente y de forma progresiva desde el grupo U-9 hasta U-16, mientras que sigue incrementando de forma moderada, pero estadísticamente no significativa desde el grupo U-16 hasta el U-23, indicando que a la edad media de 16.21 años se alcanza un rendimiento adulto en el golpeo de balón con la pierna dominante.

Sin embargo, la velocidad de golpeo con la pierna no dominante incrementa significativamente de forma progresiva desde el grupo U-9 hasta el U-18, indicando que con la pierna no dominante el rendimiento adulto en el golpeo de balón no es alcanzado hasta la edad media de 17.91 años.

Los mayores incrementos en la velocidad de golpeo se produjeron entre los grupos U-13 y U-16, coincidiendo con la etapa en la que ocurren los principales cambios asociados con el proceso maduración y crecimiento en sujetos masculinos (Malina et al., 2006). Estos resultados confirman que los incrementos en la velocidad de balón asociados con la edad, en futbolistas jóvenes, no son debidos únicamente a una mejora en el patrón de golpeo, sino que también están relacionadas con los cambios producidos con el proceso de crecimiento y maduración como el incremento del tamaño corporal y los niveles fuerza muscular (ver apartado 4.2.3).

Confirmando los resultados obtenidos en los Artículo Nº 3 y Nº 4, en todos los grupos de edad analizados en el Artículo Nº 5 los futbolistas producían mayores velocidades de golpeo con la pierna dominante, confirmando que el KD es un elemento constante en los futbolistas de élite, y sus valores permanecen sin cambios significativos entre los grupos de edad (U-9 hasta U-23). Sin embargo, el KD alcanza sus valores más altos entre los grupos U-12 y U-15, debido al estancamiento de la velocidad de golpeo con la pierna no dominante.

5. CONCLUSIONES

En esta sección se exponen las principales conclusiones para cada uno de los objetivos específicos de esta tesis.

La Subsección 5.1 está relacionada con las dos primeras publicaciones de esta tesis (Artículo Nº 1 y Artículo Nº 2). Ambos artículos son revisiones bibliográficas que tienen como finalidad alcanzar el Objetivo General 1 *"Analizar el estado actual de las investigaciones sobre el rendimiento máximo de golpeo de balón en fútbol"*, y sus correspondientes objetivos específicos.

La Subsección 5.2 está relacionada con las investigaciones de campo (Artículo Nº 3, Artículo Nº 4 y Artículo Nº 5) que tienen como finalidad alcanzar el Objetivo General 2: *Estudiar la velocidad máxima de golpeo de balón y el Kicking Deficit (KD) en diferentes grupos de edad de futbolistas de élite, e iniciar la exploración de la naturaleza de ese déficit,* y sus correspondientes objetivos específicos.

5.1. Conclusiones relacionadas con la revisión de la literatura.

Objetivo 1.1: *Identificar los factores que afectan a la velocidad máxima de golpeo en fútbol relacionados con las características de la muestra.*

La edad, el género, el tiempo de práctica acumulado, y la dominancia lateral de los participantes, condicionan la velocidad máxima de golpeo de balón en fútbol. Estas variables deben ser descritas y tenidas en cuenta a la hora de evaluar e interpretar la velocidad máxima de golpeo, para poder realizar comparaciones entre diferentes grupos de sujetos.

Objetivo 1.2: *Identificar los factores que afectan a la velocidad máxima de golpeo en fútbol relacionados con la ejecución del golpeo y conocer los diversos métodos e instrumentos utilizados para registrar la velocidad del balón.*

La superficie de contacto pie-balón, la carrera de aproximación, la velocidad del balón en el momento del impacto, la realización de una finta previa o la intención de precisión en el golpeo afectan a la velocidad máxima de golpeo en fútbol. Estas variables deben ser tenidas en cuenta para su medición.

No existe consenso sobre como deben ser los protocolos para registrar la velocidad máxima de golpeo de balón en fútbol.

Los instrumentos utilizados en la medición de velocidad del balón han sido muy diversos. Se está imponiendo el uso del radar como principal instrumento de medida de la velocidad del balón, debido a que aporta datos en tiempo real, y es fácil su transporte y utilización.

Objetivo 1.3: *Identificar la relación entre la velocidad de golpeo de balón y la fuerza muscular.*

En base a la literatura científica disponible actualmente no es posible establecer una relación de causa-efecto entre la fuerza máxima y la velocidad máxima de golpeo.

Existen pocas investigaciones que estudien la relación entre test de fuerza explosiva, y sus resultados son contradictorios.

Objetivo 1.4: *Conocer los efectos de programas de entrenamiento de fuerza en la velocidad máxima de golpeo.*

Los programas de entrenamiento de fuerza explosiva, en combinación con las sesiones habituales entrenamiento de fútbol, resultaron efectivos a la hora de mejorar la velocidad de golpeo de balón. Estás mejoras fueron acompañadas de un aumento de rendimiento en los test de salto vertical.

5.2. Conclusiones relacionadas con las investigaciones de campo

Objetivo 2.1: *Determinar la velocidad máxima de golpeo de balón con cada una de las piernas y el Kicking Deficit (KD).*

La velocidad máxima de golpeo de balón es mayor cuando los jugadores golpean con la pierna dominante, confirmando la existencia de un déficit de golpeo (KD) con la no dominante en todos los grupos de edad analizados.

Objetivo 2.2: *Identificar la intensidad y significación estadística de la relación entre los test de salto vertical y la velocidad máxima de golpeo con cada una de las piernas.*

En futbolistas jóvenes, existe asociación entre la altura alcanzada en los saltos verticales (SJ, CMJ, CMJA, 1RJA) y velocidad máxima de golpeo con la pierna dominante y no dominante.

En futbolistas adultos (U-23), solo existe relación entre la altura alcanzada en los saltos verticales (SJ, CMJ, CMJA, 1RJA) y velocidad máxima de golpeo con la pierna dominante.

Objetivo 2.3: *Identificar la intensidad y significación estadística de la relación entre las variables antropométricas y la velocidad máxima de golpeo con cada una de las piernas.*

En futbolistas jóvenes (G-14, G+14), existe asociación entre la mayoría de variables antropométricas analizadas y la velocidad de balón alcanzada con las piernas dominante y no dominante.

En futbolistas adultos (U-23), no se encontró asociación entre la velocidad máxima de golpeo y las variables antropométricas.

Objetivo 2.4: *Describir la evolución de velocidad máxima de golpeo con cada una de las piernas y el Kicking Deficit (KD), en los grupos de edad de futbolistas de élite.*

La velocidad máxima de golpeo con la pierna dominante aumenta con la edad desde los 9 hasta los 16 años.

La velocidad máxima de golpeo con la pierna no dominante aumenta con la edad desde los 9 hasta los 18 años.

El KD permanece estable entre los diferentes grupos de edad analizados (U-9 hasta U-23).

6. APLICACIONES PRÁCTICAS

Cuándo se registre la velocidad máxima de golpeo, la interpretación de los resultados tendrá en cuenta las variables edad, género, tiempo de práctica acumulado y dominancia lateral para realizar comparaciones entre diferentes tipos de sujetos.

Cuándo se registre la velocidad máxima de golpeo, se tendrá en cuenta la validez y reproductibilidad del protocolo utilizado (superficie de contacto pie-balón, la carrera de aproximación, la velocidad del balón en el momento del impacto, la realización de una finta previa, la intención de precisión). Sugerimos la realización de prueba de Markovic et al. (2006) con la modificación realizada para esta Tesis.

En el proceso de entrenamiento y evaluación el instrumento de registro que proporciona datos en tiempo real y de fácil utilización es el radar.

Los programas de entrenamiento de fuerza y técnica más efectivos para la mejora de la velocidad de golpeo, son aquellos que combinan ejercicios y las manifestaciones de la fuerza que han mostrado relación significativa en esta tesis: fuerza explosiva, fuerza explosivo-elástica y fuerza explosivo-elástica-reactiva. Se realizarán para ambas piernas.

Las estrategias para reducir el KD requieren abordaje múltiple, y deben de llevarse a cabo preferentemente desde los 13 hasta los 16 años de edad:

- Utilizar tareas de golpeo real, donde se potencie el uso de la pierna no dominante.
- Utilizar estrategias que fomenten el uso de la pierna no dominante en los entrenamientos y las competiciones.

Se prestará especial atención a las recomendaciones de entrenamiento con respecto a las edades:

- Para la pierna dominante, hasta los 16 años.
- Para la pierna no dominante, hasta los 18 años.

7. LIMITACIONES DEL ESTUDIO Y PROPUESTAS DE INVESTIGACIONES FUTURAS

En este apartado se reflexiona sobre las limitaciones de la investigación realizada. El objetivo no es otro que el de advertir al lector de ellas y facilitar el análisis y comprensión de la discusión sobre los resultados de este estudio con respecto a la literatura. Entre las limitaciones del estudio, podemos definir las siguientes.

a) En relación con la literatura: A pesar de que existen numerosas investigaciones que analicen el rendimiento máximo de golpeo con las dos piernas, son escasas las investigaciones que examinen la evolución del golpeo a lo largo de la edad en un amplio rango de edad. Además, esta carencia de información es aún mayor con la pierna no dominante.

b) En relación con el diseño de las investigaciones de los Artículos Nº 3 y Nº 4: Debido a la naturaleza descriptivo-correlacional, se hace necesario manejar los datos obtenidos con la oportuna cautela. Las relaciones halladas tienen carácter asociativo y nunca causal.

c) En relación con el diseño de la investigación del Artículo Nº 4: Debido a no haber establecido el estado de maduración de los sujetos.
d) En relación a la edad de las muestras de los estudios correspondientes al Artículo Nº 4: El criterio utilizado para agrupar a los sujetos en los grupos de menos y más de 14 años, fue la edad decimal de los participantes. Por lo que se deberá tener muy en cuenta en la comparación con los resultados de otros estudios con jóvenes futbolistas que establezcan la edad cronológica o la categoría de edad deportiva.
e) En relación a la edad de las muestras de los estudios correspondientes al Artículo Nº 5: El criterio utilizado para agrupar a los sujetos, fue la edad cronológica de los participantes. Por lo que se deberá tener muy en cuenta en la comparación con los resultados de otros estudios con jóvenes futbolistas que establezcan la edad cronológica o la categoría de edad deportiva.
f) En relación con fecha de toma de datos: Nuestros test fueron llevados a cabo al final de la temporada competitiva, y todavía debe ser explorado si nuestros resultados son consistentes a lo largo del período competitivo.

g) En relación con los procedimientos registro: La diversidad de métodos, instrumentos y protocolos empleados para registrar la velocidad de golpeo de balón en las investigaciones de campo, hacen muy difícil la comparación de los resultados con otras investigaciones.

h) En relación con la muestra: Todos los jugadores que participaron en nuestros estudios, son jugadores de élite en su edad, de género masculino, pertenecientes al Real Club Deportivo de la Coruña (ver apartado 3.1). La extrapolación de nuestros resultados a jugadores o equipos de diferentes niveles de competición y género debe hacerse con precaución.

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COMPENDIO DE PUBLICACIONES

Artículo Nº 1

A Critical Review of the Technique Parameters and Sample Features of Maximal Kicking Velocity in Soccer

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A Critical Review of the Technique Parameters and Sample Features of Maximal Kicking Velocity in Soccer

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ABSTRACT

THE STUDY OF THE MAXIMAL KICK BALL VELOCITY (MKBV) IN SOCCER IS OF RELEVANCE FOR THE SCORE ACHIEVED IN A SOCCER MATCH. THIS REVIEW FOCUSES ON STUDIES THAT HAVE EXPLORED TECHNIQUE PARAMETERS AND INDIVIDUAL FEATURES THAT CAN CONTRIBUTE TO THE MKBV. THE EFFECTS OF AGE, GENDER, LIMB DOMINANCE, PRACTICE DURATION, COMPETITION LEVEL, PLAYING POSITION, AND VARIATIONS IN THE KICKING TECHNIQUE ARE DISCUSSED. WE PROVIDE METHODOLOGICAL SUGGESTIONS THAT MAY HELP IN THE COMPARISON OF RESULTS ACROSS DIFFERENT STUDIES AND THUS LEAD TO A BETTER UNDERSTANDING OF THE UNDERLYING FACTORS THAT CONTRIBUTE TO MAXIMAL KICKING VELOCITY. FOR A VIDEO ABSTRACT OF THIS ARTICLE, SEE SUPPLEMENTAL DIGITAL CONTENT 1 (http://links.lww.com/SCJ/A164).

INTRODUCTION

Kicking is the most widely studied soccer skill (4,18,24,43,50) and is defined as the ability of a player to consciously hit the ball (16). Kicking is considered a fundamental skill for the soccer players' performance (7,35,47) because it is used in passes, crosses, and clearances. Moreover, kicking is a determining factor for scoring goals in a game (13,34,57). An analysis of the 2010 soccer world cup revealed that 80.69% of the goals were achieved by kicking (53).

From a biomechanical point of view, a kicking action can be described as a "throw-like" pattern in which the distal segments are allowed to lag behind the proximal segments as they move forward (19). In addition, kicking can also be described as a summation of forces (62), in which the foot is the last and fastest segment to intervene in the open kinetic chain (78). Therefore, the foot velocity at the initial instant of the impact correlates with the ball velocity (5,6,17,39,42).

The performance of soccer kicking depends on the kicked ball velocity and accuracy (40). Although accuracy is an important factor, the kicking performance in soccer has been evaluated predominantly by the maximum ball velocity (22,31,45). Therefore, assuming that the kick is accurate, the chance of scoring increases with an increased ball velocity as there is less time for the goalkeeper to react (45).

The role of the ball velocity in soccer has been investigated by several studies by identifying the factors that contribute to the maximal kicking velocity. These factors include the effect of age (7,44), gender (10,65), limb dominance (5,8–10,14,18,48,49,51,55,59,76), practice time (4,65), competition level (1,15), and playing position (27,37,67,72). Other studies have explored the relationship between the ball velocity and the different kicking techniques, such as the ability to strike a target (kicking accuracy) (7,29,30,38,41,71), the different contact surfaces of the foot with the ball (28,32,42,52,54,56), with or without

KEY WORDS:
kicking accuracy; maximal ball velocity; maximal kicking performance; protocols

a previous run-up (26,36,45,47,58,64), and after "faking" (cutting) a maneuver task (33).

The purpose of this review is to critically discuss the relevance of each of the factors mentioned above to the maximal kicking velocity in soccer, so that these could be interpreted by coaches and practitioners accordingly.

METHODS

The following databases were used in this review: MEDLINE, Sport Discus, Dialnet, Google Scholar, and Scopus. The keywords used were combinations of "football," "soccer," "kick," "kicking," "speed," "maximal," "ball," "velocity," and "shot." Studies in English, Spanish, and Portuguese from 1979 to 2014 were included in this review with a focus on the maximal kicking velocity and one or more of the following factors: age, gender, limb dominances, practice time, competition level, playing position, and kicking technique. We analyzed more than 300 articles, of which 210 were studies about ball velocity, and 48 of which were included in this review.

FACTORS RELATED WITH THE SAMPLE CHARACTERISTICS

Age and gender. Kicking ability, as a basic skill, has been shown to naturally develop from an early age (40). The ball velocity increases with age during the first stages of human development (7,12,44). Bloomfield et al. (12) suggest that the skill develops rapidly between the ages of 4 and 6 years and at the mean age of 11.2 years a mature kicking pattern is achieved by 80% of the children (12). The authors also suggest that this age is ideal for the evaluation of stable parameters for investigation. The ball velocity increments associated with age are likely not only due to skill development of the kicking pattern but also due to the increased body size and muscle strength associated with growth and maturation (60,62,74,75).

The youngest sample used in the study of the maximal kicking velocity in soccer included children from 10.3 ± 0.9 to 17.1 ± 2.3 years (44). In this study, the authors compared the maximal kicking velocity across ages and reported the highest maximal velocities for postadolescence and preadolescence. These results have been replicated by Bacvarevic et al. (7) for ages of 12.2 ± 0.3 to 15.3 ± 0.3 years. Bacvarevic et al. (7) also reported that the differences between children of 12 and 15 years old remain when the kick is performed with the nondominant limb and when subjects were instructed to kick with accuracy. The values of the above-mentioned studies are included in Table 1.

The studies comparing the maximal kicking soccer velocity between genders are scarce and have been conducted primarily in adults (10,23,65). These studies show that the maximal kicking velocity in females is significantly lower than males. These findings have been replicated in skilled and novice soccer players (65). However, the factors contributing to these gender differences remain inconclusive. Barfield et al. (10) have shown that females have the ability to kick with both the dominant and nondominant limbs with similar kinematic profiles of males. However, other studies attribute the lower maximal velocity in females to the use of different techniques in comparison with males (23,65). Thus, after a powerful kick, males follow through with a jump to dissipate residual leg momentum, whereas females avoid this airborne phase and, instead, counteract the momentum with an upper-body flexion (65). In addition, male players use absolute explosive muscle work patterns (higher maximum and faster increase rate of muscle tension) and effective deceleration of the more proximal joints (hip and knee) to a greater extent than skilled female players (23,65).

In the following review for the sake of fluency, the gender will be discussed explicitly only when the studies include female subjects.

Practice time accumulation and competition level. Table 2 summarizes the maximal kicking velocity values for players with different practice time accumulation, competition level, and playing position. Practice time accumulation is clearly a factor that affects maximal kicking velocity (4,65), likely because of the influence of experience. This experience provides the player with a greater capacity to adjust to different forms of neuromuscular coordination (65). Thus, it is supported by findings showing that expert players can kick further than inexperienced players (18). Additionally, expert male and female soccer players reached higher ball velocity values compared with novice players (65). Similar results have been obtained comparing trained and untrained players (4) and elite versus nonelite university soccer players (1) (Table 2). However, the ball velocity values did not show significant differences between different groups of professional elite players (15). Nevertheless, a comparison between these studies is difficult because there is no clear definition for the amount of training and experience of the elite and novice players.

Different play positions in soccer: Goalkeepers, defenders, midfielders, and strikers. Several studies (Table 2) have shown that the ball velocity values did not differ across various soccer player positions, nor between the dominant (27,67,72) and nondominant legs (27,67). However, 1 study demonstrated higher ball velocities by midfielders and strikers compared with defenders (37).

Limb dominance. Table 3 summarizes the maximal kicking velocity values for dominant and nondominant leg performance. There is an agreement across studies that ball velocity is significantly faster after a kick with the dominant leg compared with the nondominant one. This is true for expert soccer players (9,10,18), amateurs (48,49,51,55,59,76), young subjects (8), both genders (10,14), for kicks with or without accuracy demand (7), and for different techniques and kick conditions (46,48). The

Table 1
Maximal kicking velocity values for different ages and gender

Research	Subject characteristics				Kick	Approach steps/angle	RI	VB ($m \cdot s^{-1}$)
	n	Age	Player level	Gender				
Age								
Luhtanen (44)	29		Amateur	M	Instep	2/free	1C	[a]
	8	10.3 ± 0.9						14.9 ± 1.7
	8	14.4 ± 1.1						18.4 ± 1.7
	13	17.1 ± 2.3						22.2 ± 3.0
Bacvarevic et al. (7)	106	11.514.5	High level	M	Instep	Free	R	
	27	12.2 ± 0.3			Maximum			22.7 ± 2.5[b]
	26	13.1 ± 0.2			Maximum			24.8 ± 2.1[b]
	26	14.3 ± 0.3			Maximum			27.1 ± 2.8[b]
	27	15.3 ± 0.3			Maximum			28.7 ± 2.3[b]
Gender								
Barfield et al. (10)	8	19–22	Elite		Instep	2/30–45°	2C	[a]
	2			M				25.3 ± 1.51
	6			F				21.5 ± 2.44
Shan (65)	44	21.7 ± 2.2	College students		Instep	Free	3D	[b]
			Skilled	M				24.2 ± 3.1
			Skilled	F				19.6 ± 2.6
			Novice	M				16.9 ± 2.7
			Novice	F				13.2 ± 2.3

3D = motion capture system; C = video camera; F = female; M = male; n = sample size; R = radar; RI = register instrument; VB = kicking ball velocity.

[a] $P < 0.001$.

[b] $P < 0.05$.

consistent ball velocity differences between the 2 limbs are likely due to a more efficient intersegmental motion pattern and transfer of velocity from the foot to the ball when kicking with the preferred leg (18). Furthermore, faster leg swing observed for the preferred leg was most likely the result of a larger muscle momentum (55). In addition, these differences depend on the skill level of the players so that the higher the skill level, the better the coordination of both limbs (55). For a young soccer player, performance with the dominant leg is characterized by a faster and more accurate "powerful-kick" in comparison with the nondominant leg (48). However, during a "chip kick," the velocity and accuracy do not show this trend (48). The chip kick places more emphasis on skill and could thus account for the similar performance observed for both legs (48). Furthermore, the playing position did affect the performance of the dominant versus the nondominant leg (67).

The use of the dominant leg, compared with the nondominant one, during a soccer game occurs about 90% of the time in controls, passes, and crosses of the ball (57). However, this percentage decreases to 70%, for kicks aimed at the goal, probably due to time limitation, the proximity of rival players, and the stress that players are subjected to (57). This could explain why

Table 2
Maximal kicking velocity values for players with different practice time accumulation, competition level, and playing position

Research	Subject characteristics				Kick	Approach steps/angle	RI	VB ($m \cdot s^{-1}$)
	n	Age	Player level	Gender				
Practice time accumulation								
Anthrakidis et al. (4)	24	21.4 ± 0.7	Amateur	M	Instep	Free	R	[a]
			Trained					29.45 ± 1.86
			Untrained					23.86 ± 1.81
Shan (65)	44	21.7 ± 2.2	College students		Instep	Free	3D	[b]
			Skilled	M				24.2 ± 3.1
			Skilled	F				19.6 ± 2.6
			Novice	M				16.9 ± 2.7
			Novice	F				13.2 ± 2.3
Competition level								
Cometti et al. (15)	95		Elite/amateur	M	Free	Free	R	
	29	26.1 ± 4.3	1° France division					29.55 ± 3.58
	34	23.2 ± 5.6	2° France division					29.54 ± 2.09
	32	25.8 ± 3.9	Amateur (regional)					29.94 ± 1.59
Ali et al. (1)	48	20.02 ± 1.5	University	M	Free		R	****
	24		1–2 division					22.22 ± 1.25
	24		3–4 division					20.55 ± 1.67
Playing position								
Taïana et al. (72)	15	18.1 ± 0.3	Experts	M	Instep	Free	P	[c]
			Defenders					27.95 ± 1.15
			Midfielders					27.14 ± 1.80
			Strikers					28.19 ± 1.46
Sousa et al. (67)	31	16.5 ± 0.6	Young elite	M	Free	90°	R	27.3 ± 1.4
	4		Goalkeepers					27.1 ± 1.3
	9		Defenders					26.9 ± 1.8
	13		Midfielders					27.4 ± 1.4
	5		Strikers					27.5 ± 1.0
Khorasani et al. (37)	15	20.8 ± 0.77	Elite	M	Free	3 meters/90°	4C	[b]
			Defenders					22.19 ± 2.8
			Midfielders					30.14 ± 5.4
			Strikers					29.29 ± 1.6

(continued)

Table 2 (continued)

Izquierdo et al. (27)	40	18.02 ± 0.54	Young elite	M	Instep	2/free	R	[c]
	4		Goalkeepers					28 ± 1.40
	12		Defenders					27.86 ± 1.35
	12		Midfielders					28.11 ± 1.54
	12		Strikers					28.14 ± 0.33

3D = motion capture system; C = video camera; F = female; M = male; n = sample size; P = photocell; R = radar; RI = register instrument; VB = kicking ball velocity.

[a] $P < 0.001$.

[b] $P < 0.05$.

[c] Nonsignificant.

the nondominant leg is most frequently used when the player kicks the ball toward the goal in comparison with other situations (57).

Taking into account all the findings from the above-mentioned studies, it seems that the expertise of the soccer player and the difficulty of the task are the main factors that affect the symmetric or asymmetric performance of the legs.

FACTORS RELATED WITH THE TECHNIQUE CHARACTERISTICS

Accuracy. Table 4 summarizes the maximal kicking velocity values for kicks under accuracy demands. Kicking accuracy is an important factor of success in soccer, and it can be defined as the ability to kick the ball at a specified area (20,61). However, this factor has been relatively understudied compared with maximal kicking in soccer (34). Nevertheless, several studies have evaluated the relationship between different kinematic parameters and the accuracy of a soccer kick (29,30,41,73), using both lower limbs (48), and across different kicking techniques (38,48,71).

There is no standard procedure for the evaluation of accuracy of a soccer kick. Thus, accuracy can be defined as the number of goals scored per game, the number of shots toward a goal per game, the ability to strike a target (number of points and the time needed for execution), the ability to kick the ball between 2 markers, or the subjective assessment of independent referees (7). In addition, there have been several attempts to validate kick test protocols to obtain a reliable kicking accuracy measurement (1,7,20,45,63,77). However, to date, none of these protocols has been used extensively. The validation of a protocol to measure kicking accuracy is relevant, especially when the variability of accurate soccer kicks is higher than those of powerful kicks (71), probably because of different muscle activation patterns (31). It is likely that the complex requirements involved in the performance of an accurate kick complicate the development of a feasible, reliable, and operative test to measure the kick accuracy. For instance, although the assessment of the kicking velocity of a stationary ball requires few trials (1,2), the simultaneous evaluation of both the accuracy and kicking may require a significantly higher number (7,11–41). Thus, the accuracy test loses its validity because it does not replicate a real game situation in which there is a dynamic change of the context.

Nevertheless, maximal ball velocities for kicks under accuracy demands are significantly lower in comparison with kicks that are performed without accuracy requirements (2,30,41,73). Furthermore, other studies suggest that the soccer players with highest maximal kicking velocity are also the fastest under accuracy demands (29,30).

Contact surfaces at the moment of impact. Table 5 summarizes the kicking velocity values for different kicking surfaces. There are several kicking techniques that can be used to cope with the demands of specific game situations (69). Bisanz and Gerisch (11) distinguished between the side-foot kick and 3 variations of the instep kick: the inner instep kick, the outer instep kick, and the full instep kick (68). Whereas the side-foot kick is predominantly used for highly accurate and relatively slow passes or for goal shots over short distances, the instep kicking techniques are mainly used for faster passes and for goal shots from longer distances (69). Furthermore, the inner and outer instep kicks aim to rotate the ball to tradeoff velocity (52).

Findings show that the instep and inner instep kicks are faster compared with the side-foot kicks (32,42,54,71). However, these differences were absent in female soccer players (28). Among the 3 types of instep kicks, the

Table 3
Maximal kicking velocity values for dominant and nondominant legs

Research	Subject characteristics				Kick	Approach steps/angle	RI	VB (m·s^{-1}), dominant	VB (m·s^{-1}), nondominant
	n	Age	Player level	Gender					
Narici et al. (51)	11	25.1 ± 5.0	Amateur	M			ARS	20.0 ± 3.6[a]	17.7 ± 2.2[a]
McLean and Tumilty (48)	20	16.8 ± 0.7	Elite junior	M	Drive kick		R	21.95 ± 1.67[b]	18.34 ± 1.39[b]
					Chip kick			18.34 ± 2.22	17.78 ± 1.39
Mognoni et al. (49)	24	NA	Junior	M				23.6 ± 2.5	21.4 ± 2.6
Barfield (9)	18	NA	Expert	M			R	26.4 ± 2.1	24.3 ± 2.0
Patritti et al. (59)	10	25.2	Amateur	M		2/free	R	23.05 ± 1.23	21.10 ± 1.30
Dörge et al. (19)	30		Skilled	M		3 meters/90°	R	24.7 ± 2.5[b]	21.5 ± 2.0[b]
Barfield et al. (10)	8	19–22	Elite		Instep	2/45–30°	2C	[a]	[a]
	2			M				25.3 ± 1.51[a]	23.6 ± 1.57[a]
	6			F				21.5 ± 2.44[a]	18.9 ± 2.05[a]
Vaverka et al. (76)	12	15.7 ± 0.4	Skilled	M			3D	27.68 ± 1.32	23.49 ± 2.05
Nunome (55)	5	16.8 ± 0.4	Skilled	M	Instep	Free	3C	32.1 ± 1.7[b]	27.1 ± 1.2[b]
Barbieri et al. (8)	19	13.6 ± 0.5	Indoor players	M	Instep	Free	4C	18.2 ± 1.8[a]	14.7 ± 2.8[a]
Sedano et al. (14)	10	22.8 ± 2.1	Elite female	F	Pretrained	2/free	R	19.45 ± 0.7[b]	16.25 ± 0.45[b]
					Posttrained			21.75 ± 0.58[b]	18.39 ± 0.64[b]
Bacvarevic et al. (7)	106	11.514.5	Elite young	M	Instep	Free	R		
	27	12.2 ± 0.3			Maximal			22.7 ± 2.5[b]	19.7 ± 2.3[b]
	26	13.1 ± 0.2			Maximal			24.8 ± 2.1[b]	20.3 ± 2.7[b]
	26	14.3 ± 0.3			Maximal			27.1 ± 2.8[b]	23.1 ± 2.9[b]
	27	15.3 ± 0.3			Maximal			28.7 ± 2.3[b]	24.5 ± 3.1[b]
	27	12.2 ± 0.3			Accuracy			16.3 ± 1.7[b]	15.2 ± 1.4[b]
	26	13.1 ± 0.2			Accuracy			16.8 ± 1.5[b]	15.8 ± 1.2[b]
	26	14.3 ± 0.3			Accuracy			18.0 ± 2.7[b]	16.5 ± 1.7[b]
	27	15.3 ± 0.3			Accuracy			18.4 ± 2.5[b]	16.9 ± 1.6[b]

3D = motion capture system; ARS = audio recording system; C = video camera; F = female; M = male; n = sample size; NA = no available data; R = radar; RI = register instrument; VB = kicking ball velocity.

[a] $P < 0.001$.

[b] $P < 0.05$.

full instep kick resulted in significantly higher ball velocities followed by the inner and outer instep kicks (52,69,71). In contrast, the side-foot kick was the most accurate technique compared with the inner instep and the full instep kick (71). Furthermore, inner swerve instep kicks were faster compared with outstep swerve kicks

Table 4
Maximal kicking velocity values for kicks under accuracy demands

Research	Subject characteristics: n	Age	Player level	Gender	Kick	Approach steps/trials	RI	VB ($m \cdot s^{-1}$), maximal kick	VB ($m \cdot s^{-1}$), accuracy kick
Lees and Nolan (41)	2	—	Professional	M	Instep	5–5	2C		
			Subject 1					26.6 ± 1.51[a]	20.4 ± 0.77[a]
			Subject 2					24.3 ± 1.52[a]	18.1 ± 0.77[a]
Kristensen et al. (38)	11	18–28	Subelite	M	Instep	3–10	P	23.38 ± 1.45[a]	21.11 ± 1.69[a]
					Punt	3–10		22.99 ± 1.16[a]	21.13 ± 1.20[a]
Juárez and Navarro (29)	10	24.7 ± 3.0	Elite indoor	M	Free	3–3	ARS	27.24 ± 1.60[a]	25.78 ± 1.42[a]
Sterzing et al. (71)	19	23.7 ± 3.4	Amateur	M	Full instep	6–6	R	28.65 ± 1.80[a]	24.38 ± 3.10[a]
					Inner instep			27.99 ± 1.92[a]	23.05 ± 4.02[a]
					Side foot			21.50 ± 3.13[a]	24.94 ± 1.57[a]
Juárez and Navarro (30)	108	22.17 ± 3.6	Amateur	M	Free	3	P	28.35 ± 1.79[a]	27.00 ± 1.96[a]
Bacvarevic et al. (7)	106	11.514.5	Elite young	M	Instep	Free	R		
	27	12.2 ± 0.3			Maximal			22.7 ± 2.5[b]	16.3 ± 1.7[b]
	26	13.1 ± 0.2			Maximal			24.8 ± 2.1[b]	16.8 ± 1.5[b]
	26	14.3 ± 0.3			Maximal			27.1 ± 2.8[b]	18.0 ± 2.7[b]
	27	15.3 ± 0.3			Maximal			28.7 ± 2.3[b]	18.4 ± 2.5[b]
	27	12.2 ± 0.3			Accuracy			19.7 ± 2.3[b]	15.2 ± 1.4[b]
	26	13.1 ± 0.2			Accuracy			20.3 ± 2.7[b]	15.8 ± 1.2[b]
	26	14.3 ± 0.3			Accuracy			23.1 ± 2.9[b]	16.5 ± 1.7[b]
	27	15.3 ± 0.3			Accuracy			24.5 ± 3.1[b]	16.9 ± 1.6[b]

ARS = audio recording system; C = video camera; M = male; n = sample size; P = photocell; R = radar; RI = register instrument; VB = kicking ball velocity.

[a] $P < 0.01$.

[b] $P < 0.05$.

(52,71), and barefoot kicks were faster compared with footwear kicks (70).

Finally, one study compared the kicking velocity and accuracy of the instep to the punt kick (the less frequently used toe kick), showing that the toe kick is less precise compared with the instep kick at 90% of maximum kicking velocity (38). However, the toe kick is faster than the instep kick when a player is restricted to a short execution time (3,66).

Effects of the approach angle, and other variations. Table 6 summarizes the ball velocity values for different approach angles and kicking techniques. The maximal kicking velocity for a stationary ball in comparison with a ball that is approaching the player at a speed of 2.2 m/s tends to be lower for the former condition (74). However, the maximal velocity of a drop kick (kicking the ball in a descending vertical movement) is higher than that of a stationary ball (45). The reason for this discrepancy is unlikely to be related to the speed of the ball because a ball that drops from approximately 1 meter could reach a velocity of 0.5 m/s,

Table 5
Maximal kicking velocity values for kicks with different kicking surfaces

Research	Subject characteristics				Kick	Approach steps/angle	RI	VB (m·s^{-1})
	n	Age	Player level	Gender				
Levanon and Dapena (42)	6	Intercollegiate	Experts	M	Side foot		2C	22.5 ± 1.8[a]
					Full instep			28.6 ± 2.2[a]
Jónsdóttir and Finch (28)	11		Amateur	F		2 steps	1C	[b]
					Inner instep			14.6 ± 2.4
					Side instep			14.4 ± 2.8
Nunome et al. (54)	5	High school	Experts	M	Side		2C	24.3 ± 1.7[c]
					Full instep			28.0 ± 2.1[c]
Kristensen et al. (38)	11	18–28	Subelite	M	Punt		P	22.99 ± 1.16[c]
					Instep			23.38 ± 1.45[c]
Neilson and Jones (51)	25	19.68 ± 2.17	Professionals	M	Instep	Free	1C	27.05 ± 2.23[a]
					Inner instep swerve			23.52 ± 2.31[a]
					Side instep swerve			20.85 ± 3.08[a]
Sterzing et al. (71)	19	23.7 ± 3.4	Amateur	M	Full instep	Free	R	28.65 ± 1.80[c]
					Inner instep			27.99 ± 1.92[c]
					Side foot			21.50 ± 3.13[c]
Katis and Kellis (32)	10	13.6 ± 0.7	Amateur	M	Full instep	2 steps/45°	6C	19.62 ± 1.89[a]
					Side instep	2 steps/45°		18.10 ± 1.49[a]

C = video camera; F = female; M = male; n = sample size; P = photocell; R = radar; RI = register instrument; VB = kicking ball velocity.

[a]$P < 0.05$.

[b]Nonsignificant.

[c]$P < 0.01$.

which is far from the 2.2 m/s used in the study by Tol et al. (74). Therefore, it is plausible that the vertical drop of the ball allows the player to use a more efficient foot contact with the surface of the ball and thus to achieve a higher maximal kicking velocity.

Kicking a ball during running also results in higher ball velocity values compared with a nonrunning approach (45,58) (Table 6). Soccer players often prefer 2 or 3 steps before the main kicking action (34). The difference in velocity between the one-step and multistep approach remains unclear (34), possibly because of higher coordinative demands associated with the long distance approach. Finally, one study indicated that performing instep kicks after a double-cutting maneuver reduces the ball velocity (33).

The analysis of the approach angles in the kicking velocity demonstrated that soccer players tend to choose a kicking angle between 30 and 60° and that the maximum ball velocity is achieved with an angle of 45° (26). Similar results have been reported for maximal and accurate kicks (36,47). However, when the player is asked to perform a "faking" (cutting) maneuver before the kick, there is a reduction in the maximal kicking velocity.

DISCUSSION

The main goal of the current review is to explore several issues related with maximal kicking velocity in soccer. Specifically, this review focuses on

Table 6
Ball velocity as reported in the literature by research that used different kicking techniques

Research	Subject characteristics				Kick	Approach steps/angle	RI	VB ($m \cdot s^{-1}$)
	n	Age	Player level	Gender				
Kick a stationary ball vs a dynamic ball								
Tol et al. (74)	15	27.4 ± 8.4	Elite	M	Instep	Stationary	C	24.3 ± 4.5[d]
						Rolling		24.9 ± 4.9
Markovic.et al. (45)	77	20.1 ± 1.1	Universities	M	Instep	0 step/0°		19.5 ± 1.9[a]
					Drop kick	1 step		25 ± 2.2
With and without previous run-up								
Opavsky (58)	6	—	—	M	Instep	0 step	C	23.48[a]
						6-8 steps		30.78
Markovic et al. (45)	77	20.1 ± 1.1	Universities	M	Instep	Free	R	26.5 ± 2.5[a]
					Instep	0 step/0°		19.5 ± 1.9
					Drop kick	1 step		25 ± 2.2
Different previous run-up approach angles								
Isokawa and Lees (26)	6	20–36	Amateur	M	Instep	1 step/0°	C	18.73 ± 0.95[d]
						1 step/15°		19.12 ± 1.23
						1 step/30°		19.87 ± 1.14
						1 step/45°		20.14 ± 1.58
						1 step/60°		19.46 ± 1.59
						1 step/90°		19.13 ± 1.64
Kellis (36)	10	21.3 ± 1.4	Trained	M	Instep	1 paso/0°	2C	19.79 ± 1.49[d]
						1 paso/45°		20.41 ± 2.44
						1 paso/90°		18.51 ± 3.09
Masuda et al. (47)	14	20.6 ± 1.0	Amateur	M	Instep	Free	R	27.7
						90°		25.0
		0				135.2°		22.2
Scurr and Hall (64)	19	26 ± 3	Amateur	M	Instep	Free/free	2C	25.15 ± 07[d]
						Free/30°		24.23 ± 2.30
						Free/45°		24.47 ± 2.12
After a "faking" (cutting) maneuver task								
Katis and Kellis (33)	10	13.6 ± 0.7	Amateur	M	Instep		6C	
						2 steps/0°		19.44 ± 1.78[a]
						3 steps		17.06 ± 1.46[a]

Table 6
(continued)

Different techniques								
Asami and Nolte (6)	4		Professional		Instep		C	29.90 ± 2.9
Rodano and Tavana (62)	10	17.5 ± 0.5	Professional		Instep	2 pasos	2C	22.3–30
Asai et al. (5)	66	—	Universities		Swerve	—		25.44 ± 0.76
Lees and Nolan (41)	8	20.63	Expert			Free	R	24.5 ± 1.39
Nunome et al. (56)	9	27.6 ± 5.6	Expert		Instep	—		26.3 ± 3.4

C = video camera; F = female; M = male; n = Sample size; R = radar; RI = register instrument; VB = kicking ball velocity.

[a] $P < 0.05$.

[b] $P < 0.01$.

[c] $P < 0.001$.

[d] Nonsignificant.

studies that explore how the sample characteristics and kicking techniques affect the maximal kicking velocity. The methodological limitations of these studies are discussed and also how these may be addressed in future studies.

FACTORS RELATED WITH THE SAMPLE CHARACTERISTICS

The studies exploring the contribution of age clearly indicate a positive relation between age and maximal kicking velocity (7,44). However, most of these studies are cross-sectional (i.e., 7,44) and do not specify the eligibility criteria or levels of physical activity in the studied children (i.e., 44). Thus, the factors contributing to the association between growing and the maximal kicking velocity are difficult to ascertain. This becomes even more complicated when the studies include children who play soccer because practice and growing effects may interact. Comparing children players with nonplayers of the same age may help to clarify the effect growing has on the increased kicking ball velocity, in addition to determining the role of systematic practice.

Another important issue related with age is the definition of the age itself. All the studies included in this review used the chronological age to categorize the children (7,44). Although, from a practical point of view, this is the easiest and most direct way to evaluate age, the role of the biological age may also be of importance. For example, small differences in the biological age could account for greater differences in the maximal kicking velocity. This point is even more relevant when comparing the maximal kicking velocity between children of different gender. So far, there are no studies that have described the maximal kicking velocity in girls. The studies comparing the maximal kicking velocity between genders have only been conducted in adults (10,65) and are motivated by an increase in the number of female soccer players in several countries (e.g., USA).

Therefore, longitudinal studies, studies with a better description of the sample, and studies comparing between genders should be conducted to understand the effect of age on maximal kicking velocity. In addition, a better understanding of the characteristics of the practices used for female soccer athletes may improve training and teaching, prevent injuries, and assist with rehabilitation techniques (10).

Practice time has also been a recurrent topic in the study of maximal kicking velocity. However, it is difficult to interpret the results because of the inaccuracy in the definition of terms such as "experts," "novices," "amateurs," "trained," "untrained," and "skilled" subjects (4,65). Reaching a consensus regarding the definition of these terms is of importance so that results from different research groups may be compared more reliably. When players are categorized according to the competition level (i.e., League One France), the features of the players are easier to define (15).

The studies that focus on the differences between the dominant and nondominant legs generally do not report information about the characteristics of the subjects (i.e., 48), such as hand-dominance, trunk turn dominance, or ocular-dominance. These measures can be easily evaluated using validated scales and may contribute to determining the effects of dominance across different corporal segments on the maximal kicking performance.

The playing position in soccer does not seem to play a role in the maximal kicking velocity because most of the studies did not report differences between the player's positions (67,72). However, these studied did not evaluate the performance of accurate kicks, and thus, it is possible that such differences exist between player's positions when accuracy is required.

FACTORS RELATED WITH TECHNIQUE CHARACTERISTICS

Velocity and accuracy of a soccer kick are the main factors that contribute to a successful outcome. However, few studies explored the relationship between velocity and accuracy (34). According to the Fitts law (21), an inverse relationship exists between speed and accuracy, which can be determined by a logarithmic equation. Recently, the notion of speed-accuracy tradeoff has received renewed interest in several fields such as cognitive neuroscience (25). It could be of interest to apply this approach to soccer to reach a better understanding of the relationship between speed and accuracy of a soccer kick. For instance, the players can be instructed to perform several kicks toward a target at different percentages of their maximal speed and record in each speed and accuracy (i.e., distance to the target). This will provide information regarding the change in the relationship between speed and accuracy rather than the change in speed and accuracy separately. In turn, this may help to develop a more rational learning skill process in the soccer-training field.

Kicking with running approach showed faster ball velocities compared with static kicks (45,58). Furthermore, approach angles did not have an effect either on the ball velocity or on the kicking accuracy (26,36,64). However, protocols measuring soccer kick performance vary across studies with regard to the different variables that are evaluated such as the angle, distance, and/or the number of steps in the previous run-up (26,36). Most studies include a stationary-ball kicking procedure, and few studies also used a rolling ball procedure, either on the ground (46,74) or after a drop (45). The run-up in kicking testing procedures has, in some cases, been left to the free choice of the players (64), whereas in other studies, players were given instructions regarding the number of previous steps, the distance, and/or the approach angles. This disparity in protocols does not allow for reliable comparisons across different studies, and thus, a validated specific test to explore the effect of the approach to the ball is strongly recommended.

In summary, in this review, we have discussed studies that have evaluated the technical factors that affect maximal kicking velocity in soccer, and also effects of age and gender. Although the studies provide important information regarding the role of each parameter, several methodological issues must be addressed so that findings across studies may be compared reliably. A consensus between experts of this field should be established to standardize the protocols or tests that are used to measure the maximal kicking velocity. In addition, there are no unified criteria (often these are absent) to categorize the participants in the studies (i.e., "expert" versus "elite"). In summary, there are a wide range of technical aspects that are related to ball kicking in soccer and maximal kicking velocities. These aspects seem to interact with the participants' features (experience, age, and gender) and affect their ability to achieve the maximal kicking performance. Nevertheless, more studies are needed to clarify the nature of these interactions.

PRACTICAL APPLICATIONS

The outcomes from the current review are of interest because these may help coaches to formulate better recommendations for the assessment and selection of soccer players and also monitoring the training of a player for a competition. This review provides useful information to help interpret maximal kicking velocity values and to determine which factors should be taken into account when comparing these values across players. Several practical applications of the current review are (a) to avoid evaluation of the maximal kicking velocity in players younger than 11 years because this measurement is not reliable and (b) comparing maximal kicking velocities with and without a running approach may be useful to determine the potential existence of coordination deficits. Thus, the maximal kicking velocity must be evaluated in such a way that minimizes external variables, to allow for an objective measurement of the skill of a soccer player and to identify the most talented players.

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Artículo Nº 2

Strength and kicking performance in soccer: A review

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Strength and Kicking Performance in Soccer: A Review

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ABSTRACT

THE STUDY OF THE MAXIMAL KICK BALL VELOCITY IN SOCCER IS OF INTEREST DUE TO ITS RELEVANCE IN THE SCORE ACHIEVED IN A SOCCER MATCH. THIS REVIEW FOCUSES ON STUDIES THAT HAVE EXPLORED THE ASSOCIATION BETWEEN STRENGTH AND BALL VELOCITY, AND THE EFFECTS OF STRENGTH TRAINING IN THE MAXIMUM KICKING VELOCITY. THE STUDIES REVIEWED SUGGEST THAT THE RELATIONSHIP BETWEEN STRENGTH AND KICKING VELOCITY IN SOCCER IS INCONSISTENT. IN ADDITION, PLYOMETRIC AND EXPLOSIVE STRENGTH TRAINING CAN BE CARRIED OUT SUCCESSFULLY IN COMBINATION WITH REGULAR SOCCER TRAINING TO IMPROVE THE MAXIMUM KICKING VELOCITY.

INTRODUCTION

Kicking is one of the most frequently used skills in soccer, and the most fundamental for soccer performance (5,8,25,32,44,48). Soccer performance and other athletic kicking usually depend on kicking ball velocity and kicking accuracy (4,8,42). This speed could be particularly important while kicking towards the goal, because the chances of scoring increase with an increased ball speed (assuming that the kick is accurate) because the goalkeeper has less time to react (19,42).

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Kicking can be described as a summation of forces (58). The motion pattern is generally accepted as a proximal-to-distal sequence in which the distal segments are allowed to lag behind the proximal segments as they move forward (20), in which the foot is the last segment to intervene and the fastest segment in the open kinetic chain (65). The timing of muscle activation can be described with activation of hip flexors such as the iliopsoas followed by the rectus femoris, which is a hip flexor and knee extensor, and finally by activation of the knee extensors such as the vastus lateralis. Therefore, hip flexor and knee extensor muscles are important for developing a high foot velocity (18). In addition, the knee flexors (hamstrings) and hip extensors (gluteal muscles), which function as antagonists to decelerate the swinging-leg after ball impact, are also significantly active in a maximum soccer kick (18,57). In general, these antagonists require fundamentally eccentric strength, whereas agonists require concentric strength (18).

The ball velocity after a soccer kick is more strongly affected by the foot velocity at the initial instant of the impact phase than any other factors (26). Furthermore, significant correlation was found between these 2 variables (7,17,37) and the coefficient of restitution (9), which is influenced by skill factors, such as the part of the foot that makes contact with the ball and the stiffness of the foot at impact (65). The mass of the shank–foot segment does not influence the velocity of the ball significantly (3).

The role of the supporting leg in generation of foot speed is not clear, but it could be speculated that the strength of the support leg is important for providing a stable platform to quickly swing the kicking leg (9). Significant correlations between single-leg balance and kicking accuracy, but not velocity, were found (14).

It is clear that the strength of the lower limbs' muscles could be related to the ball velocity. Therefore, several studies have investigated the relationship between the ball velocity after a maximal soccer kick and the strength and power values of the lower limbs (10,13,15,28,30,38,44–47,51,60,61) as well as the relationship between ball velocity and the velocity values of linear sprint runs (15) and nonlinear sprint runs (13). Other studies have explored the influence of different strength training programs on ball velocity values after a soccer kick (1,10,12,27,39–41,50,55,62,63). Finally, another group of studies have validated new kick test protocols to assess the biomechanics and

KEY WORDS:
strength training; jumping performance; maximal ball velocity; nondominant leg; fatigue effects

physiological parameters in soccer kicking (2,8,22,36,42,59,63).

Therefore, the purpose of this article is to systematically review the existing data about strength and ball velocity, discuss potential limitations of the literature, and suggest directions for future research in kicking velocity performance. Additionally, practical applications of the results will be presented for the strength & conditioning practitioners, because they may have limited knowledge of this topic or are unaware of up to date research.

METHODS

The following databases were used in this review: Medline, Sport Discus, Dialnet, Google scholar, and Scopus. The keywords used were combinations of "soccer," "strength," "training," "kick," "kicking," "maximal," "ball," "fatigue," and "velocity." Studies in English, Spanish, and Portuguese were included. Studies from 1979 to 2014 were included in this review with a focus on the maximal kicking velocity and one or more of the following factors: soccer, kicking, velocity ball, strength, accuracy, muscle fatigue, and training. We analyzed more than 300 papers, of which 210 were studies about ball velocity and 96 of them were included in this review. The results of this review are classified in 2 categories, studies that describe the relation between strength and kicking velocity and studies that explore the effect of strength training on the kicking velocity.

RESULTS

THE RELATIONSHIP BETWEEN STRENGTH AND BALL VELOCITY

Isokinetic strength in soccer kicking performance. Differences in strength have been found among players from different divisions (11,49). However, the relationship between muscle isokinetic strength and kicking performance remains a subject of controversy in the soccer research field (Table 1). Cabri et al. (11) found a high correlation between kick distances and the isokinetic strength exerted by knee flexor and extensor muscles, but moderate correlation with isokinetic strength of hip flexor and extensor muscles. In addition, in young soccer players, a significant relationship between ball kicking velocity and the maximal isokinetic forces of the thigh and shank was found (38). In elite soccer players, ball velocity values after a soccer kick correlated significantly with isokinetic muscle torques reached at different angular velocities (51). These authors also reported that the intensity of the relationship tends to decrease with the increase in angular velocities. Significant correlation between knee extensors isokinetic peak torque and kick velocity score was also found in trained and untrained soccer players. (5). In addition, Masuda et al. (44) examined relationships between muscular concentric isokinetic strength and kicking ball velocity achieved with both legs during 3 different approach angles. The mean ball velocities correlated significantly with isokinetic strength of several muscles on the kicking and the supporting legs (Table 2). They concluded that different approach angles could alter the requirement on muscle strength potential of both legs during kicking. Especially, an angled approach toward the kick direction could require greater hip extension and abduction strength from the supporting leg to increase its stabilization capacity.

Maximal strength, explosive strength, and kicking performance. Elite young soccer players can be distinguished from subelite and recreational young soccer players by their higher performance in explosive and strength tests such as maximal isometric force, vertical jump height, pedaling rate, or 10 m sprint time (24). However, maximal strength in a full squat exercise did not correlate with maximal ball kicking velocity after a soccer kick in university soccer players (31). There was no correlation between ball velocity and the performance in several jump tests (squat jump; countermovement jump (CMJ)) with young soccer players (29), elite young soccer players (30,61), and elite inside soccer players (28). Furthermore, no relationship was found between the performance in a 10 meter sprint test and ball kicking velocity values. However, 2 studies found a weak relationship between explosive strength and maximal strength with the maximal ball velocity after a soccer kick. (13,23) (Tables 2 and 3).

Induced fatigue effects on ball kicking velocity. The soccer kick has been mainly studied under nonfatigued conditions. Few researches have examined the effects of fatigue on soccer and maximal ball kicking velocities (6,21,33,34,35) (Table 4), and there is only one study about fatigue effects on short-passing ability (56).

In summary, those studies have shown that there is a significant decrease in ball velocity which has been reported after: (a) a 6 minute step exercise protocol (35); (b) 90 minutes of intermittent exercise protocol (33); (c) knee extension and flexion motions on a weight-training machine until exhaustion (6); (d) a soccer specific circuit (with jumps, skipping, multiple changes of direction, dribbling the ball, passing, bursts of sprinting and jogging) (21), and (e) consecutive soccer instep kicks (34).

The significantly slower ball velocity observed in the fatigue condition may result from a reduced lower leg swing speed and poorer ball contact (6). Moreover, fatigue obscured the eccentric action of the knee flexors immediately before ball impact, which might increase the susceptibility to injury (6). This could be attributed to alterations in the function of the neuromuscular system and force generation capacity (33), and a poorer intersegmental coordination (6,35).

Finally, one study (34) showed that during repetitive kicks there was a significant reduction in the ball velocity between the first and the fifth and subsequent kicks. Therefore, it seems that no more than 4 consecutive kicks would be recommended to evaluate the kicking performance in the absence of fatigue (34).

Effects of strength training on maximum ball velocity. Several studies have explored the effect of strength training

Table 1
Relationship between isokinetic strength test and ball velocity

	Hip joint				Knee joint		Ankle joint		
	F	E	ABD	ADD	F	E	F	E	Angular velocities (°/s)
Cabri et al. (11)	0.56[a]	0.56[a]			$r = 0.77$[a]	$r = 0.74$[a]			209
Luhtanen (38)					$r > 0.9$[b]	$r > 0.9$[b]	$r > 0.9$[b]	$r > 0.9$[b]	0
Narici (47)	NR					NR			90; 180
Poulmedis et al. (51)					0.82[b]	0.82[b]			30
Mognoni et al. (46)	NR					NR			Isokinetic
McLean et al. (45)					NR	NR			60; 180; 240
Cometti et al. (15)					NR	NR			−120; −60; 60; 120; 180; 240; 300
Saliba and Hrysomallis (60)					NR	NR			60; 240; 360
Dörge et al. (19)	NR					NR			0
Masuda (44)[d,1]	0.61[b]	NR	0.57[b]	0.68[b]	0.54[b]	0.53[b]			90; 180; 240
Masuda (44)[d,2]	NR	0.7[b]	0.53[a]	NR	0.55[b]	NR			90; 180; 240
Anthrakidis et al. (5)##						0.75[b]			90; 240

F = flexion; E = extension; ABD = abduction; ADD = adduction; NR = no significant relationship.

[a]Statistical significance $p < 0.05$.

[b]Statistical significance $p < 0.01$.

[c]Statistical significance $p < 0.001$.

[d]Masuda used 3 angles of approach: [1]Supporting leg; [2]Kicking leg; ##Positive relationship but only significant in untrained soccer players.

programs on maximal ball kicking velocity. Table 5 summarizes the results and strength protocols used in those studies. Most of these studies have been conducted in nonprofessional soccer players. The studies have reported a significant increase in ball velocity values after the application of different strength training programs in young amateur (27,50,53,54), young elite (16,43,52,55,62), adult amateur (39–41), and elite females soccer players (12). The strength training program has always been implemented as an extra session to regular soccer training. The strength training programs involved maximal strength training with a loaded kicking simulating exercise (62), combined strength and kick coordination training (39–41), an explosive and/or plyometric strength training program without kicking specific exercise (12,16,43,50,53–55), core strength training performed on stable surfaces (52), and electrostimulation on both quadriceps (10).

The studies conducted by Manolopoulos et al. (39–41) deserve special attention because they record muscle activity by surface electromyography. In those studies, the strength training program led to a significant decrease in joint angular velocities with an increase in biceps femoris electromyography of the kicking leg during the backswing phase (40,62). In addition, an increase in segmental and joint velocities and muscle activation of the same leg during the forward swing phase were found (40,63). They also reported a significantly higher vertical ground reaction force on the supported leg together with an increase in the rectus femoris and gastrocnemius activations (40,63). Therefore, the authors reported that the increase in ball velocity values after a soccer kick was accompanied by changes in kinetic and kinematic indices of the kicking performance (10,40,41) mainly due to an altered soccer kick movement pattern, characterized by a more explosive backward–forward swinging movement and higher muscle activation during the final kicking phase (39).

In other studies, the enhancement in maximum kicking performance was accompanied by increases in the performance of muscular strength tests like sprint (41,50,52–55,64), CMJ (12,39–41,53–55), and other strength (Isometric) measurements (10,39–41,62).

It should be noted that a few studies have been conducted in professional soccer players. Trolle et al. (63) and Aagaard (1) did not find a significant

Table 2
Relationship between explosive strength tests and ball velocity

	Test DVT	SJ	CMJ	V-10m	BAT	1RM	TAS	FDM
Cabri et al. (11)	0.69[a]							
Cometti et al. (15)		NR	NR	NR				
Sousa et al. (61)		0.10[a]	0.07[a]					
Cervera et al. (13)		0.40[b]	0.41[b]	0.40[b]				
Juárez and Navarro (28)		NR	NR	NR				
Juárez et al. (31)						0.25 NS	0.28 NS	0.34 NS
Juárez et al. (29)			NR					
Juárez et al. (30)		NR	NR					
García-Pinillos et al. (23)					0.492[a]			

Test DVT = descent vertical test; SJ = squat jump; CMJ = countermovement jump; V-10m = 10 meter sprint test; BAT = balsom agility test; 1RM = maximal repetition; TAS = total average strength; NR = no significant relationship.

[a]Statistical significance $p < 0.05$.

[b]Statistical significance $p < 0.01$.

[c]Statistical significance $p < 0.001$.

improvement in maximal kicking velocity in professional soccer players after strength training with several intensities with (1) and without (63) regular soccer training. Although, both studies reported improvements in knee extension strength, those results were not accompanied by an increase in the maximal kicking velocity.

DISCUSSION

In this article, we review the existing data about strength and ball kicking velocity in soccer. We focus on the relationship between both parameters and also the effects of strength training on maximum ball velocity. The main outcomes of this review indicate that the relationship between strength and kicking velocity in soccer is inconsistent. In addition, strength training programs seem to enhance maximal ball kicking velocity although its effectiveness is questionable in elite soccer players.

STRENGTH IN SOCCER KICKING PERFORMANCE

In general, soccer players are stronger than nonsoccer players and differences in strength can be found among players from different divisions (11,49). However, it is not possible to establish a cause-and-effect relationship between the maximal strength and kicking performance (65) according to studies using maximal isokinetic or full squat tests (5,11,15,19,38,44,46–47,51,60). Therefore, neither isokinetic torque nor maximal full squat seems to be a good predictor of ball velocity. It is likely that those tests do not reproduce the muscular demands involved in the soccer kick.

It is reasonable to assume that tests involving explosive muscular actions could be more suitable when exploring the relationship between strength training and ball kicking velocity, than the above-mentioned tests. Vertical jumps or sprints have been the most common tests used to explore the relationship between explosive strength and ball kicking velocity. However, the small number of studies and their contradictory findings (11,13,15,23,28–31,61) make it difficult to reach a definitive conclusion about this relationship. It is important to note that the performance of vertical jumps required familiarization sessions to obtain reliable data. Most of those studies did not report whether or not such familiarization sessions were conducted, thus, we cannot assess an association between vertical jumps and ball kicking velocities.

We suggest that soccer-specific strength tests, like a maximal kicking test, should be included in the selection of young soccer players and in the elite adult soccer player's training process to guide and control their progress, because this test closely reflects the role of muscles used in this action.

INDUCED FATIGUE EFFECTS ON BALL KICKING VELOCITY

The effects of fatigue on soccer kick performance have only been studied by a few researchers. There is an agreement that after implementation of different fatigue protocols, there is a significant decrease in ball kicking velocity (6,33,34). This could be attributed to alterations of the force generation capacity and a poorer intersegmental coordination. However, no researchers have examined the effects of actual match fatigue in maximum kicking velocity.

Table 3
Maximal kicking velocity values for research that studies maximal and explosive strength and kicking performance

Research	Subject characteristics			Kick	Approach (steps/angle)	RI	VB (m·s^{-1}) dominant
	n	Age	Player level				
Poulmedis et al. (51)	11	25.5 ± 3.0	Elite	Free	Free	P	27.08 ± 1.32
Sousa et al. (61)	31	16.5 + 0.6	Young	Instep	Free	R	27.3 + 1.4
Cervera et al. (13)	55	14.59 ± 1.08	High level	Free	Free	ASR	18.84 ± 1.97
Juárez et al. (29)	21	16.1 ± 0.2	High level	Instep	Free	3D	28.25
Juárez et al. (30)	21	16.1 ± 0.2	High level	Instep	5 m/free	6C	30.1 ± 1.54
García-Pinillos et al. (23)	30	15.9 ± 1.43	Young	Instep	2 step/free	C	30.1 ± 1.5

n = sample size; RI = register instrument; VB = kicking ball velocity; P = photocell; ARS = audio recording system; 3D = motion capture system; 6C = video cameras; C = video camera.

[a]Statistical significance $p < 0.05$.

[b]Statistical significance $p < 0.01$.

[c]Statistical significance $p < 0.001$.

Therefore, we do not have available information about how muscle fatigue could be related to impairment in ball kicking velocity during a real match. This is because, in part, to explore that relationship during an actual match would be a challenge. The simulation of a real game with small pauses to perform explosive strength tests (i.e., vertical jumps and maximal kicking test) could be an interesting approach.

Previously, we have suggested that less than 5 trials seems to be adequate to avoid the fatigue effect and maintain high kinematics and kinetic responses, when measuring the maximum kicking velocity (34). Although this is interesting for evaluation purposes, it does not represent a real situation, where it is unlikely that a player can perform more than 4 maximal kicks in a 2 minute period as in Khorasani's study (34).

EFFECTS OF STRENGTH TRAINING ON MAXIMUM BALL VELOCITY

Based on the review of literature, it is difficult to reach a final conclusion about the efficacy of strength training programs in improving the ball kicking velocity. Several factors can account for the different results across studies such as: (a) the heterogeneous profile of the samples (from amateurs to elite soccer players); (b) a disparity of the features of the strength training programs (from isokinetic to plyometric exercises), and (c) the inclusion of regular soccer training sessions during the strength programs. Nevertheless, we can speculate in the following paragraphs the role of those factors in the efficacy of the strength training programs.

There is evidence in the literature that the application of different strength training programs can increase ball velocity values in soccer players, depending on gender and playing level (12). In amateur adult, young elite, and young soccer players, strength training programs in combination with technical training lead to significant increases in maximum ball velocity values (39–41,62). However, the scarce information on adult elite soccer players (Table 5), may be due to the difficulty in accessing this type of sample. Only a small pool of studies has been conducted in that population (1,12,63). One of them found a significant improvement with female soccer players (12), while no studies found any effect of a strength training program in male soccer players (1,63). Therefore, it seems that the years of experience and expertise can affect the potential enhanced effect of strength training programs. This is reasonable because the margin for improvement becomes narrower with higher levels of performance. However, this does not necessarily mean that there is still no opportunity for improvement, but it is clear that the development of strength training programs for elite soccer players is more complex.

From the diversity of training programs reviewed in the current study, it seems that the most effective approaches to improve ball kicking velocity of the programs reviewed are those that combine explosive strength training with regular soccer training. The lack of improvement in training programs that include isokinetic strength exercises (1,63) could be expected to be according to the poor specificity between isokinetic and kicking performances (see previous discussion about this issue). However, the use of plyometric exercises in the form of vertical or horizontal jumps could lead to improvements in ball kicking velocity (23,53,54) even

Table 4
Maximal kicking velocity values under fatigue conditions

Research	Subject characteristics			Kick	Approach (steps/angle)	RI	VB ($m \cdot s^{-1}$) dominant
	n	Age	Player level				
Kellis et al. (33)	10	22.6	Amateur	Instep	2 step/free	2C	
				Prefatigue	Free		24.69 ± 1.8^{b}
				Postfatigue	Free		21.78 ± 2.2^{b}
Apriantono et al. (6)	7	20.0 ± 2.1	Amateur	Instep		C	
				Prefatigue			28.4 ± 1.6^{a}
				Postfatigue			26.8 ± 1.1^{a}
Khorasani et al. (34)	5	25.6 ± 1.1	Skilled	1° trial	Free	3D	30.85 ± 0.3^{a}
				5° trial	Free		30.32 ± 0.1^{a}
				10° trial	Free		29.13 ± 0.1^{a}
Ferraz et al. (21)	10	*27.3 ± 5.25*	Amateur		Free	R	
				Before			26.30 ± 3.48^{a}
				After 1 circuit			24.67 ± 2.98^{a}
				After 2 circuit			23.86 ± 2.37^{a}

n = sample size; RI = register instrument; VB = kicking ball velocity; 2C = video cameras; C = video camera; 3D = motion capture system; R = radar.

[a]Statistical significance $p < 0.05$.

[b]Statistical significance $p < 0.01$.

[c]Statistical significance $p < 0.001$.

in combination with isometric strength exercises (23). In those studies, the increases in maximum kicking velocity were accompanied by an increase in the performance of countermovement jumps. Another important factor is whether or not the strength training program is combined with regular soccer training or technical kicking training. From all the studies that lead to improvements in ball kicking velocity, 94.1% of them (1,4,10,12,16,23,27,39–41,50,52–55,62) combined strength and regular soccer training. Therefore, this supports Aagaard's suggestion (1) that strength training should be integrated with other types of training, involving the actual movement pattern to increase the performance within more complex movement patterns.

Studies about the effect of strength training programs on ball kicking velocity are focused on the dominant leg, whereas studies evaluating the nondominant leg are clearly limited. Only 3 studies have explored or compared the improvements between legs (12,16,23). Interestingly, their results showed higher gains in the kicking ball velocities for the nondominant in comparison with the dominant legs. It is likely that diminished baseline performance kicking with the nondominant leg could explain this result. Nevertheless, more studies must be conducted to explore the effects of strength training programs in kicking ball velocity with the nondominant leg because the ability to kick with both legs leads to an advantage for the soccer player.

PRACTICAL APPLICATIONS

The current review explores the existing data about the relationship between strength tests and ball kicking velocity and the efficacy of the strength training programs. The results of this review suggest that tests such as isokinetic, 1RM, or vertical jumps are not strongly related to maximal kicking velocity. Thus, their role in understanding the force requirements during soccer ball kicking is questionable. In addition, the development of a strength training program with the goal of improving the ball kicking velocity must include explosive strength exercises in combination with regular soccer training. We also recommend evaluation in the efficacy of those programs by a direct measurement of ball kicking movement (i.e., by

Table 5
Research that studies the effects of strength training on maximum ball velocity

Study	Training program	Subject details	Duration	Strength gain	Vball Pre	Vball Post	KPI, %
Jelusic et al. (27)	Explosive strength with pulleys simulating the kicking action	20 Amateur young	15 wk, 2 sessions/ week	NA	39.4 ± 7.4	49.4 ± 8.0	↑ 25.3[a] DL
Taïana et al. (62)	Maximal strength + loaded kicking exercises (explosive strength)	15 Elite young (18.1 ± 0.3 y)	10 wk, 1 session/ week	↑ 3.57[a] CMJ	26.25 ± 1.7	28.08 ± 1.4	↑ 7.0[a] DL
Trolle et al. (63)	Isokinetic strength at high or low resistance or loaded kicking movements without ball	20 Elite adult	12 wk, 3 session/ week	↑ [a]Isokinetic measurements			No significant increase
Aagaard et al. (1)	Isokinetic strength at high or low resistance or loaded kicking movements without ball	22 Elite adult	12 wk, 3 session/ week	↑ [a]Isokinetic measurements			No significant increase
Manolopoulos et al. (40)	Combined strength (for the lower limb) and kicking coordination (simulated pulley kick exercise) with a progressively increasing load from 50% up to 95% of maximum strength	16 Amateur adult (21.1 ± 1.3 y)	8 wk, 3 session/ week	↑ [a]Isometric force of the lower limbs	26.5 ± 2.1	27.9 ± 1.8	↑ 5.3[a]
Manolopoulos et al. (41)	Combined strength and kicking coordination (including general strength of various muscle groups, soccer-specific strength exercises and real and/or loaded kicking actions)	20 Amateur adult (20.7 ± 0.8 y)	10 wk, 3 session/ week	↑ [a]Maximum isometric strength and ↓ [a]sprint times	25.0[a]	28.0[a]	NA
Campo et al. (12)	Plyometric	20 Elite female (22.9 ± 2.65 y)	12 wk, 3 session/ week	↑ 12.9 [a]CMJ, ↑ 18.1 [a]DJ	19.45 ± 0.7	21.75 ± 0.6	↑ 11.8[a] DL, ↑ 16.2[a] NDL
					16.25 ± 0.5	18.39 ± 0.5	
Billot et al. (10)	Electrostimulation (12-min sessions on both quadriceps)	20 Amateur adult (20.9 ± 2.7 y)	5 wk, 3 session/ week	↑ Isokinetic strength	27.19 ± 0.7	28.72 ± 1.3	↑ 5.63[a] With run-up, ↑ 9.61[a] without DL
					24.25 ± 1.3	26.58 ± 1.9	
Ramos (55)	Explosive strength (jumps and sprints)	12 Élite young (14.3 ± 0.5 y)	8 wk, 2 session/ week	↑ 13.6[a] CMJ, ↓ 6.8[a] sprint times	24.33 ± 2.2	26.12 ± 1.9	↑ 7.4[a] DL

Table 5 (continued)

Pereira (50)	Explosive strength (jumps and sprints)	21 Amateur young (14.1 ± 0.5 y)	8 wk, 2 session/week	↓ 3.3[a] sprint times	21.86 ± 2.4	23.29 ± 2.7	↑ 6.4[a] DL
Manolopoulos et al. (39)	Resistance exercise (mainly for the lower limb) + simulated kicking actions (with rubber band)	20 Amateur adult (20.25 ± 1.3 y)	12 wk, 3 session/week	↑ 7.7[a]CMJ, ↓ 3.1[a] sprint times	26.14 ± 1.2	27.59 ± 1.5	↑ 4.3[a] DL
Marques et al. (43)	Plyometric and sprint program	52 Élite young (13.4 ± 1.4 y)	6 wk, 2 session/week	↑ 7.7[a] CMJ, ↓ 3.2[a] sprint times	26.14 + 1.0	27.31 + 1.3	↑ 6.6[a] DL
Prieske et al. (52)	Progressive core strength training performed on unstable (CSTU) compared with stable surfaces (CSTS)	39 Élite young (16.6 ± 1.0 y)	9 wk, 2–3 session/week	↓ 3[a] sprint times, ↑ 5[a] trunk extensor	28.13 ± 1.89	28.7 ± 1.75	↑ 2.1[a] CSTU DL, ↓ # −0.3[a] CSTS DL
					29.97 ± 1.5	29.86 ± 1.7	
García-Pinillos et al. (23)	Contrast training program (isometric + plyometric), progressed in volume	30 Amateur young (15.9 ± 1.43 y)	12 wk, 2 session/week	↑ 7.1[a] CMJ, ↓ 8.1[a] sprint times	22.03 ± 1.50	23.60 ± 1.6	↑ 7.2[a] DL, ↑ 12.8[a] NDL
					17.03 ± 1.70	19.21 ± 2.04	
Ramírez-Campillo et al. (54)	Plyometric training performed with (PPT) and without (NPPT) a progressive increase in volume	24 Amateur young (13.0 ± 2.3 y)	6 wk, 2 session/week	↑ 16.6[a] CMJ, ↓ 1.6[a] sprint times	18.64 ± 4.53	20.49 ± 4.78	↑ 10.1[a] PPT DL, ↑ 5.7 NPPT DL
					18.96 ± 4.27	20.13 ± 4.74	
Ramírez-Campillo et al. (53)	Vertical (VG), horizontal (HG), or combined vertical and horizontal (VHG) plyometric training	44 Amateur young (10–14 y)	6 wk, 2 session/week	↑ 19.0[a] CMJ, ↓ 6.0[a] sprint times	16.83 ± 1.67	18.14 ± 2.8	↑ 7.1 VG DL, ↑ 11.1 HG DL, ↑ 15.5[a] VHG DL
					16.61 ± 4.47	18.27 ± 4.33	
					16.19 ± 4.42	18.25 ± 2.42	
de Villarreal et al. (16)	Combined plyometric and sprint training	26 Amateur elite (14–15 y)	9 wk, 2 session/week	↑ 9.4[a] CMJ, ↓ 8.6[a] sprint times	21.97 ± 2.53	23.97 ± 2.78	↑ 9.1[a] DL, ↑ 10.1[a] NDL
					21.28 ± 2.92	23.39 ± 2.83	

All the above mentioned studies with exception of Trole et al. (1993), combined the strength training program with regular soccer training.

All the above mentioned studies with exception of Trole et al. (1993), included a control group. All studies report no significant increment in control group.

Vball = ball velocity; NA = no available data; DL = dominant leg; NDL = nondominant leg.

[a]Statistical significance $p < 0.05$.

radar) rather than other strength measurements.

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Artículo Nº 3

Role of neuromuscular and anthropometric parameters in maximal kicking ball velocities in elite soccer players

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Role of Vertical Jumps and Anthropometric Variables in Maximal Kicking Ball Velocities in Elite Soccer Players

by
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Kicking is one of the most important skills in soccer and the ability to achieve maximal kicking velocity with both legs leads to an advantage for the soccer player. This study examined the relationship between kicking ball velocity with both legs using anthropometric measurements and vertical jumps (a squat jump (SJ); a countermovement jump without (CMJ) and with the arm swing (CMJA) and a reactive jump (RJ)). Anthropometric measurements did not correlate with kicking ball velocity. Vertical jumps correlated significantly with kicking ball velocity using the dominant leg only ($r = .47$, $r = .58$, $r = .44$, $r = .51$, for SJ, CMJ, CMJA and RJ, respectively). Maximal kicking velocity with the dominant leg was significantly higher than with the non-dominant leg ($t = 18.04$, $p < 0.001$). Our results suggest that vertical jumps may be an optimal test to assess neuromuscular skills involved in kicking at maximal speed. Lack of the relationship between vertical jumps and kicking velocity with the non-dominant leg may reflect a difficulty to exhibit the neuromuscular skills during dominant leg kicking.

Key words: *kicking performance, jumping performance, strength, dominant leg, non-dominant leg, kicking deficit.*

Introduction

Soccer is one of the most popular sports in the world with 265 million players worldwide (FIFA, 2007). Different studies have investigated match skills in soccer (Lees et al., 1998; Masuda et al., 2005).

Kicking is the most widely studied soccer skill (De Proft et al., 1988; Masuda et al., 2005; Rodríguez-Lorenzo et al., 2015), as it is one of the most important skills in soccer (Bacvarevic et al., 2012; Barfield et al., 2002). Moreover, kicking is the most used and determinant skill in competition (Kellis and Katis, 2007; Sedano et al., 2009).

The performance of soccer kicking usually depends on kicking ball velocity and accuracy (Lees and Noland, 1998). Although, accuracy is an important factor, kicking performance in soccer has been evaluated predominantly by maximum ball velocity (Markovic et al., 2006). Therefore, when a soccer player performs an accurate kick towards an area of difficult interception by the goalkeeper, the chance of scoring increases with an increased ball velocity since there is less time for the goalkeeper to react (Markovic et al., 2006). In addition, it has been shown that the most successful goal scorers are those players who are able to score with both legs (Starosta, 1988). Therefore, the ability to kick with both legs leads to an advantage for the soccer player. However, the majority of the players have a slower maximal ball velocity when they kick with the non-dominant leg in comparison with the dominant leg (Barfield, 1995; Barfield et al., 2002; Dörge et al., 2002; Nunome et al., 2006a).

Several studies have been conducted in order to explore different factors that could affect maximal kicking velocity (Rodríguez-Lorenzo et al., 2015). Maximum kicking velocity is a complex

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skill that depends on technical (Juárez et al., 2010; Nunome et al., 2006b), biomechanical (Young and Rath, 2011), physiological (Ferraz et al., 2012), neuromuscular (Dörge et al., 1999; Kristensen et al., 1996; Nunome et al., 2006a) and strength factors (Masuda et al., 2005). In addition, anthropometric measurements have been studied in the context of potential use for the selection and future development of young soccer players (Helsen et al., 2005; Wong et al., 2009). Although, a positive relationship has been found between kicking performance and anthropometric measurements (Alessandro et al., 2014; Luhtanen, 1988), no studies have been conducted with adult elite soccer players. Therefore, it remains unknown whether the anthropometric variables are related with kicking performance once the players complete their physical growth. Improvement in maximal kicking velocity may be mediated by any one of the above mentioned factors. For instance, an increase in maximum kicking velocity performance may be attributed to an improvement in strength and explosiveness of the leg extensor muscles (Maulder and Cronin, 2005). However, the relationship between strength measurements and kicking performance is a subject of controversy (Young and Rath, 2011).

One way to determine the potential importance of the function of various muscles is to identify the relationship between strength measures and maximum ball velocity (Young and Rath, 2011). Some investigators reported positive and significant correlations between isokinetic strength and maximum kicking velocity (Luhtanen, 1988; Masuda et al., 2005). However, other studies did not find that relationship (Dörge et al., 2002; McLean and Tumilty, 1993; Mognoni et al., 1994; Narici et al., 1988). Therefore, there is a lack of consistency in the relationship between isokinetic strength and maximum kicking velocity, and thus, it is not possible to establish a cause-and-effect relationship between the strength measures and kicking performance (Young and Rath, 2011).

An alternative to isokinetic tests could be vertical jump tests. Explosive strength in the form of vertical jumping has been deemed to be functional for optimal performance in soccer (Stolen et al., 2005). However, only a few studies have previously investigated the possible relationship between vertical jump variables and maximal kicking velocity. Furthermore, the results from these studies are inconsistent. While some studies reported significant correlations between vertical jump variables and maximal kicking performance (Clark and Brooks, 2011), others found unclear (Juárez et al., 2008; Sousa et al., 2003) or non-significant correlations (Juárez et al., 2008, 2010). Moreover, these studies were conducted in students and children and thus, it remains unknown whether performance in the vertical jump is associated with maximal kicking velocity in elite soccer players and whether that relationship is similar for both the dominant and non-dominant leg.

Therefore, the goals of this study were as follows: i) to explore the relationship between vertical jumps and maximal kicking ball velocity with both legs in elite soccer players, ii) to compare the kicking performance between both legs, and iii) to explore the relationship between maximal kicking ball velocity and anthropometric measurements. This study provides further information regarding the role of strength in maximal kicking velocity, the nature of the kicking deficit of the non-dominant leg and the effect of the anthropometric features in kicking velocity.

Material and Methods

Experimental Approach to the Problem

Two experimental sessions were conducted on 2 days, separated by 48 hours of rest, at an ambient temperature of 16 to 18°C. Four familiarization sessions were conducted where subjects practiced maximal kicking and jump tests, in order to minimize any learning or habituation effects. For vertical jumps we followed the procedure described by Acero et al. (2011). To avoid inter-observer variability, the same experienced investigator tested all subjects.

The first experimental session started with the anthropometric measurements, followed by a warm-up which consisted of 5 min indoor running at a self-selected pace, a 5 min active stretching protocol, mainly for the lower limbs, 2 submaximal squat jumps and 2 submaximal countermovement jumps. After the warm-up, subjects were demonstrated each of the tests and performed 1 practice trial for habituation. The following 2 trials were recorded as experimental trials. Each subject had at least 3 min of rest between 2 consecutive trials on the vertical jumps in order to avoid fatigue.

The second experimental session consisted of the maximal kick test. The session started with a warm-up consisting of 5 min indoor running at a self-selected pace, a 5 min active stretching protocol, mainly for the lower limbs, 6 submaximal and 2 maximal instep kicks performed with each leg. After warming-up the kick test was demonstrated, followed by 1 practice trial performed with each leg. The following 3 trials with both the preferred and the non-preferred leg were recorded as experimental trials. The trial that produced the highest speed for both the preferred and the non-preferred leg was selected for further analysis. The order of testing was randomized between the preferred and the non-preferred leg. Each subject had at least 1 min of rest between 2 consecutive trials to avoid fatigue.

Participants

Twenty three male elite soccer players (mean age 20.27 ± 4.49 years; body mass 71.84 ± 6.52 kg; body height 177.3 ± 5.83 cm; body mass index 22.84 ± 1.2 kg·m^{-2}; goalkeepers n = 2, defenders n = 7, midfielders n = 7, and attackers n = 7) from the Real Club Deportivo de la Coruña second team (3rd Spanish Division), were tested as a part of their athletic training program during the final month of the 2013-2014 competitive season (May, 2014).

At the time of the study, all players had an average of over 10 years of soccer training experience and had trained an average of 4 times, as well as one game per week for at least 4 years. Fifteen players preferred to kick with the right leg and eight preferred to kick with the left leg.

After receiving a detailed explanation of the study's benefits and risks, all participants signed informed consent and completed a form giving, personal, medical and training details. None of the subjects reported neurological diseases or recent injuries. The study was approved by the medical department of Real Club Deportivo de la Coruña (Spain). The experimental procedures of the study were carried out in accordance with the Declaration of Helsinki.

Procedures

Anthropometric measurements

A total of eleven anthropometric measurements were recorded according to the International Society for the Advancement of Kinanthropometry's protocol (Marfell-Jones et al., 2006). All anthropometric measurements were taken twice in the right side of the body by the same trained anthropometrist in standardized order after a proper calibration of the measuring instruments.

Body mass was measured using a BFW300 Platform scale (Adam Equipment Co. Ltd., UK.) to the nearest 0.1 kg. Body stature was measured using a Harpenden stadiometer (Holtain Limited, UK.) to the nearest 0.1 cm. Lengths and breadths were measured using a Siber-Hegner Anthropometer (Zurich, Switzerland) to the nearest 0.1cm. Girths were measured using a Lufkin W606PM flexible steel tape (Cooper Industries, USA) to the nearest 0.1cm.

Kicking test

A modified version of the kicking test described by Markovic et al. (2006) was used to measure maximal ball velocity. The participants were instructed to perform an instep kick of a stationary ball of standard size and standard inflation (Fédération Internationale de Football Association, FIFA, standard) as fast as possible towards the radar gun. To standardize the procedure, the participants were restricted to a 5-step run-up from a position directly behind the ball. They were specifically instructed to focus only on maximum kicking velocity and the trials that missed the entire target area were repeated. Only 6 players needed to perform additional kicks and the maximum number of kicks performed by a player was 8.

Kicking performance was determined from maximal ball velocity. Velocity, expressed in m/s, was assessed using a stationary Doppler radar gun (Stalker Sport 2, Stalker Radar, Plano, Texas, USA) that can measure speeds between 2.23 m·s^{-1} and 67.04 m·s^{-1} with accuracy of ±0.045 m·s^{-1}. The radar gun (operating frequency of 24.125 GHz) was attached to a 0.7 m high stand and positioned behind a net, approximately 5 m from the starting position of the ball. The size of the net was sufficient to cover all kicks that deviated less than 15° from the direction of the radar gun (Markovic et al., 2006). The radar gun was always calibrated immediately before the sessions according to the instructions given in the user's manual.

Vertical Jump Tests

The SJ and CMJ tests were performed according to the protocols described by Bosco et al. (1983). The CMJA and 1RJA tests were performed according to the protocols described by Acero et al. (2012), where a more restricted action of the arms was imposed compared with the protocols of Bosco et al. (1983).

All vertical jumps were performed on a force plate (Quattro Jump, Kisler, Winterhur, UK) in the following order: a squat jump (SJ), a countermovement jump (CMJ), a countermovement jump with the arm swing (CMJA) and a reactive jump with the arm swing (1RJA).

Data Analyses

Anthropometric variables consisted of eleven measurements: body mass, body stature, 2 lengths (trochanterion and tibiale laterale height), 3 girths (arm flexed and tensed girth; thigh girth; calf girth), and 4 breadths (biiliocristal; biepicondylar femur). The mean value of the 2 measurements at each site was used for the analyses.

For the kicking test average velocity, maximal velocity and the coefficient of variation (CV) from the 3 trials were calculated. In addition, a kicking deficit variable (KD) was calculated according to the following formula:

$$KD = \left(\frac{KVdomMax - KVnodomMax}{KVdomMax}\right) \cdot 100$$

where *KVdomMax* and *KVnodommax* are the maximal velocities achieved with the dominant and non-dominant leg, respectively. The kicking deficit was defined as the percentage of the difference between maximal velocity obtained with the non-dominant leg in relation with the dominant leg.

For the vertical jump, height was calculated according to the following formula (Bosco et al., 1983):

$$SJ\_H = 0.5 \cdot g \cdot \left(\frac{flight\ time}{2}\right)^2$$

where flight time was the time between the takeoff and landing.

Statistical Analyses

Normal distribution of the variables was tested using the Shapiro-Wilk W-test. A Student's *t*-test for dependent samples was performed to compare maximal kicking velocities and CVs obtained with the dominant and non-dominant leg.

In order to explore whether the kicking deficit was related to maximal kicking velocity achieved by the dominant or non-dominant leg (i.e. to test whether the players with the highest maximal kick velocity with the dominant leg also had the greatest kicking deficit), the sample was divided into two groups according to the median value of the kicking deficit velocity. A Student's *t*-test for independent samples was performed for *KVdomMax* and *KVnodomMax*.

Pearson product correlation analysis was performed to assess the relationships between the kick test (KVdomMax, KVnodomMax), anthropometric measurements and the vertical jumps (SJ, CMJ, CMJA, RJ).

All statistical analyses were performed using SPSS version 21 (SPSS, Chicago, IL). A p value < 0.05 was considered statistically significant.

Results

Mean and SD values of the variables are shown in Table 1. None of the data violated the normality assumption necessary to conduct parametric statistical tests.

T-test analysis revealed that maximal kicking velocity with the dominant leg (KVdomMax) was significantly higher than with the non-dominant leg (t = 18.04, $p < 0.001$). No significant differences were found for the individual CV values of the kicking velocity between the legs.

There were no differences in the KVdomMax and KVnodomMax between the groups with higher and lower kicking deficits, suggesting no relationship between maximal kicking velocity achieved by either leg and kicking velocity.

Table 2 shows the coefficients of correlation among variables. Anthropometric measurements did not correlate with kicking velocities. Maximum kicking velocities between legs correlated significantly (r = .75, $p < 0.01$).

Table 1

Characteristics of the sample

Dimension	Mean	SD	Minimum	Maximum
Age (years)	21.12	2.42	18.03	26.31
Body mass (kg)	71.84	6.52	61.20	86.20
Stature (cm)	177.23	5.83	167.50	189.00
Trochanterion height (cm)	90.91	4.00	83.30	99.70
Tibiale laterale height (cm)	43.92	2.63	39.50	49.20
Arm flexed and tensed girth (cm)	31.62	2.04	27.70	35.50
Thigh girth (cm)	51.04	3.84	42.50	57.60
Calf girth (cm)	36.00	2.07	30.50	39.00
Biiliocristal breadth (cm)	28.97	1.27	26.80	31.20
Maximum velocity Dominant leg (m/s)	31.48	1.45	29.17	34.5
Maximum velocity Non-Dominant leg (m/s)	27.54	1.53	24.72	30.72
CV Average velocity Dominant leg (m/s)	1.03	0.74	0.30	3.49
CV Average velocity Non-Dominant leg (m/s)	1.36	1.19	0.03	4.82
Kicking Deficit	12.49	3.24	5.52	17.59
SJ (cm)	31.10	4.34	21.60	38.20
CMJ (cm)	33.07	3.88	23.90	38.70
CMJA (cm)	37.79	3.94	29.00	45.00
RJ (cm)	31.68	7.37	16.40	44.40

Table 2

Correlation values between variables.

Variables	Maximum velocity Dominant leg	Maximum velocity Non-Dominant leg
Anthropometric measurements		
Body mass	0.274	0.157
Stature	0.287	0.174
Trochanterion height	0.029	0.021
Tibiale laterale height	-0.099	-0.136
Arm flexed and tensed girth	0.329	0.323
Thigh girth	0.035	0.103
Calf girth	0.252	0.293
Biiliocristal breadth	0.226	0.281
Kicking test		
Maximun velocity Dominant leg	-	0.754**
Maximun velocity Non-Dominant leg	0.754**	-
Jump test		
SJ	.475*	0.075
CMJ	.582**	0.312
CMJA	.444*	0.317
RJ	.510*	0.112

* Correlations significant at $p < 0.05$; ** Correlations significant at $p < 0.01$.

Table 3

Kicking deficit and maximal kicking velocity values for dominant and non-dominant leg performance

Research	Subject characteristics			Kick	Kicking deficit †	RI	VB (m·s-1) Dominant	VB (m·s-1) Non-dominant
	n	Age Instep	Player level					
Narici et al. (1988)	11	25.1±5.0	Amateur		11.5	ARS	20.0 ± 3.6***	17.7± 2.2***
McLean and Tumilty (1993)	20	16.8±0.7	Elite junior	Drive kick	16.45	R	21.95±1.67*	18.34±1.39*
Mognoni et al. (1994)	24	NA	Junior		9.32		23.6±2.5	21.4±2.6
Barfield. (1995)	18	NA	Expert		7.95	R	26.4±2.1	24.3±2.0
Dörge et al. (2002)	30		Skilled		12.95	R	24.7±2.5*	21.5±2.0*
Barfield et al. (2002)	8	19-22	Élite	Instep		2C	***	***
	2		Male		6.71		25.3±1.51***	23.6±1.57***
	6		Female		12.09		21.5±2.44***	18.9±2.05***
Vaverka et al. (2003)	12	15.7±0.4	Skilled		15.14	3D	27.68±1.32	23.49±2.05
Nunome (2006a)	5	16.8±0.4	Skilled	Instep	15.58	3C	32.1±1.7*	27.1±1.2*
Sedano et al. (2009b)	10	22.8±2.1	Elite female	Pre-Trained	16.45	R	19.45±0.7*	16.25±0.45*
				Post-Trained	15.45		21.75±0.58*	18.39±0.64*
Berjan et al. (2012)	106	11.514.5	Elite young	Instep		R		
	27	12.2±0.3		Maximal	13.21		22.7±2.5*	19.7±2.3*
	26	13.1±0.2		Maximal	18.15		24.8±2.1*	20.3±2.7*
	26	14.3±0.3		Maximal	14.76		27.1±2.8*	23.1±2.9*
	27	15.3±0.3		Maximal	14.63		28.7±2.3*	24.5±3.1*
Barbieri et al. (2015)	10	21.8±2.2	Amateur futsal	Instep	10.91	3D	24.27±2.21***	21.62±2.26***

Note: n = Sample size; RI = Register instrument; R=Radar;
ARS = Audio recording system; C = Video camera; 3D = Motion capture system;
VB= Kicking ball velocity; NA= No available data;
*Statistical significance: *p < 0.05, **p < 0.01, ***p < 0.001;*
† Kicking deficit is calculated from the total average reported by those studies

The results obtained from vertical jump tests revealed a significant and moderate relationship between maximum kicking velocity with the dominant leg and the height of each vertical jump (SJ, CMJ, CMJA, RJ). Interestingly, maximum kicking velocity with the non-dominant leg did not correlate with any vertical jump.

Discussion

The purpose of this study was to compare maximum kicking velocity between the dominant and non-dominant leg and their relationship with the performance of a vertical jump. The main finding of our study was that there was a significant correlation between the performance of a jump test and maximum kicking velocity with the dominant leg, while no significant relationship was found for the non-dominant leg. In addition, maximum ball velocity after a soccer kick was significantly different between the dominant and non-dominant leg, indicating a kicking deficit with the non-dominant leg.

Ball velocity of maximal instep kicks for the dominant and non-dominant leg had been previously studied (Table 3). Ball velocity values of the dominant (mean 31.48 ± 1.45 m/s) and non-dominant (mean 27.54 ± 1.53 m/s) leg recorded in the present study were higher than in previous studies (mean 14.7). This may be due to the fact that our subjects were elite soccer players with at least 10 years of extensive practice.

We found a significant relationship between the height achieved in the vertical jump tests and maximum kicking velocity with the dominant leg. To the best of our knowledge only two studies had shown a significant relationship between maximal kicking velocity with the dominant leg and vertical jumps (Sousa et al., 2003). Sousa et al. (2003) reported a very weak significant relationship between kicking velocity and the SJ (r = .10) and the CMJ (r = .07). It is possible that the wider range of values during the vertical jumps in the Sousa's study in comparison with our study could explain the low relationship that the authors found between both variables. Nevertheless, our results contrast with previous studies that have shown no relationship between ball velocity and performance in different jump tests (Juárez et al., 2008, 2010). Several methodological issues, such as familiarization with the testing protocols or the features of the sample, may account for these differences. In our study the subjects performed four preliminary familiarization sessions of the testing procedures in order to minimize any effects of learning, achieve their maximal performance during the experimental sessions, and obtain reliable data. No familiarization sessions were conducted in previous studies (Juárez et al., 2008, 2010; Sousa et al., 2003). It is possible that the lack of familiarization sessions could increase the intra-subject variability (Acero et al., 2011), affecting the correlation analysis. In addition, the sample used in previous studies was very small, the soccer players were non-elite and under 15 years old (Juárez et al., 2008). The elite level and years of practice in the current study's sample mean that the data are reliable, as recent studies have reported that experienced players displayed less variability in the kicking pattern (Southard, 2014). In summary, it is likely that the rigorous methodology used in our study for data acquisition together with the expertise of the soccer players contributed to the strong correlations observed between the vertical jump and kicking performances.

It is also plausible that, in the current study, the core strength training program that the soccer players performed as a part of their regular soccer training may have contributed to the performance of both the ball kick and the vertical jump and thus, enhanced the correlation between these variables. This is supported by a recent study which showed that core training improved maximum kicking velocity due to a better transfer of forces from the trunk to limb muscles (Prieske et al., 2015). In addition, performance of a vertical jump is also enhanced by trunk stability exercises (Butcher et al., 2007).

The observed correlation between the performance of the vertical jumps and ball kicking with the dominant leg suggests that both tasks share some common muscle demands, such as the ability to reach high levels of force in a short period of time. The vertical jump test could be an optimal test to assess the neuromuscular skills involved when kicking at maximal speed. This hypothesis is supported by previous studies that have reported similar improvements in kicking velocity and the height of vertical jumps after strength training programs (García-Pinillos et al., 2014; Marques et al., 2013; Sedano et al., 2009). Interestingly, no correlations were found between the vertical jumps and kicking velocity with the non-dominant leg. This lack of the relationship could be interpreted as a difficulty to utilize the neuromuscular skills required for an optimal kicking performance. Higher ball velocity can be achieved by increasing foot velocity at impact (Young and Rath, 2011), which is dependent on the neuromuscular skill and technique levels (Dörge et al., 1999; Katis and Kellis, 2010; Kellis et al., 2004; Southard, 2014). It is possible that in our players the muscular function of each leg was highly specific. While the non-dominant leg is trained to develop isometric tension (to provide a stable platform for the swing of the kicking leg), the kicking and dominant leg is characterized by an explosive action (Dörge et al., 2002; Lees and Noland, 1998; Young and Rath, 2011). This muscle specificity could be compromised during the kicking action with the non-dominant leg, which may explain the lack of correlation with the vertical jump, a skill that requires an explosive muscle contraction.

Our results show that subjects produced significantly higher ball velocity with their preferred leg than with their non-preferred leg. Similar findings have been shown in expert soccer players (Barfield, 1995, 2002), amateurs (Marques et al., 2011; Mognoni et al., 1994; Narici et al., 1988; Vaverka, 2003), young subjects (Berjan et al., 2012), for both genders (Barfield et al., 2002; Sedano et al., 2009), for kicks with or without accuracy demand (Bacvarevic et al., 2012), and for different techniques and kicking conditions (Marques et al., 2011; McLean and Tumilty, 1993). The most straightforward explanation for these results is that the kicking technique is better with the dominant compared to non-dominant leg (Barbieri et al., 2015; Barfield et al., 2002; Teixeira, 1999; Vaverka et al., 2003). Unfortunately, in the current study we did not record the biomechanics of the kick in order to test this hypothesis. However, the coefficient of variation of the kicking performance was not significantly different between legs. It is known that the expertise of a task is related to lower variability in performance (Schmidt, 1988). Thus, it is possible that the specificity of the muscle function of each leg during kicking could be a possible reason for the difference in kicking velocity observed between dominant and non-dominant legs.

In our study the players who achieved higher ball velocities with the dominant leg, also achieved higher ball velocities with the non-dominant leg. However, when the players were divided into two groups according to the median value of the kicking deficit, there were no differences between kicking velocities with the dominant and non-dominant leg. These results suggest that the kicking deficit is independent of the absolute maximal kicking velocity of the dominant leg. In addition, the values of the kicking deficit were more variable across players compared with the values for maximal kicking velocity for both dominant and non-dominant legs. For instance, the player with the highest kicking deficit reported values threefold that of the player with the lowest deficit (17.59% vs. 5.52%, respectively). Therefore, the kicking deficit may be more helpful when evaluating and monitoring the individual capacity of each player to perform at similar levels with both legs rather than the use of absolute maximal velocity values. This is of relevance since the ability to kick with both legs is an advantage for the soccer player (Starosta, 1988).

The correlational analysis did not show any relationship between the anthropometric measurements and kicking velocity. This is in contrast with previous findings in young soccer players that had shown a significant correlation between kicking performance and body mass (Alessandro et al., 2014; Luhtanen, 1988) or between kicking performance and stature (Luhtanen, 1988). Lack of this relationship in the current study with adult elite soccer players suggests that anthropometric characteristics may be overvalued during the process of sports training, especially during puberty. Our results are in line with Alessandro et al. (2014) who found that anthropometric characteristics did not predict match-related technical performance and concluded that anthropometric features should be used with caution for talent identification or training purposes. However, it has been reported that soccer coaches select young players based on their anthropometric characteristics rather than their technical and tactical performance (Helsen et al., 2005; Maulder and Cronin, 2005). Such procedures could provide short-term benefits in soccer team performance, but may prevent the long-term development of young soccer players, since once players complete their physical growth value of the anthropometric advantages decreases and technical and tactical factors become significantly more important. Therefore, as suggested by Reilly et al. (2000) and Wong et al. (2009), psychological and soccer-specific skills should also be considered in the selection of young soccer players.

Our study has several limitations. The players were from a single soccer team and participated in the 3rd Spanish Division, thus, extrapolation of our findings to other teams and soccer player's levels must be done with caution. In addition, the tests were conducted at the end of the competitive season and thus, it remains to be explored whether the relationships between variables found in the current study are consistent throughout the competitive season. Therefore, futures studies must address those questions in order to further understand the relationship between vertical jumps, anthropometric variables and maximal kicking ball performance.

Nevertheless, and from a practical point of view, the current study suggests that the kicking deficit variable may be useful for coaches when evaluating and monitoring the individual player's capacity to perform at similar levels with both legs rather than the use of the absolute maximal velocity. Finally, lack of a relationship between anthropometric variables and kicking performance supports the hypothesis that the anthropometric characteristics should not be overvalued by coaches during training and the selection process of soccer players.

Conclusions

In summary, our results show a positive relationship between the performance of vertical jumps and the dominant leg maximal kicking velocity. This suggests that vertical jumps may be an optimal test to assess the neuromuscular skills involved in kicking at maximal speed. This relationship was absent for the non-dominant leg and may be interpreted as a difficulty to utilize the neuromuscular skills required for an optimal kicking performance. Furthermore, our findings show that the kicking deficit exhibited by the non-dominant leg is independent of the absolute maximal kicking velocities of the dominant leg.

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Artículo Nº 4

Kicking Deficit in Young Elite Soccer Players

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KICKING ABILITY AND KICKING DEFICIT IN YOUNG ELITE SOCCER PLAYER

Abstract

Kicking ability in soccer has been evaluated predominantly by maximum ball velocity. Kicking deficit (KD) could be defined as the percentage of the difference between the maximum velocity obtained for each player with the non-dominant leg in relation to the preferred leg. This study aimed to compare: side-to-side kicking velocity, vertical jumps and anthropometrics between younger (G-14) and older (G+14) 14 years old soccer players. An additional aim was to investigate groups between these variables. Participants were 92 young elite soccer players from the development programme of a top Spanish division club. They were divided into two age groups according to growth and motor development stages (10.80–13.55 yrs, n = 46; 14.02–16.39 12 yrs, n = 46). Student's t-test showed that maximum kicking velocity with the preferred and non-preferred leg, jumping performance, and all anthropometric measurements were significantly ($p<0.01$) higher in G+14 compared with G-14. In contrast, KD values remained stable (15.31% - 15.83%) without significant changes among groups. Pearson's correlation analysis revealed that, vertical jump tests and anthropometric measurements, correlated with kicking ball velocity with the preferred and non-preferred leg. Our results show that in young soccer players kicking skills are not so consolidated and power factors are determinant for kicking performance. In addition, Kicking Deficit is a constant element in young elite soccer players and could result from an unequal and greater use of the preferred leg in comparison with the non-preferred leg.

Keywords: *ball velocity, skill, performance, jumping, non-preferred leg, strength.*

Introduction

Kicking ability represents the most important soccer-specific skill (Bacvarevic, et al., 2012) since, besides being used in passes, crosses, and clearances, it is also used to score goals and win games. In fact, an analysis of the 2010 Soccer World Cup revealed that 80.69% of the goals were achieved by kicking (Njororai, 2013). Moreover, although accuracy is an important factor, kicking performance in soccer has been evaluated predominantly by maximum ball velocity (Markovic, Dizdar, & Jaric, 2006). It is important for players to achieve a high ball velocity in soccer goal kicking to give the goalkeeper less time to react (Dörge, Andersen, Sørensen, & Simonsen, 2002). In addition, the ability to kick with both preferred and non-preferred leg leads to an advantage for the soccer players (Grouios, Kollias, Tsorbatzoudis, & Alexandris, 2002), generating more situations to shoot and thus improving their chance of scoring (Lago-Peña s& Lago-Ballesteros, 2011) Therefore, improving maximal kicking velocity with both preferred and non-preferred leg must be an important goal for soccer coaches. Furthermore, the rationale for training both legs equally is also important to minimize potential asymmetrical forces acting on joints, reduce muscle imbalances and decrease the workload of the preferred leg which may eventually lead to overuse injuries (Hides, Stanton, Stanton, McMahon, & Wilson, 2008). Another reason for the non-preferred leg to be trained and strong enough in soccer players is to support coordinative motor actions of the preferred leg. (Rahnama, Lees, & Bambaecichi, 2015; Ruas, Brown, & Pinto, 2015).

Despite the importance of the ability to kick with both preferred and non-preferred leg in soccer, there is an agreement across studies that ball velocity is significantly higher after a kick with the preferred leg compared with the non-preferred one (Barfield, Kirkendall, & Yu, 2002; Dörge, et al., 2002). This pointed to a kicking deficit (KD) with the non-preferred leg, which could be in a range of 9.32-18.35% of the kicking velocity with the preferred leg, depending of the sample features. Those values of KD were calculated from the average velocity values of the total sample rather than the ones from the individual KD values. Nonetheless, one recent study reported the individual values of the KD (12.49 ± 3.24%) and defined the kicking deficit (KD) as the percentage of the difference between the maximal velocity obtained for each player with the non-preferred leg in relation with the preferred leg (Rodríguez-Lorenzo, et al., 2016). Interestingly, in this study it has been found that, KD is independent of the absolute maximal kicking velocity achieved with the preferred leg. Therefore, KD may be a helpful index when evaluating and monitoring the individual capacity of each player to perform at similar levels to kick with the preferred and non-preferred leg in addition to the absolute maximal velocity values.

Although there are several factors that may affect maximal kicking velocity, such as technical (Juárez, et al., 2010; Nunome, Lake, Georgakis, & Stergioulas, 2006), biomechanical (Young & Rath, 2011), physiological (Ferraz, Van Den Tillaar, & Marques, 2012) and muscle strength factors (Masuda, Kikuhara, Demura, Katsuta, & Yamanaka, 2005). Rodríguez-Lorenzo, et al. (2016) suggest that kicking deficit could be due to a difficulty to exhibit the same neuromuscular skills that occur during a kick with the non-preferred and preferred leg. This supports for the significant relationship found between the height achieved in the vertical jump tests (SJ, CMJ, CMJA, 1RJA) and the maximum kicking velocity with the preferred leg, but not with the non-preferred one. However, this study was conducted in adults and thus, it remains unknown whether kicking deficit already exists in young soccer players and is associated, as in adult players, with neuromuscular skills. Indeed, ball velocity increments associated with age are likely not only due to skill development of the kicking pattern but also due to the increased absolute muscle strength associated with growth and maturation (Poulmedis, Rondoyannis, Mitsou, & Tsarouchas, 1988; Tol, Slim, van Soest, & van Dijk, 2002; Wong, Chamari, Dellal, & Wisloff, 2009). In Galicia, the region where the club is located and where the data was collected, it has been reported that most age-related changes occur before the ages of 14 (Acero, et al, 2002; Pippi, et al., 2003), according to growth and motor development stages proposed by Crasselt (1988) and Hebbelinck (1991). Therefore, the sample was divided into two subgroups (younger and older than 14 years old) according to their chronological age.

The purpose of this study was to compare side-to-side kicking velocity, vertical jumps and anthropometrics between younger (G-14) and older (G+14) than 14 years old soccer players. An additional aim was to investigate associations between these variables.

Methods

Subjects

Ninety-two elite male soccer players, belonging to the Real Club Deportivo de la Coruña youth development programme were tested as a part of their athletic training program during the final month of the 2014-2015 competitive season (May, 2014).

The G-14 group (under 14 years), included 46 players (age 12.18 ± 0.94 years; body mass 40.86± 7.84 kg; body height 149.60 ± 9.42 cm; body mass index 18.09 ± 1.65 $kg \cdot m^{-2}$; goalkeepers n = 6, defenders n = 16, midfielders n = 10, and attackers n = 14). They had an average of 4.84 ± 1.17 years of soccer training experience and had trained an average of 2.5 times a week, as well as one game per week during the last 4 years. Thirty-three players preferred to kick with their right leg, thirteen preferred to kick with their left

The G+14 group (above 14 years), included 46 players (age 15.04 ± 0.80 years; body mass 60.72 ± 9.59 kg; body height 169.34 ± 7.86 cm; body mass index 21.09 ± 1.86 $kg \cdot m^{-2}$; goalkeepers n = 6, defenders n = 16, midfielders n = 12, and attackers n = 12). They had an average of 7.82 ± 0.79 years of soccer training experience and had trained an average of 3.5 times a week, as well as one game per week during the last 4 years. Thirty-four players preferred to kick with their right leg, twelve preferred to kick with their left.

The experimental procedures of the study were carried out in accordance to the Spanish laws that regulate clinical research in humans (Royal Decree 561/1993), the Organic Law on Personal Data Protection 15/1999, and the necessary ethics principles in the 2013 review of the Declaration of Helsinki. The study was approved by the PhD Committee of the Faculty of Sport Sciences and Physical Education of the University of A Coruña and by club authorities. After receiving a detailed explanation of the study's benefits and risks, all participants and their parents signed a consent and completed a form giving personal, medical and training details. None of the subjects reported neurological diseases or recent injuries.

Design and Methodology

Participants were familiarized with the test procedures during four sessions conducted once a week, six weeks prior to the initial assessment, in order to minimize any learning or habituation effects. Each familiarized session consisted in performing the same experimental procedures for kicking and jumping tests on the same day. Participants had seven days of rest between the last familiarized session and the first experimental day.

Two experimental sessions were conducted on 2 days, separated by a 48 hour rest, at an atmosphere temperature of 16 to 18°C. All tests were always managed in the same order. The first experimental session started with the anthropometric measurements, followed by the vertical jump tests. The second experimental session consisted of the maximal kick test. The total duration of each experimental session was an hour an hour and a half. To avoid inter-observer variability, the same experienced investigator tested all subjects.

Testing Procedures

Anthropometric Measurements

A total of eleven anthropometric measurements were recorded according to the International Society for the Advancement of Kinanthropometry's protocol (Marfell-Jones, M., Olds, T., Stewart, A., & Carter, 2006). All anthropometric measurements were taken twice on the right side of the body by the same trained anthropometrist in standardized order after a proper regulation of the measuring instruments.

Body mass was measured using a BFW300 Platform scale (Adam Equipment Co. Ltd., UK.) to the nearest 0.1 kg. The body height was measured using a Harpenden stadiometer (Holtain Limited, UK.) to the nearest 0.1 cm. Lengths and breadths were measured using a Siber-Hegner Anthropometer (Zurich, Switzerland) to the nearest 0.1 cm. Waist was measured using a Lufkin W606PM flexible tape (Cooper Industries, USA) to the nearest 0.1 cm.

Anthropometric variables consisted of eleven measurements: body mass, body height, 2 lengths (trochanterion and tibiale laterale height), 3 girths (arm flexed and tensed girth;

thigh girth; calf girth), and 3 breadths (biiliocristal; biepicondylar femur; ankle breadth). The value of the 2 measurements at each site was used for the analyses.

Kicking Test

A modified version of the kick test described by Markovic et al. (2006) was used to measure maximal ball velocity. Foot preference was self-selected based on the players response to which foot they preferred to kick with for maximal ball velocity. The kicking test was preceded by a standard 15-minute warm up consisting of 5 minutes of indoor running at a self-selected pace, a 5 minutes active stretching protocol for the lower limbs (2 sets x 3 repetitions of hip flexion and extension, hip abduction and adduction, knee extension and flexion, and ankle plantarflexion–dorsiflexion exercises), 6 submaximal and 2 maximal instep kicks performed with each leg.

After detailed explanations and a qualified demonstration, participants performed one practice trial with each leg. The following 3 trials with the preferred and the non-preferred leg were recorded as experimental trials. The participants were instructed to perform an instep kick of a stationary ball of standard size and standard inflation (Fédération Internationale de Football Association, FIFA, standard) as fast as possible towards the radar gun. To standardize the procedure, participants were restricted to a 5-step run-up from a position directly behind the ball. They were specifically instructed to focus only on maximum kicking velocity and the trials that missed the entire target area were repeated. Only six players needed to perform additional kicks and the maximum number of kicks performed by a player were 8. The order of testing was randomized between each leg. Each subject had at least 1 minute of rest between 2 consecutive trials to avoid fatigue.

Kicking performance was determined from maximal ball velocity. Velocity, expressed in m/s, was assessed using a stationary Doppler radar gun (Stalker Sport 2, Stalker Radar, Plano, Texas, USA) that can measure speeds between 2.23 $m \cdot s^{-1}$ and 67.04 $m \cdot s^{-1}$ with accuracy of ±0.045 $m \cdot s^{-1}$. The radar gun (operating frequency of 24.125 GHz) was attached to a 0.7 m high stand and positioned behind a net, approximately 5 m from the starting position of the ball. The size of the net was sufficient to cover all kicks that deviated less than 15° from the direction of the radar gun (Markovic, et al., 2006). The radar gun was always calibrated immediately before the sessions according to the instructions given in the user's manual (Campo, Vaeyens, Philippaerts, Redondo, de Benito, & Cuadrado, 2009).

The trial that produced the highest velocity for both the preferred and the non-preferred leg was selected for further analysis. The coefficient of variation (CV) from the 3 trials were calculated. In addition, kicking deficit (KD) variable was calculated according to the following formula (Rodríguez-Lorenzo, et al., 2016):

$$KD = \left(\frac{KVdomMax - KVnodomMax}{KVdomMax}\right) \cdot 100$$

where *KVdomMax* and *KVnodommax* are the maximal velocities achieved with the dominant and non-dominant leg, respectively.

Vertical Jump Tests

Before performing the vertical jump tests, the athletes completed 15 minutes of standard warm-ups which consisted of 5 minutes of indoor running at a self-selected pace, 5 minutes of the same active stretching protocol described in the kicking test, 2 submaximal squat jumps and 2 submaximal countermovement jumps. After the warm-up, subjects were demonstrated each of the tests and performed 1 practice trial. The following 2 trials were recorded as experimental trials. Each subject had at least 3 minutes of rest between 2 consecutive trials on the vertical jumps in order to avoid fatigue.

The squat jump (SJ) and countermovement jump (CMJ) tests were performed according to the protocols described by Bosco, Luhtanen & Komi (1983). In the SJs, the participants were instructed to maintain a static semi squatted position (knee angle around 60-90°, after individual motor adjustment) for 2 seconds before starting the jump without any preliminary movement. Individual ground reaction force traces were checked to verify that a countermovement had not occurred, and trials in which a countermovement was detected were not considered valid and were repeated. For the CMJs, the subjects started from an upright position, performing a rapid downward movement (knee angle around 60-90°) followed by a dynamic complete extension of the lowerlimb joints. During these tests, starting position was with feet parallel at a distance equal to the width of shoulders and hands were kept on hips throughout the test.

The countermovement jump with the arm swing (CMJA) and a reactive jump with the arm swing (1RJA) tests were performed according to the protocols described by Acero, Sánchez, and Fernández-del-Olmo (2012). In the Countermovement jump (CMJA) participants performed the same movement as in the CMJ, with a different arm movement. In the starting position arms were at shoulder level, flexed 90°. When the participants performed a rapid downward movement, arms move down with elbows extended. When the extension of the lowerlimb joints the elbows begin to flex and the hands go up to face height. Finally shoulders and elbows would be locked in place when the maximum height of the jump has been achieved. For the 1RJA the individual started from an upright position with feet parallel at an equal distance to the width of the shoulders and arms straight to the side of the body. First, 2 or 3 progressive small jumps with knees straight, with the help of the arm swing, then, jump progressively higher during 5 or 6 seconds to achieve 2 or 3 maximum height jumps. After each of the jumps, the landing is with extended feet and knees, same as takeoff position.

All vertical jumps were performed on a force plate (Quattro Jump, Kisler, Winterhur, UK) in the following order: SJ, CMJ, CMJA and 1RJA. The vertical jump height was calculated according to the following formula (Bosco, et al., 1983).

$$SJ\_H = 0.5 \cdot g \cdot \left(\frac{flight\ time}{2}\right)^2$$

where flight time was the time between takeoff and landing. The result that produced the highest velocity was selected for further analysis.

Statistical Analysis

Normality and homoscedasticity assumptions were checked respectively with Shapiro-Wilk and Levene tests. A Student's t-test for independent samples with the Bonferroni correction was applied to compare anthropometric and vertical jump variables between G-14 and G+14 players.

We conducted an ANOVA of repeated measurements with one intrasubject factor (leg) and one intersubject factor (group) over the maximal kicking velocity and over the within-subject CV of the kicking velocity. In case of a significant interaction post-hoc analysis was performed with Bonferroni corrections. Effect size was evaluated with η2 (partial eta-squared).

Pearson product correlation analysis was performed to assess the relationships between the kick test (KVdomMax, KVnodomMax), anthropometric measurements and the vertical jumps (SJ, CMJ, CMJA, RJ). All statistical analyses were performed using

SPSS version 21 (SPSS, Chicago, IL). A p value < 0.05 was considered statistically significant.

Table 1. Results of a t-test to reveal mean differences between groups for evaluation parameters

	Group -14 (n=46)		Group +14 (n=46)		
Dimension	Mean	SD	Mean	SD	*t* Value
Age (years)	12.18	0.94	15.04	0.80	-14.89**
Bodymass (kg)	40.86	7.84	60.72	9.59	-10.31**
Stature (cm)	149.60	9.42	169.34	7.86	-10.24**
Body mass index (kg/m^2)	18.09	1.65	21.04	1.92	-7.47**
Trochanterion height (cm)	82.34	10.02	90.96	10.06	-3.89**
Tibiale laterale height (cm)	38.56	3.17	43.13	3.00	-6.69**
Arm flexed and tensed girth (cm)	23.17	2.07	28.40	5.62	-5.69**
Thigh girth (cm)	42.90	4.03	50.60	5.07	-7.64**
Calf girth (cm)	30.34	2.68	35.46	2.99	-8.17**
Biiliocristal breadth (cm)	23.65	1.64	26.70	1.64	-8.40**
Biepicondylar femur breadth (cm)	9.28	0.70	10.02	1.01	-3.89**
Ankle breadth (cm)	6.52	0.58	6.90	0.43	-3.33**
Kicking Deficit	15.31	7.32	15.83	7.88	-0.32
SJ (cm)	20,70	4,43	22.84	7.01	-8.69**
CMJ (cm)	22.59	4.76	28.32	5.07	-5.33**
CMJA (cm)	25.30	4.98	32.53	5.31	-6.43**
RJ (cm)	23.05	4.16	27.99	4.40	-5.29**

*SJ= squat jump; CMJ= countermovement jump; CMJA= countermovement jump with the arm swing; 1RJA= reactive jump with the arm swing; Statistical significance: *p < 0.05, **p < 0.01*

Results

None of the data violated the normality assumption necessary to conduct parametric statistical tests. Table 1 shows the results of the t-test to display the mean data differences between groups G-14 and G+14 for anthropometric and vertical jump variables. Jumping performance, and all anthropometric measurements, showed significantly larger values in group G+14 than in group G-14. The mean (+ SD) data for maximal kicking performance and the within-subject CV average of the kicking velocity, with the preferred and non-preferred leg for each age groups are presented in Table 2.

Table 2. Mean values (± SD) for the maximum velocity and within-subject CV of the kicking velocity.

		Maximum velocity (m/s)	CV kicking velocity
Preferred leg	Group -14	22.25 ± 2.11	5.10 ± 3.69
	Group +14	27.54 ± 2.45	3.94 ± 2.02
Non-preferred leg	Group -14	18.82 ± 2.28	5.94 ± 3.33
	Group +14	23.14 ± 2.58	5.67 ± 3.50

The ANOVA of repeated measurements showed a main effect of Leg (F=365.02, $p<0.05$, $\eta 2 = 0.82$) and Group (F=103.4, $p<0.05$, $\eta 2 = 0.56$) over maximal kicking velocity. There was a significant Leg*Group interaction (F =5.68, $p<0.05$, $\eta 2 = 0.06$.). Post-hoc analysis revealed that maximal kicking velocity with the preferred leg (KVdomMax) was significantly ($p < 0.001$) higher than with the non-preferred leg in both groups. Maximum kicking velocity with the preferred and non-preferred leg, showed significantly ($p < 0.001$) larger values in group G+14 than in group G-14.

The ANOVA of repeated measurements showed a main effect of Leg (F=9.07, $p<0.05$, $\eta 2 = 0.10$.) over the within-subject CV of the kicking velocity. The within-subject CV values of the kicking velocity was not significantly affected by the group. No interactions between leg and group were found for the CV of the kicking. Post-hoc analysis revealed that the within-subject CV of the kicking velocity with the preferred leg were significantly ($p < 0.01$) lower compared to the non-preferred one.

Table 3. Correlation values between variables

Dimension	Maximum velocity Dominant leg		Maximum velocity Non-Dominant leg	
	G-14	G+14	G-14	G+14
Age (years)	0.689**	0.632**	0.525**	0.335*
Anthropometric measurements				
Bodymass (cm)	0.691**	0.855**	0.502**	0.535**
Stature (cm)	0.738**	0.753**	0.574**	0.486**
Body mass index (kg/m^2)	0.374**	0.719**	0.210	0.401*
Trochanterion height (cm)	0.101	0.335*	0.198	0.047
Tibiale laterale height (cm)	0.684**	0.306	0.565**	0.222
Arm flexed and tensed girth (cm)	0.605**	0.527**	0.357*	0.419**
Thigh girth (cm)	0.599**	0.626**	0.353*	0.284
Calf girth (cm)	0.599**	0.727**	0.465**	0.527**
Biiliocristal breadth (cm)	0.645**	0.587**	0.470**	0.221
Biepicondylar femur breadth (cm)	0.385*	0.500**	0.264	0.260
Ankle breadth (cm)	0.493**	0.476**	0.298*	0.365*
Kicking test				
Maximun velocity Dominant leg	-	-	0.723**	0.650**
Maximun velocity Non-Dominant leg	0.723**	0.650**	-	-
Kicking Deficit	0.108	0.108	0.108	0.108
Jump test				
SJ (cm)	0.569**	0.513**	0.455**	0.495**
CMJ (cm)	0.576**	0.465**	0.524**	0.446**
CMJA (cm)	0.665**	0.616**	0.594**	0.606**
RJ (cm)	0.302**	0.317**	0.505**	0.420**

*SJ= squat jump; CMJ= countermovement jump; CMJA= countermovement jump with the arm swing; 1RJA= reactive jump with the arm swing; * Correlations significant at $p < 0.05$; ** Correlations significant at $p < 0.01$.*

Table 3 shows the coefficients of correlation among variables. There is a significant high positive correlation between age, body mass and stature and kicking ball velocity with the preferred and non-preferred leg in both groups of age. A greater number of anthropometric measurements correlate with kicking velocity with the preferred leg (20/22) than the non-preferred one (16/22) for the total of the 2 groups. Maximum kicking velocities between legs correlated significantly for both groups (r = .72, $p < 0.01$) (r = .65, $p < 0.01$). The results obtained from vertical jump tests revealed a significant and moderate-high relationship between maximum kicking velocity with the preferred and non-preferred legs and the height of each vertical jump (SJ, CMJ, CMJA, RJ).

Discussion

This study aimed to compare side-to-side kicking velocity, vertical jumps and anthropometrics between younger (G-14) and older (G+14) than 14 years old soccer players. An additional aim was to investigate associations between these variables. The main results were that maximum ball velocity after a soccer kick was, for the entire sample, significantly different between the preferred and non-preferred leg, indicating a kicking deficit with the non-preferred leg. Furthermore, there were, for each group, significant correlations between the height achieved in the vertical jump tests (SJ, CMJ, CMJA and RJ) and the maximum kicking velocity with the preferred and non-preferred leg.

To the best of our knowledge, the present study is the first to report the individual's values, of the KD, in young soccer players. Surprisingly, our results showed that KD is a constant element in young elite soccer players, since their values remain stable without significant changes between these age groups, 15.31 ± 7.32 % for G-14; 15.83 ± 7.88 % for G+14. The lower kicking performance with the non-preferred leg in elite players were in agreement with the results obtained in previous studies, Dörge et al., 2002; Nunome, 2006; Berjan et al., 2012. Berjan et al. (2012) reported mean differences of 15.20% between the preferred and non-preferred legs in 106 youth Serbian national players divided into 4 age groups (12–15). A similar difference,15.58% was also reported (Nunome, 2006) in highly skilled soccer players (n = 5, age = 16.8 ± 0.4). Lower differences (12%) were reported by (Tomáš, František, Lucia, & Jaroslav, 2014) in youth Czech national team players (n = 22, age = 15.6 ± 0.4 years) and in seven skilled soccer players (12.95%) (Dörge et al., 2002). However, these percentages were calculated from the total average reported by the research, and does not allow reliable comparisons across different studies. Comparison of our findings to another must be done with caution.

Interestingly, our results show that despite no significant difference in KD values was found among age groups, maximum kicking velocity with the preferred and non-preferred leg was significantly higher in G+14. In addition, there was no correlation between KD and maximal kicking velocity with the preferred and non-preferred leg in both age groups. Taken together, this discovery revealed that KD is independent of the absolute maximal kicking velocity of the player.

In order to explore the nature of KD we conducted a correlation analysis for each age group. We found a significant relationship between the height achieved in vertical jump tests (SJ, CMJ, CMJA, 1RJA) and the maximum kicking velocity with the preferred leg. These findings are consistent with those of Mercé, González, Mayo, Pardo and Sorli (2004) who found a moderate significant relationship between kicking velocity with the preferred leg and the height reached in SJ (r = .40) and CMJ (r = .41) in young elite soccer players, similar to the values obtained in our study. This discovery agrees with those reported in adult elite soccer players, Rodríguez-Lorenzo et al. (2016) which described a moderate significant relationship between kicking velocity with the dominant leg and the height reached in SJ (r = .48), CMJ (r = .58), CMJA (r = .44) and RJ (r = .51) by adult elite male soccer players. Higher correlation (r = 0.91) was found by Clark and Brooks (2011) with a CMJ in adult elite female soccer players, which contrasts with other studies that showed low significant relationships (Sousa, Garganta, & Garganta, 2003) or no significant relationship (Juárez, et al., 2008; Juárez, López, & Navarro, 2010) between SJ and CMJ with maximal kicking velocity with the dominant leg. Several methodological factors such as the use of different testing protocols and instruments, the moment of the season at which the test was carried out, and the subject's expertise level and age can help explaining these differences.

Interestingly, we also found a significant relationship between the maximum kicking velocity with the non-preferred leg and the height achieved in the vertical jump tests. In contrast to the preferred leg, the relationship between kicking velocity with the non-preferred leg and the vertical jump performance has received minimal research attention in the literature. To the best of our knowledge, only one study conducted by our group in elite adult players attempted to examine this relationship (Rodríguez-Lorenzo, et al., 2016), and found that this relationship was absent using exactly the same methodology than the present study. Nunome et al. (2006a) attributed the differences in kick biomechanics, between the two limbs, depend on the skill level of the players (Nunome et al. 2006a), the higher the skill level, the better importance of the co-ordination factors. Furthermore, Schmidt (1988) indicates that the expertise of a task, is related to lower variability in performance. The much higher within-subject CV (5.16) values found in the present study, compared to those reported in our previous study with adult soccer players (1.16), and the lower maximal kicking performance, indicate that in young soccer players the kicking skill is not so consolidated. Furthermore, although a correlation does not imply causality between variables, our results suggest that, in young soccer players, power factors might play an important role in kicking performance. However, in adult soccer players, the high muscle specificity developed due to a higher practice time accumulation (Shan, 2009) and higher use of the preferred leg with respect to the non-preferred, one (Oliva, et al., 2015) leads to a better inter-segmental pattern and a transfer of velocity from the foot to the ball when kicking with the preferred leg (Dorge et al., 2002). Indeed, during a soccer game the use of the preferred leg occurs about 90% of the time in controls, passes, and crosses of the ball, and about 70%, for kicks aimed at the goal (Oliva, et al., 2015). As a result, the soccer player develops a highly specific muscular function for each leg. While the non-preferred leg is trained to activate in an isometric fashion (to provide a stable platform for the swing of the kicking leg), the kicking and preferred leg is characterized by an explosive action (Dörge, et al., 2002; Young & Rath, 2011). This muscle specificity could be compromised during the kicking action with the non-preferred leg, which may explain the lack of correlation with the vertical jump in adult soccer players.

For instance, in both G-14 and G+14 groups most of the anthropometric measurements were significantly associated with the maximal kicking velocities achieved with the preferred and non-preferred leg. The present findings seem to be consistent with another research, conducted in young soccer players, which found that maximal kicking velocity was significantly correlated body mass, height and body mass index (Wong, et al., 2009; Brahim, Bougatfa, & Mohamed, 2013; Bekris, et al., 2015). However, adult soccer players did not show any correlation between those parameters (Rodríguez-Lorenzo, et al., 2016). One posible explanation is that during prepubertal and pubertal periods, transitory anthropometrical features associated physical maturity process, such as weight, height, and strength (Figueiredo, Gonçalves, Coelho, Silva, & Malina, 2009; Malina, et al., 2000; Malina, et al., 2005; Ré, Cattuzzo, Santos, & Monteiro, 2014) may have a high influence on kicking performance. However, after puberty, when the transitory differences associated with the maturity process cease to exist, the anthropometric variables have less importance in the performance. Accordingly, selecting young players based on their anthropometric characteristics could only provide short-term benefits in soccer team performance. Once players complete their physical growth, the anthropometric advantages decrease and technical and tactical factors become significantly more important (Ré, Corrêa, & Boehme, 2010). Therefore, technical and tactical factors should be mainly considered in the selection process of young soccer players (Reilly, Williams, Nevill, & Franks, 2000; Wong, et al., 2009).

Taking into account all the above mentioned, it seems that KD is multifactorial in nature and thus, can result from the influence of different factors, which correlate and influence each other, according to the experience of the player. This is of relevance to establish the best training procedures in order to reduce KD. Our results are in line with the result of a very recent studies (Ramírez-Campillo et al., 2014; de Villarreal, Suarez-Arrones, Requena, Haff, & Ferrete, 2015; Ramírez-Campillo et al., 2015) that demonstrated that the application of different strength training programs (jumps and sprints, and plyometric exercises adapted to the age of our player) can increase ball velocity values in young soccer players. Furthermore, this kind of training should be incorporated in daily workout routines since we can improve, at the same time, two of the most important and determinant soccer skills: jumping (heading) and kicking. However, it has been recommended that strength training should be integrated with other types of training, involving the actual movement pattern to increase the performance within more complex movement patterns and in combination with regular soccer training (Aagaard, Simonsen, Trolle, Bangsbo, & Klausen, 1996; Manolopoulos, Papadopoulos, & Kellis, 2006). Although, it has been demonstrated that incorporating analytical tasks to improve kicking performance with the non-preferred leg increased the use of this leg by the player during competition (Guilherme, Garganta, Graça, & Seabra,2015), coaches should reward and give more positive reinforcing feedback to their players to continue using their non-preferred leg in other parts of training sessions and matches, avoiding negative feedback when the players fail (Velázquez & Jorge, 2012). These behaviors should be a determining factor for consolidating performance improvement with the non-preferred leg and gradually reducing KD to reach a point where players have a good performance with the preferred and non-preferred leg and do not have to resort to safety situations all the time, using the preferred leg, increasing the KD.

Our study has several limitations. The players were part of the youth development programme of a professional soccer team (Real Club Deportivo de la Coruña), that play in the best division of Spain (LFP). Therefore, extrapolation of our findings to other teams and soccer player levels must be done with caution. Furthermore, the subjects were tested during the final month of the competitive season and thus, it remains to be explored whether our findings are consistent throughout the competitive season.

Conclusions

In summary, Kicking Deficit (KD) is a constant element in elite young soccer players, and its values remain stable without significant changes between G-14 and G+14 groups. The unequal and greater use of the preferred leg, compared with the non-preferred one in training sessions and games, is one of the main factors that could affect asymmetric performance of the legs, since it produces a highly specific muscular function for each leg. Furthermore, according to our results, we could suggest that, in young soccer players, kicking skill is not so consolidated and power factors may be determinant for kicking performance. This seems to contrast with data from adult soccer players (Rodríguez-Lorenzo, et al., 2016), where coordination factors play a more important role.

Practical implications

The results of our study stress the need to evaluate in young soccer players their ability to kick with both legs in order to follow up the kicking deficit observed in those players. Therefore, the development of different methodology and protocols to measure the kicking deficit and the nature of this deficit should be of interest for both researchers and coaches.

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Artículo Nº 5

Age-related differences in kicking velocity and kicking deficit in elite soccer players

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Short communication

Age-related differences in kicking velocity and kicking deficit in elite soccer players

ABSTRACT

The ability to achieve high kicking velocities with the preferred and the non-preferred leg is an advantage for soccer players. Thus, improving maximal kicking velocity with each leg is becoming an important goal for strength and conditioning coaches.

This article is unique in providing normative data for the evolution of maximum kicking performance with each leg and Kicking Deficit in elite football players. These findings might help strength and conditioning coaches to prescribe specific training and to monitor the current status of their players.

Keywords: Maximal kicking performance; non-preferred leg; kicking strength training; training factors.

INTRODUCTION

Kicking ability represents the most frequently used and determinant soccer-specific skill (2, 7) since, besides being used in passes, crosses, and clearances, it is also used to score goals and win games.

The performance of soccer kicking depends on the kicked ball velocity and accuracy (8). Although the kicking accuracy can be an important factor to success, the kicking performance in soccer has been evaluated predominantly by maximum ball velocity (6,10). Therefore, assuming that the kick is accurate, the chance of scoring increases with an increased ball velocity as there is less time for the goalkeeper to react (5).

Moreover, achieving maximal kicking performance with both legs leads to an advantage for the soccer player because it provides attacking players with more situations to shoot (19).

However, there is an agreement across studies that ball velocity is significantly higher after a kick with the preferred leg compared with the non-preferred one (2,15,16). Furthermore, there is a Kicking deficit (KD) with the non- preferred leg, that could be defined as the percentage of the difference between the maximal velocity obtained for each player with the non- preferred leg in relation with the preferred leg (21).

Due to this inherent importance, the study of maximal kicking velocity in soccer has raised scientific interest (14,23), resulting in several studies that explore the effects of different strength training in maximal kicking velocity (20). These studies showed that explosive strength training programs, in combination with regular soccer training, can increase ball velocity values in soccer players (4,17,18). For all these reasons, improving maximal kicking velocity with each leg is becoming an important goal for strength and conditioning coaches.

However, the effect of age on kicking performance has not been extensively studied (19). Age has been reported to positively affect maximum kicking velocity (1,9,12), but the age range examined in these studies was limited. Indeed, there is no information in the literature regarding the annual kicking performance development in a wide range of age, and this lack of data is even higher with the non-dominant leg.

Accordingly, the purpose of this study was to examine the evolution of kicking performance with both legs and KD with age, in young elite soccer players, to gather information that may be used for specific training prescription.

METHODS

SUBJECTS

A total of 175 elite male soccer players (aged 8.74–26.39 years) belonging to the Real Club Deportivo de la Coruña youth development programme (from U-9 to U-18), were tested as a part of their athletic training program during the final month of the 2012-2013 competitive season (May, 2013). The players were divided, exactly the way they are matched in training and competition and according to the football federation rules, in eleven age categories from U-9 to U-19, in addition to the club's second team (U-23: between 19 and 23 yearas old) (Table 1). Written informed consent was obtained from the players and their parents. The study was approved by the medical department of Real Club Deportivo de la Coruña (Spain). The experimental procedures of the study were carried out in accordance with the Declaration of Helsinki.

DESIGN AND METHODOLOGY

The experiment was conducted within a single testing session, at an ambient temperature of 16 to 18°C. Four familiarization sessions were conducted where subjects practiced maximal kicking tests, in order to minimize any learning or habituation effects. To avoid inter-observer variability, the same experienced investigator tested all subjects.

The session started with a warm-up consisting of 5 min indoor running at a self-selected pace, a 5 min active stretching protocol, mainly for the lower limbs, 6 submaximal and 2 maximal instep kicks performed with each leg. After warming-up the kick test was demonstrated, followed by 1 practice trial performed with each leg. The following 3 trials with both the preferred and the non-preferred leg were recorded as experimental trials. The trial that produced the highest speed for both the preferred and the non-preferred leg was selected for further analysis. The order of testing was randomized between the preferred and the non-preferred leg. Each subject had at least 1 min of rest between 2 consecutive trials to avoid fatigue.

A modified version of the kick test described by Markovic et al. (11) was used to measure maximal ball velocity. Foot preference was self-selected based on the players response to which foot they preferred to kick with for maximal ball velocity. The participants were instructed to perform an instep kick of a stationary ball of standard size and standard inflation (FIFA, standard) as fast as possible towards the radar gun. To standardize the procedure, the participants were restricted to a 5-step run-up from a position directly behind the ball. They were specifically instructed to focus only on maximum kicking velocity and the trials that missed the entire target area were repeated.

Kicking performance was determined from maximal ball velocity. Velocity, expressed in m/s, was assessed using a stationary Doppler radar gun (Stalker Sport 2, Stalker Radar, Plano, Texas, USA) that can measure speeds between 2.23 $m \cdot s^{-1}$ and 67.04

$m \cdot s^{-1}$ with accuracy of $\pm 0.045\ m \cdot s^{-1}$. The radar gun (operating frequency of 24.125 GHz) was attached to a 0.7 m high stand and positioned behind a net, approximately 5 m from the starting position of the ball. The size of the net was sufficient to cover all kicks that deviated less than 15° from the direction of the radar gun (11). The radar gun was always calibrated immediately before the sessions according to the instructions given in the user's manual.

STATISTICAL ANALYSIS

The trial with the highest ball velocity was selected as the kicking performance measure for the preferred and for the non-preferred leg. Kicking deficit (KD) variable was calculated according to the following formula (21):

$$KD = \left(\frac{KVdomMax - KVnodomMax}{KVdomMax}\right) \cdot 100$$

where *KVdomMax* and *KVnodommax* are the maximal velocities achieved with the preferred and non-preferred leg, respectively.

Normal distribution of the variables was confirmed using the Shapiro-Wilk W-test, whereas the homogeneity of the variance was verified using the Levene test. We conducted an ANOVA of repeated measurements with one intrasubject factor (leg) and one intersubject factor (age-group) over maximal kicking velocity. In case of significant interactions, we conducted post-hoc analysis post-hoc analysis with Bonferroni corrections for the tracing of differences among age groups and between legs respectively. Effect size was evaluated with η2 (partial eta-squared). One-way analysis of variance (ANOVA) was used to evaluate age group differences in Kicking Deficit. The Tukey post-hoc test was used to specify where significant differences lay. All statistical analyses were performed using SPSS version 21 (SPSS, Chicago, IL). Statistical significance was set at $p < 0.05$.

Table 1. Mean and standard desviations of kicking performance and kicking deficit. Significant differences be-tween age groups

Group	Age	Kicking Performance		KD (%)
		KVdomMax (km/h)	Kvnodommax (km/h)	
U-9 (n=12)	9.13 ± 0.23	69.92 ± 4.15 [a]	57.74 ± 4.54 [b]	17.26 ± 6.68*
U-10 (n=12)	10.14 ± 0.26	71.72 ± 4.13 [b]	63.62 ± 4.34 [c]	11.14 ± 6.23*
U-11 (n=15)	11.08 ± 0.21	74.29 ± 4.56 [b]	64.30 ± 7.34 [c]	13.36 ± 9.48*
U-12 (n=15)	12.00 ± 0.28	79.02 ± 3.98 [d]	64.56 ± 2.77 [c]	18.18 ± 3.73*
U-13 (n=15)	13.05 ± 0.22	82.49 ± 4.47 [e]	70.23 ± 1.81 [d]	14.79 ± 7.44*
U-14 (n=19)	14.04 ± 0.32	92.65 ± 7.06 [f]	80.15 ± 8.45 [g]	13.27 ± 9.18*
U-15 (n=16)	15.12 ± 0.25	100.42 ± 7.10 [f]	82.44 ± 10.29 [h]	18.08 ± 6.52*
U-16 (n=15)	16.21 ± 0.13	108.33 ± 6.53 [i]	90.77 ± 6.33 [j]	16.18 ± 3.64*
U-17 (n=13)	17.11 ± 0.26	106.43 ± 5.65 [i]	90.66 ± 9.07 [j]	14.71 ± 5.42*
U-18 (n=12)	17.91 ± 0.23	107.32 ± 7.99 [i]	95.30 ± 8.29 [i]	11.02 ± 6.91*
U-19 (n=11)	18.98 ± 0.30	107.98 ±5.70 [i]	97.57 ± 2.66 [i]	9.43 ± 4.97*
U-23 (n=20)	22.11 ± 1.89	114.74 ± 6.12 [i]	100.43 ± 5.11[k]	12.40 ± 3.25*

Note. KVdomMax = Maximal kicking velocity with the dominant leg; KVnodommax = Maximal kicking velocity with the non-dominant leg; KD = Kicking Deficit.

Significantly different ($p < 0.01$) from: [a] U-12 to U-23; [b] U-13 to U-23; [c] U-14 to U-23; [d] U-9 and U-14 to U-23; [e] U-9 to U-11 and U-14 to U-23; [f] any other group; [g] U-9 to U-13 and U-16 to U-23; [h] U-9 to U-13 and U-18 to U-23; [i] U-9 to U-15; [j] U-9 to U-14 and U-19 to U-23; [k] U-9 to U-17;

* Nonsignificant.

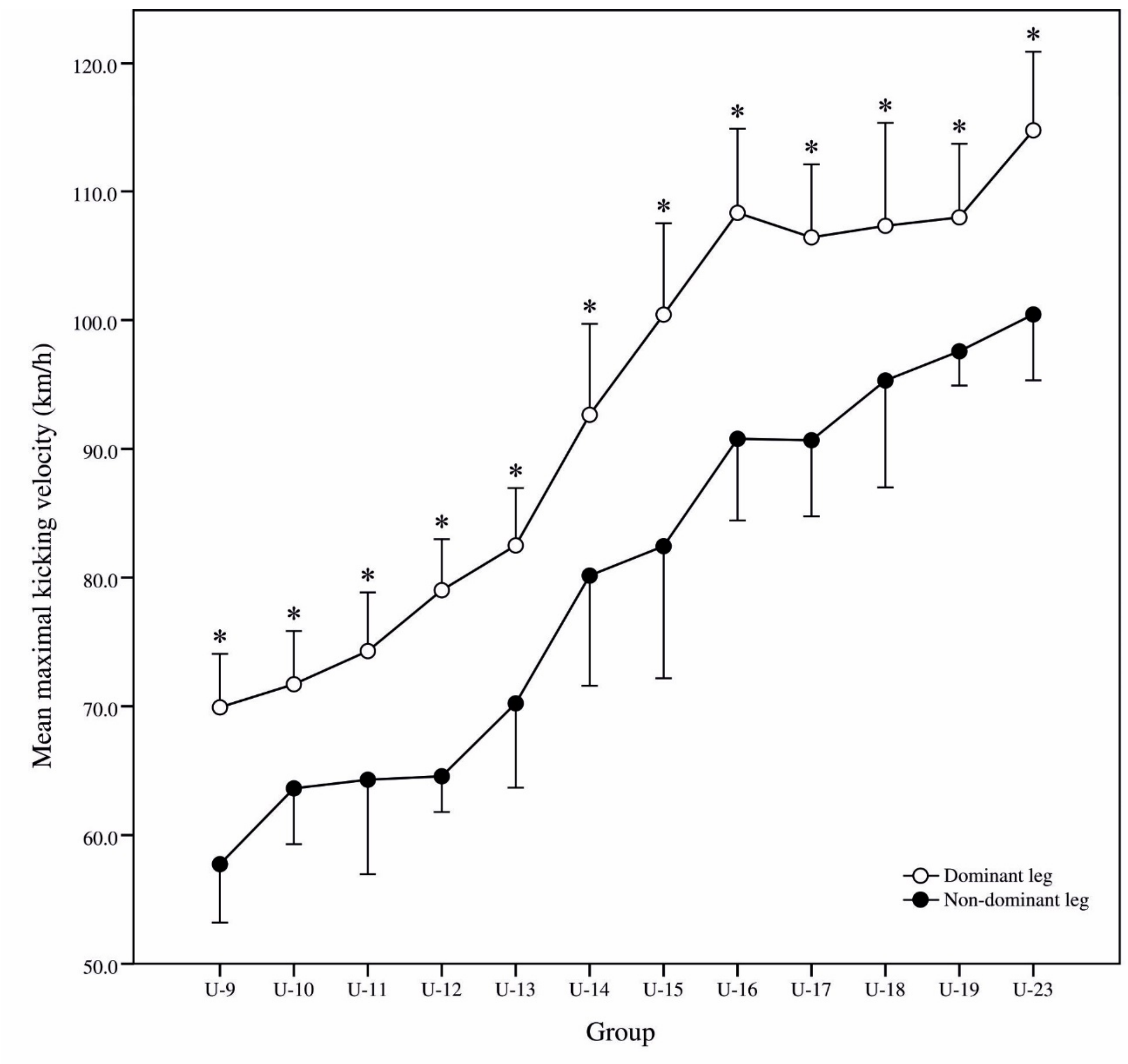

Figure 1. Mean maximal kicking velocity for the preferred and non- preferred leg of different age groups

RESULTS

The mean (+ SD) data for maximal kicking performance with both legs, and KD are presented in Table 1. The Anova of repeated measurements showed a main effect of Leg (F = 579.495, P = .000, η2 = 0.82) and Age-group (F = 81.56, P = .001, η2 = 0.85) over maximal kicking velocity. There was a significant Leg*Age-group interaction (F = 3.55, P = .000, η2 = 0.21). As can be seen in Table 1, post-hoc analysis revealed significant differences between age groups in maximal kicking performance. However, there were no significant differences in maximal kicking velocity with the preferred leg among U-16, U-17, U-18, U-19 and U-23 groups. There were no significant differences in maximal kicking velocity with the non- preferred leg among U-18, U-19 and U-23 groups. Finally, there were no significant differences in KD among age groups.

Regarding the kicking performance between legs, maximal kicking velocity was significantly higher with the preferred leg in all age-groups (Figure 1).

DISCUSSION

As far as we are aware, this is the first study to thoroughly investigate the evolution of kicking performance and KD, in a wide range of age, in elite soccer players. Our main finding was that maximal kicking velocity with the preferred leg improved progressively from the U-9 to U-16 age groups, whereas moderate but non-statistically significant improvements were observed between age groups from U-16 to U-23. However, with the preferred leg maximal kicking velocity continued to improve until U-18 group. In addition, another important finding was that this is the first study that reveals the stability of Kicking Deficit (KD) among ages in elite soccer players.

Kicking, like many of the skills in football, has been shown to develop from an early age. Bloomfield, Elliott, and Davies (3) points out that kicking ability develops rapidly between the ages of 4 and 6 years and at the mean age of 11.2 years a mature kicking pattern is achieved by 80% of the children. Nonetheless, ball velocity increments associated with age are likely not only due to skill development of the kicking pattern but also due to the increased body size and muscle strength associated with growth and maturation (19). This is supported by the observation that the greatest improvements in kicking performance, in our study, occurred from U-13 to U-16 age groups, where the most marked changes associated with growth and maturation occurred (10). Our findings are consistent with Luhtanen (9), who also reported a positive effect of age on kicking performance with the preferred leg between U-10 and U-17 years old, and with

Bacvarevic et al. (1), who also reported a positive effect of age on kicking performance with both legs between U-12 and U-15 years old. The recent study of Marques et al. (12) demonstrated that maximum kicking velocity with the preferred leg increased across U14, U16 age categories in youth elite soccer players, but no significant differences were found among U16 to U18 age groups. Our results confirm that no significant effect of age was found between U16 to U18. However, one unanticipated finding was that kicking velocity of U-16 players, did not differ from that of U-23 players, indicating that at the mean age of 16.21 years a mature kicking performance is achieved. Nevertheless, with the non-preferred leg a mature kicking performance is not achieved up to the mean age of 17.91 years.

Regarding the results that compare maximum kicking performance between legs, we found that ball velocity is significantly faster after a kick with the preferred leg compared with the non-preferred one in all age groups, and confirmed that KD is a constant element in elite soccer players. These results are consistent with those of a great deal of the previous work in this field with different kinds of sample (2,16) and different techniques and kick conditions (1,13,15). However, this is the first study that reveals the stability of Kicking Deficit (KD) among ages, with values between 9.43 % and 18.18%, without significant changes among players from U-8 to U-23 categories. Nonetheless, maximum KD was reached in U-12 and U-15 age groups, chiefly due to a stagnation in KD with the non- preferred leg (Figure 1).

From a practical perspective, Kicking Deficit (KD) may be a useful index to evaluate the individual capacity of each player to perform at similar levels with both legs. Therefore, the outcomes from the current study may constitute a rough guideline for strength and conditioning coaches to monitor and to assess the current status and progress of their players.

Nevertheless, our work has presents some limitations. These results can only be applied to male populations of similar characteristics. The use of these reference values in women's soccer is not appropriate since it has been reported that maximal kicking velocity in females is significantly lower than males (2,22).

CONCLUSION

In summary, this study describes the cross-sectional evolution of kicking ability with both legs in elite male youth soccer players. Our results show that KD stays steady without significant changes among ages. Moreover, maximal kicking velocity improves with age, markedly from U-11 to U-15, and much more slowly thereafter. Further longitudinal studies and across the sexes are required for a better understanding of the effect of age on maximal kicking velocity.

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ANEXOS

ANEXO A

Consentimiento informado

R.C. Deportivo de La Coruña S.A.D. | Plaza de Pontevedra 19, 1º. 15003 A Coruña Teléf: 981 259 500 Fax: 981 265 919 www.canaldeportivo.com

Asunto: autorización prueba de valoración edad biológica

Estimados padres:

Dentro del programa de valoración morfo-funcional que se está desarrollando en nuestros equipos de categorías de base, y con el fin de mejorar el proceso de entrenamiento de nuestros jugadores de las categorías alevín, infantil, cadete y juvenil, se procederá realizar una valoración antropométrica.

Por ello, solicitamos autorización para que los servicios médicos del club realicen esta valoración o bien comuniquéis a los responsables que vuestro hijo no desea participar en las pruebas.

Esta valoración se realizará mediante observación directa y sin registro de imágenes.

Miguel Gamallo Ponte
Coordinador del fútbol Base del R.C. Deportivo de La Coruña S.A.D

AUTORIACIÓN

Yo don/doña:…………………………………………………………………………. con DNI:…………………… como madre/padre/tutor del jugador ………………………………………………………., AUTORIZO a que los servicios médicos del club realicen la prueba de valoración antropométrica.

Fecha:…………………….

Firma:………………………

Todos estos datos serán tratados con arreglo a la Ley *Orgánica 15/1999 de 13 de diciembre de* Protección de Datos *de Carácter Personal, (LOPD)*

ANEXO B

Protocolos de Calentamiento

Tabla 1. Protocolo de calentamiento A

PROTOCOLO de Calentamiento A Día 1	
Actividad	**Cantidad**
Carrera continua	5'
Estiramientos dinámicos activos (con rebotes)	
Cuádriceps	2 series de 4 repeticiones con cada pierna
Isquiotibiales	
Aductores	
Psoas	
Gemelos	
Glúteos	
Saltos	
SJ submáximos	2 repeticiones
CMS submáximos	2 repeticiones

Tabla 2. Protocolo de calentamiento B

PROTOCOLO de Calentamiento B Día 2	
Actividad	**Cantidad**
Carrera continua	5'
Estiramientos dinámicos activos (con rebotes)	
Cuádriceps	2 series de 4 repeticiones con cada pierna
Isquiotibiales	
Aductores	
Psoas	
Gemelos	
Glúteos	
Golpeos de Balón	
Golpeo submáximos pierna dominante	6 repeticiones
Golpeo submáximos pierna no dominante	6 repeticiones
Golpeo pierna dominante	2 repeticiones
Golpeo pierna no dominante	2 repeticiones

ANEXO C

Test de salto vertical

Squat Jump (SJ)

Posición de partida:

- Los sujetos se situarán sobre la plataforma en una posición de **media sentadilla** *(ángulo de entre 90˚ - 120˚ en la articulación de la rodilla.*
- **Pies** colocados a la *misma altura* y separados aproximadamente como *la anchura de las caderas y hombros***.**
- **Planta de los pies** totalmente en contacto con la plataforma (*talones apoyados*).
- **Tronco** erguido y **manos** agarrando la cintura, **vista** en el horizonte cercano.

Desarrollo del salto:

- Mantener la posición de partida **2-3 segundos** *(para eliminar cualquier influencia de la energía elástica acumulada durante el descenso en los componentes músculo-tendinosos).*
- Realizar un salto vertical lo más alto posible **sin** efectuar ningún tipo de **contramovimiento**.
- Mantener la verticalidad del tronco, fijar la **vista** en el horizonte próximo.
- Mantener la posición inicial de las manos

Recepción:

- El sujeto deberá tomar contacto con las **puntas de los pies**.
- **Rodillas** extendidas y **tobillos** en flexión plantar *(sugerir al individuo que efectúe una serie de pequeños saltos sobre las puntas de los pies después del aterrizaje).*
- Mantener la posición inicial de las manos.

Poner especial atención:

- El salto no será considerado válido si se percibe contramovimiento *(ya que implicaría mecanismos neuromusculares diferentes a los que se pretenden valorar)*.
- El salto debe ser lo más vertical posible (*ya que cualquier modificación en la trayectoria del centro de gravedad implicaría un incremento del tiempo de vuelo).*
- Aterrizar con las articulaciones de rodilla y tobillos completamente extendidas (*mismo motivo que la anterior).*

Tabla 3. Criterios para considerar la realización de un SJ como correctos

*Criterios para considerar la realización de un **SJ** como correctos*		
Fase	**Nº**	**Criterios establecidos como correctos**
Posición de partida	1	Estar localizados, aproximadamente, en el centro de la plataforma.
	2	Planta de los pies totalmente en contacto con la plataforma (*Talones apoyados*)
	3	Pies paralelos con una distancia equivalente a la anchura de hombros: Buen equilibrio.
	4	Flexión de rodillas de entre 90˚-180˚ (después de ajuste individual del propio sujeto).
	5	Mantener el tronco lo más vertical posible.
	6	Cabeza arriba. Mirar al horizonte cercano.
	7	Manos agarrando la cintura.
	8	Mantener la posición inicial durante 2-3 s.
Fase de acción	9	Iniciar la impulsión: Salto vertical sin contramovimiento.
	10	Despegar con los metatarsos (de puntillas).
Fase de vuelo	11	Mantener el tronco en posición vertical y la vista en el horizonte próximo.
	12	Mantener la posición inicial de las manos.
	13	Caderas, rodillas y tobillos completamente extendidos y alineados durante las fases de subida y bajada.
Fase de aterrizaje	14	Mantener el tronco en posición vertical y vista en el horizonte próximo.
	15	Mantener la posición inicial de las manos.
	16	El ángulo de las rodillas sobre 180˚ en el momento de contactar con el suelo.
	17	Tobillos extendidos. Contactar primero con el metatarso.
	18	Rebota con la punta de los dedos después del primer contacto en la plataforma.
	19	Se debe aterrizar en los mismos puntos del despegue, (sin desviaciones del centro de gravedad)

Counter Movement Jump (CMJ)

Posición de partida:

- Los sujetos se situarán sobre la plataforma en una posición de **bipedestación** *(rodillas extendidas).*
- **Pies** colocados a la misma altura y separados aproximadamente como la anchura de las caderas y hombros.
- **Planta de los pies** totalmente en contacto con la plataforma (*talones apoyados*).
- **Tronco** erguido y **manos** agarrando la cintura, vista en el horizonte cercano.

Desarrollo del salto:

- Mantener la posición de partida **2-3 segundos.**
- Bajar rápidamente a una posición de aproximadamente media sentadilla, con un ángulo de entre 90˚ y 120˚ en la articulación de las rodillas, y sin parar, realizar un salto vertical lo más alto posible.
- Mantener la verticalidad del tronco, fijar la **vista** en el horizonte próximo.
- Mantener la posición inicial de las manos.

Recepción:

- El sujeto deberá tomar contacto con las **puntas de los pies**.
- **Rodillas** extendidas y **tobillos** en flexión plantar *(sugerir al individuo que efectúe una serie de pequeños saltos sobre las puntas de los pies después del aterrizaje).*
- Mantener la posición inicial de las manos.

Poner especial atención:

- El salto no será considerado válido si se percibe contramovimiento *(ya que implicaría mecanismos neuromusculares diferentes a los que se pretenden valorar)*.
- El salto debe ser lo más vertical posible (*ya que cualquier modificación en la trayectoria del centro de gravedad implicaría un incremento del tiempo de vuelo).*
- Aterrizar con las articulaciones de rodilla y tobillos completamente extendidas (*mismo motivo que la anterior).*

Tabla 4. Criterios para considerar la realización de un CMJ como correctos

*Criterios para considerar la realización de un **CMJ** como correctos*		
Fase	**Nº**	**Criterios establecidos como correctos**
Posición de partida	1	Estar localizados, aproximadamente, en el **centro** de la plataforma.
	2	**Planta de los pies** totalmente en contacto con la plataforma (*Talones apoyados*).
	3	**Pies** paralelos con una distancia equivalente a la anchura de hombros: Buen equilibrio.
	4	**Rodillas** lo más rectas posibles (180˚ aproximadamente).
	5	Mantener el **tronco** lo más vertical posible.
	6	Cabeza arriba. Mirar al horizonte cercano.
	7	**Manos** agarrando la cintura.
	8	Mantener la posición inicial durante 2-3 s.
Fase de acción	9	Descender rápidamente: rápida flexión de rodillas hasta alcanzar un ángulo de entre 90 y 120˚ en la articulación de las rodillas.
	10	**Sin parar,** iniciar la fase concéntrica: **Salto vertical lo más alto posible.**
	10	Despegar con los metatarsos (de puntillas).
Fase de vuelo	11	Mantener el tronco en posición vertical y la vista en el horizonte próximo.
	12	Mantener la posición inicial de las manos.
	13	Caderas, rodillas y tobillos completamente extendidos y alineados durante las fases de subida y bajada.
Fase de aterrizaje	14	Mantener el tronco en posición vertical y vista en el horizonte próximo.
	15	Mantener la posición inicial de las manos.
	16	El ángulo de las rodillas sobre 180˚ en el momento de contactar con el suelo (rodillas extendidas).
	17	Tobillos extendidos. Contactar primero con el metatarso.
	18	**Rebota con la punta de los dedos después del primer contacto en la plataforma.**
	19	Se debe aterrizar en los mismos puntos del despegue, (sin desviaciones del centro de gravedad)

Counter Movement Jump with arm swing (CMJA)

Posición de partida:

- Los sujetos se situarán sobre la plataforma en una posición de **bipedestación** *(rodillas extendidas).*
- **Pies** paralelos colocados a la *misma altura* y separados aproximadamente como *la anchura de las caderas y hombros***.**
- **Planta de los pies** totalmente en contacto con la plataforma (*talones apoyados*).
- **Tronco** erguido y **brazos** en cruz con las palmas hacia abajo (*codos extendidos*).
- **Mirada** horizonte cercano.

Desarrollo del salto:

- Mantener la posición de partida **2-3 segundos**.
- Bajar rápidamente a una posición de casi media sentadilla, ángulo de las rodillas 90-120˚, a medida que bajamos los **brazos**, *(hasta que queden totalmente extendidos paralelos al tronco)* con los **codos** extendidos.
- y sin parar, realizar un salto vertical lo más alto posible*, (a medida que realizamos una flexión de hombros y codos).*
- Despegar con el metatarso *(de puntillas).*

Fase de vuelo:

- Mantener la verticalidad del tronco, fijar la **vista** en el horizonte próximo.
- Los hombros se bloquean en un ángulo recto y los codos se flexionan 90˚ quedando las palmas de las manos mirando hacia la cara.
- Rodillas, caderas y tobillos completamente extendidas.

Recepción:

- **Mantener la flexión de los codos,** comprobando que las **manos** se mantienen **al nivel de la cara** durante la bajada.
- El sujeto deberá tomar contacto con las **puntas de los pies**.
- **Rodillas** extendidas y **tobillos** en flexión plantar *(sugerir al individuo que efectúe una serie de pequeños saltos sobre las puntas de los pies después del aterrizaje).*

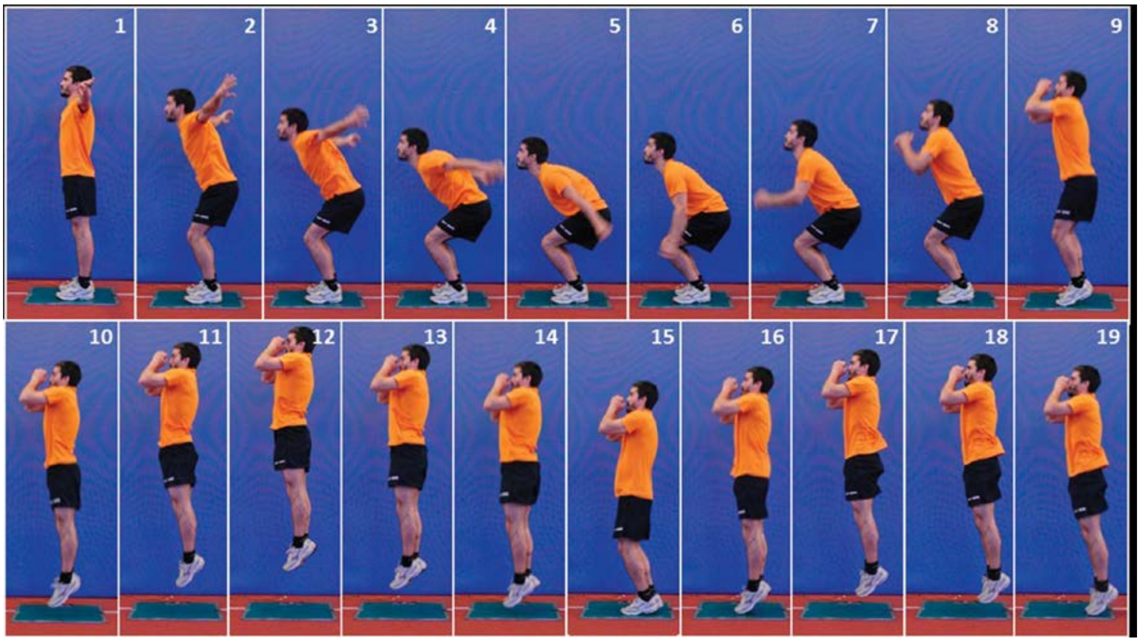
Poner especial atención:

- El salto debe ser lo más vertical posible (*ya que cualquier modificación en la trayectoria del centro de gravedad implicaría un incremento del tiempo de vuelo).*
- Aterrizar con las articulaciones de rodilla y tobillos completamente extendidas (*mismo motivo que la anterior).*

Tabla 5. Criterios para considerar la realización de un CMJA como correctos

*Criterios para considerar la realización de un **CMJA** como correctos (Acero et al., 2012)*		
Fase	**Nº**	**Criterios establecidos como correctos**
Posición de partida (1)	1	Estar localizados, aproximadamente, en el **centro** de la plataforma.
	2	**Planta de los pies** totalmente en contacto con la plataforma (*Talones apoyados*).
	3	Pies paralelos con una distancia equivalente a la anchura de hombros: Buen equilibrio.
	4	**Rodillas** lo más rectas posibles (180˚ aproximadamente).
	5	Mantener el **tronco** lo más vertical posible.
	6	Cabeza arriba. Mirar al horizonte cercano.
	7	**Brazos** extendidos horizontalmente en forma de cruz.
	8	**Palmas** de las manos hacia abajo y hacia atrás (en ligera pronación) a la altura de los hombros, sin balanceo.
	9	Mantener la posición inicial durante 2-3 s.
Fase de acción (2-9)	**10**	**Descender rápidamente:** rápida flexión de rodillas hasta alcanzar un ángulo de entre 90 y 120˚ (2-5).
	11	Realizar una circunducción de hombros durante la fase de descenso del cuerpo (2-4).
	12	Codo en extensión durante toda la fase de descenso del cuerpo(2-6).
	13	**La mayor flexión de las rodillas coincide con la posición más baja de las manos (6).**
	14	**Sin parar,** iniciar la fase concéntrica**: Salto vertical con una simultanea flexión de hombros y codos (7-9).**
	15	Los brazos y antebrazos salen lanzados hacia arriba y hacia delante.
	16	Despegar con los metatarsos (de puntillas) (9).
Fase de vuelo (10-14)	17	Mantener el tronco en posición vertical y vista en el horizonte próximo
	18	**Hombros** se bloquean en 90˚, y **los codos se flexionan en 90 ˚ cuando la altura máxima de salto ha sido alcanzada (12)**. *(Quedando las **manos** delante de la cara).*
	19	Caderas, rodillas y tobillos completamente extendidos y alineados durante las fases de subida y bajada.
	20	**Mantener la flexión de los codos,** comprobando que las manos se mantienen al nivel de la cara durante la bajada.
Fase de aterrizaje (15-19)	21	Mantener el tronco en posición vertical y vista en el horizonte próximo
	22	El ángulo de las rodillas sobre 180˚ en el momento de contactar con el suelo.
	23	Tobillos extendidos. Contactar primero con el metatarso.
	24	**Rebota con la punta de los dedos** después del primer contacto en la plataforma.
	25	Se debe aterrizar en los mismos puntos del despegue, (sin desviaciones del centro de gravedad)

Secuencia de imágenes de CMJA realizado correctamente



Reaction Jump with arm swing (1RJA)

Posición de partida:

- Los sujetos se situarán sobre la plataforma en una posición de **bipedestación** *(rodillas extendidas).*
- **Pies** paralelos colocados a la *misma altura* y separados aproximadamente como *la anchura de las caderas y hombros***.**
- **Planta de los pies** totalmente en contacto con la plataforma (*talones apoyados*).
- **Tronco** erguido y **brazos** en cruz con las palmas hacia abajo (*codos extendidos*).
- **Mirada** horizonte cercano.

Primeros saltos progresivos:

- Mantener la posición de partida **2-3 segundos**.
- Realizar 2 o 3 pequeños saltos progresivos, con las rodillas rectas y coordinándolos con el balanceo de los brazos (*en realidad existe una pequeña flexión en las rodillas, pero la idea, es comunicar al ejecutante la realización de saltos reactivos*).
- Continuar saltando durante 5-6 segundos hasta realizar 2 o 3 saltos alcanzando la máxima altura posible.
- *Después de cada uno de los saltos, el aterrizaje es con los pies y las rodillas extendidos, la misma posición que durante el despegue. (esta extensión ayuda a reducir el tiempo de contacto, y por lo tanto, facilita la participación de la vía refleja y el aumento de la rigidez)*
- Mantener la verticalidad del tronco, fijar la **vista** en el horizonte próximo.

Realización del salto

- De todos los saltos anteriores el que vamos a medir es este, seguimos la misma dinámica que los anteriores, aterrizando y despegando con las caderas, rodillas y tobillos lo más extendidos posibles.
- Despegamos lanzando los brazos hacia arriba *(coincidiendo con la máxima altura los hombros formarán un ángulo recto y los codos se flexionan 90, con el descenso se realiza una circunducción hasta que se vuelven a extender paralelos al tronco y detrás del plano frontal del mismo).*

Recepción:

- El sujeto deberá tomar contacto con las **puntas de los pies**.
- **Rodillas** extendidas y **tobillos** en flexión plantar.
- Realizar otro salto igual que el anterior.

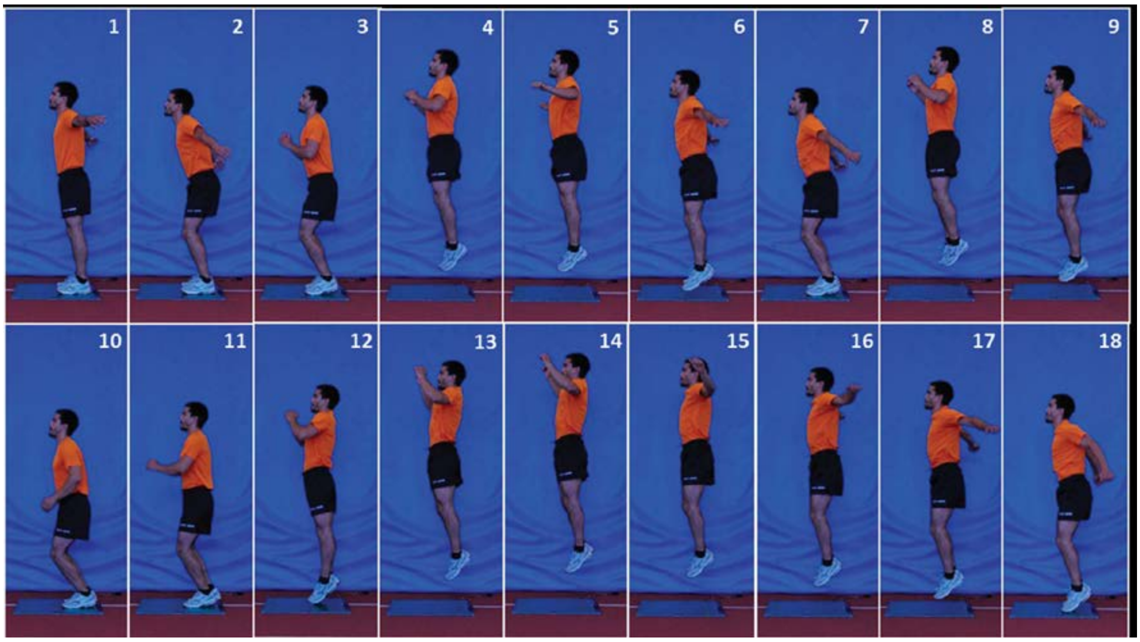
Poner especial atención:

- El salto debe ser lo más vertical posible (*ya que cualquier modificación en la trayectoria del centro de gravedad implicaría un incremento del tiempo de vuelo).*
- El salto más alto con el tiempo de contacto de entre 249 milisegundos y 119 milisegundos será seleccionado para el análisis.

Tabla 6. Criterios para considerar la realización de un 1RJA como correctos

*Criterios para considerar la realización de un **1RJA** como correctos (Acero et al., 2012)*		
Fase	**Nº**	**Criterios establecidos como correctos**
Posición de partida (1)	1	Estar localizados, aproximadamente, en el **centro** de la plataforma.
	2	**Planta de los pies** totalmente en contacto con la plataforma (*Talones apoyados*).
	3	Pies paralelos con una distancia equivalente a la anchura de hombros: Buen equilibrio.
	4	**Rodillas** lo más rectas posibles (180˚ aproximadamente).
	5	Mantener el **tronco** lo más vertical posible.
	6	Cabeza arriba. Mirar al horizonte cercano.
	7	**Brazos** extendidos horizontalmente en forma de cruz.
	8	**Palmas** de las manos hacia abajo y hacia atrás (en ligera pronación) a la altura de los hombros, sin balanceo.
	9	Mantener la posición inicial durante 2-3 s.
Primeros saltos progresivos (2-9)	3	Coordinar 2-3 pequeños saltos con el movimiento de brazos
	4	Las rodillas deben estar los más rectas posibles durante las fases de impulso, vuelo y aterrizaje en el transcurso de los repetidos saltos.
	5	La altura durante los progresivos saltos
Últimos saltos progresivos (10-18)		
Información general	7	Realizar saltos repetidos durante 5-6s hasta alcanzar 2 o 3 saltos a máxima altura.
	8	Mantener el tronco recto durante todas las fases.
	9	Aterrizar con los pies paralelos y un buen equilibrio (10).
Fase de acción (13-17)	10	Brazos y antebrazos son lanzados hacia arriba (10-11).
	11	Contactar con los metatarso y las rodillas tan estiradas como sea posible (12).
Fase de vuelo (13-17)	12	Articulaciones de cadera, rodillas y tobillos completamente extendidas (12-17).
	13	Hombros a 90˚ y los codos flexionados durante la fase de subida de cada salto. Referencias: ver las manos delante de la cara.
	14	Realizar una circunducción hacia atrás de los hombros, después del comienzo del descenso del cuerpo.
	15	El movimiento hacia debajo de los brazos debe ser simétrico para evitar el balanceo del cuerpo (14-17).
	16	Los brazos deben situarse detrás del plano frontal del cuerpo durante la fase de descenso (15-17).
Fase de aterrizaje (18)	17	El ángulo de las rodillas debe estar sobre 180˚ (rodillas extendidas).
	18	Pies en extensión.
	19	Aterrizar con los metatarsos.
	20	Caderas, rodillas y tobillos extendidos.
	21	Brazos tensos todavía detrás del plano frontal del cuerpo.
Empezar un nuevo vuelo	22	Empezar el movimiento de brazos hacia arriba.
	23	Las extremidades inferiores suavizan ligeramente el aterrizaje.
	24	Breve tiempo de contacto entre saltos (Límites: entre 249 y 119ms).
	25	Repetir las fases de acción, vuelo y aterrizaje.

Secuencia de imágenes de 1RJA realizado correctamente



ANEXO D

Test de golpeo máximo

Se trata de una prueba que tiene por objetivo medir la velocidad máxima del balón, tras un golpeo máximo. Para ello utilizaremos una versión modificada del protocolo descrito por Markovic et al. (2006). En ella se considera tanto la elección del sujeto como pierna dominante, así como la diferencia de rendimiento entre la pierna dominante y no dominante. Su desarrollo implica los siguientes factores:

Material

- Radar (Stalker Sport 2, Stalker Radar, Plano, Texas, USA).
- Balón
- Portería de fútbol 11 en un campo de hierba artificial.

Se realizan dos marcas delante y detrás de la portería a una distancia de cinco metros una de la otra, de forma que la línea imaginaría que uniría estos dos puntos pase por el centro de la portería. En la marca detrás de la portería se coloca la pistola de Radar, elevándolo mediante un trípode a una altura de 0.7m sobre el suelo y enfocando hacia la portería.

La marca situada delante de la portería la utilizaremos para colocar el balón. Se utilizará un campo de hierba artificial para no estropear la zona de golpeo y que garantizar que todos los sujetos realicen la prueba en igualdad de condiciones.

Con el objetivo de proteger la pistola de radar es importante comprobar el estado de la red antes de cada sesión de registro. Además, si la red está muy suelta se deberá fijar al suelo para evitar que tras el impacto, el balón alcance la pistola de radar.

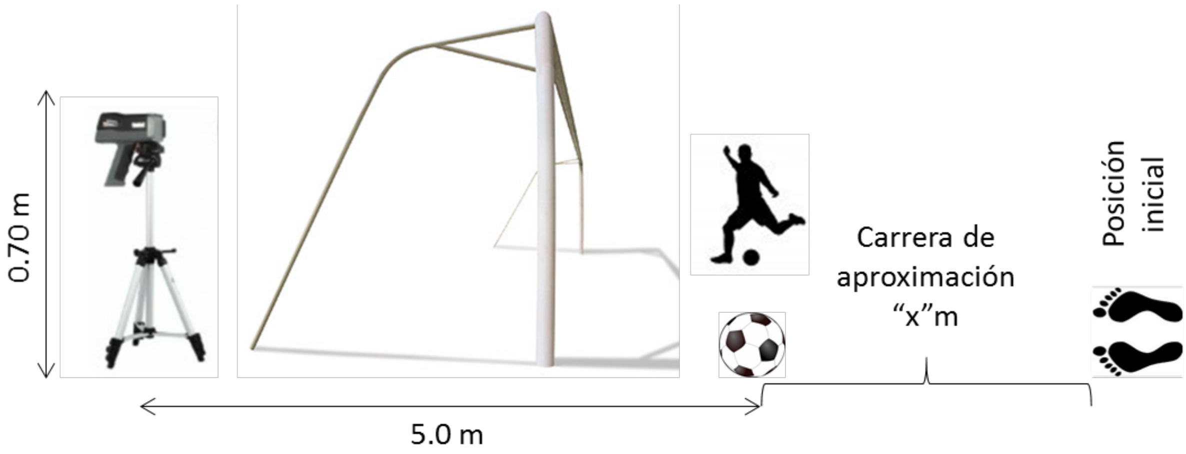


Figura 1. Test de golpeo de balón

Test de golpeo máximo

Posición Inicial

El ejecutante debe colocar el balón en la marca situada a 5m del radar, y escoger una la distancia mediante la cual el sujeto realizará su carrera de aproximación (esta distancia la determina cada jugador y puede variar de un intento a otro). Una vez determinada el sujeto se colocará con los pies paralelos (ver figura 1).

Desarrollo

El sujeto deberá realizar un golpeo máximo en dirección al radar con la superficie del empeine total, sin preocuparse de la precisión focalizando la atención en golpear con la intención de alcanzar la velocidad máxima de golpeo, pudiendo repetir el golpeo si sale fuera de la portería.

La carrera de aproximación estará compuesta por 4 pasos, realizando el primer el primer apoyo con la pierna que va a golpear el balón, y golpeando el balón justo después del cuarto apoyo.

Finalización

La prueba se daba por buena si el sujeto golpeaba el balón por dentro de la portería cumpliendo correctamente los pasos establecidos en la carrera de aproximación. En caso contrario el intento será repetido.

Instrucciones al ejecutante

A cada uno de los evaluados se le indicó: "Debes realizar un golpeo de balón con el empeine total, hacia el radar situado detrás de la portería, con la intención de alcanzar la máxima velocidad de balón posible. Antes de golpear el balón tienes que partir de una posición con los pies paralelos, dar 4 pasos empezando con la pierna con la que vas a golpear y golpear después del 4º apoyo. Tienes tres intentos con cada pierna".

Anotación

En cada ejecución se anotará el pie de golpeo y la velocidad máxima alcanzada por el balón en cada una de las ejecuciones. Se llevarán a cabo 3 intentos válidos con cada pierna.

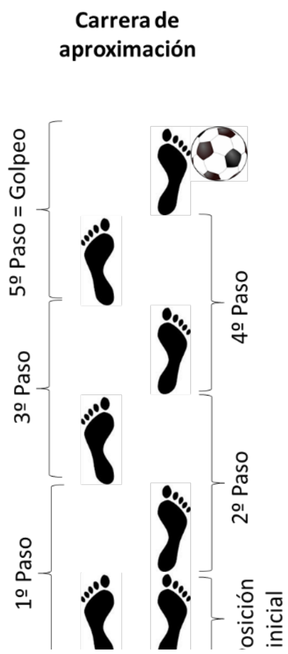


Figura 2. Carrera de aproximación (Test de golpeo de balón)

ANEXO E

Cuestionario de valoración de antecedentes deportivos

NOMBRE: APELLIDOS:

EQUIPO ACTUAL: FECHA NACIMIENTO:

Normas para cubrir el cuestionario

Tu colaboración en la realización de este cuestionario es muy importante dado que los resultados obtenidos representarán y generarán un soporte científico de gran valía para conocer mejor el fútbol y tus posibilidades de mejora dentro de esta especialidad deportiva y de nuestro club.

Las preguntas están agrupadas en 4 bloques: fútbol, otros deportes, lesiones y preferencia funcional. Toda la información que se recoge en este cuestionario y en las demás pruebas de esta evaluación es confidencial y está protegida en cumplimiento de la normativa vigente.

Por favor, lee atentamente las siguientes recomendaciones:

- El cuestionario debe ser cubierto de forma totalmente individual.
- Todas las preguntas son de contestación única, en aquellas que puedas escoger más de una opción se indica en dicha pregunta.
- La respuesta elegida se marca con una “X” en el cuadro que correspondiente.
- En las preguntas en las que tengas que escribir se indicará previamente.
- Si tienes alguna duda sobre alguna cuestión solicita ayuda alguno de los técnicos presentes.

Muchas gracias por tu colaboración

FÚTBOL

1.- Indica, marcando con una “x”, en que categoría estabas cuando jugaste por primera vez en un equipo de forma federada (pregunta a tu entrenador si no lo tienes claro).

Benjamín			Alevín		Infantil		Cadete		Juvenil		
1º	2º	3º	1º	2º	1º	2º	1º	2º	1º	2º	3º

2.- Indica, marcando con una “x”, en que categoría estabas cuando jugaste tu primera temporada con el R.C Deportivo de la Coruña

Benjamín			Alevín		Infantil		Cadete		Juvenil		
1º	2º	3º	1º	2º	1º	2º	1º	2º	1º	2º	3º

3.- Indica, marcando con una “x”, la posición en la que más te ha utilizado tu entrenador durante este último año.

Portero	Central	Lateral	Medio	Extremo	Delantero

4.- Indica, marcando con una “x”, las categorías en las que has entrenado durante todo el año con un club de categoría superior *(Si eras cadete de 1º y entrenaste todo el año con el Cadete A, marcas con una X la casilla Cadete 2º).*

Benjamín			Alevín		Infantil		Cadete		Juvenil		
1º	2º	3º	1º	2º	1º	2º	1º	2º	1º	2º	3º

5.- Indica, marcando con una “x”, las categorías en las que has jugado al menos 10 partidos con un club de categoría superior *(Si eras cadete de 1º y jugaste 10 partidos con el Cadete A, marcas con una X la casilla Cadete 2º).*

Benjamín			Alevín		Infantil		Cadete		Juvenil		
1º	2º	3º	1º	2º	1º	2º	1º	2º	1º	2º	3º

6.- Has ido alguna vez seleccionado con la selección de tu ciudad (selección coruñesa, selección ferrolana)

Si □ No □

(En caso afirmativo)

6.1.- Indica, marcando con una “X” las categorías en las que has sido convocado por la selección de tu ciudad, *(entiéndase por convocatoria si te han llamado a lo largo de la temporada para asistir, al menos una vez, a unas jornadas de entrenamiento, a un partido o a una competición)*:

Observa el siguiente ejemplo:

Benjamín			Alevín		Infantil		Cadete		Juvenil		
1º	2º	3º	1º	2º	1º	2º	**X**	**X**	**X**	2º	3º

Benjamín			Alevín		Infantil		Cadete		Juvenil		
1º	2º	3º	1º	2º	1º	2º	1º	2º	1º	2º	3º

7.- Has ido alguna vez seleccionado con la selección de tu comunidad autónoma (selección gallega, cántabra)

Si □ No □

(En caso afirmativo)

7.1 Indica, marcando con una "X" las categorías en las que has sido convocado por la selección de tu comunidad autónoma, *(entiéndase por convocatoria si te han llamado a lo largo de la temporada para asistir, al menos una vez, a unas jornadas de entrenamiento, a un partido o a una competición)*:

Benjamín			**Alevín**		**Infantil**		**Cadete**		**Juvenil**		
1º	2º	3º	1º	2º	1º	2º	1º	2º	1º	2º	3º

8.- Has ido alguna vez seleccionado con la selección nacional (selección española) .

Si □ No □

(En caso afirmativo)

8.1.- Indica, marcando con una "X" las categorías en las que has sido convocado por la selección nacional, *(entiéndase por convocatoria si te han llamado a lo largo de la temporada para asistir, al menos una vez, a unas jornadas de entrenamiento, a un partido o a una competición)*:

Cadete		**Juvenil**				**Senior**		
-	Sub 15	Sub 16	Sub 17	Sub 18	Sub 19	Sub 20	Sub 21	Sub 23

OTROS DEPORTES

9.- Has practicado alguna vez otro deporte durante al menos 1 vez por semana durante 1 año (ya sea como actividad extraescolar o a nivel federado)

Si □ No □

(En caso afirmativo, contesta la siguiente pregunta)

9.1 Indica el tipo de deporte (o deportes) que practicabas, si era o no de forma federada, qué edad tenías durante el tiempo que lo practicaste y el número de horas semanales que le dedicabas. *Observa el siguiente ejemplo:*

<table>
<tr><td>Deporte</td><td>Balonmano</td><td colspan="2">Federado</td><td>Si</td><td>No</td><td colspan="4">Horas semanales</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>+6</td></tr>
<tr><td colspan="3">Edad</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td></tr>
<tr><td colspan="3">Categorías de fútbol * (No cubrir)</td><td colspan="2">Pre-Benj</td><td colspan="2">Benjamín</td><td colspan="2">Alevín</td><td colspan="2">Infantil</td><td colspan="2">Cadete</td><td colspan="3">Juvenil</td></tr>
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</table>

Deporte		**Federado**	Si	No	**Horas semanales**				1	2	3	4	5	+6
Edad		6	7	8	9	10	11	12	13	14	15	16	17	18
Categorías de fútbol * *(No cubrir)*		Pre-Benj		Benjamín		Alevín		Infantil		Cadete		Juvenil		

Deporte		**Federado**	Si	No	**Horas semanales**				1	2	3	4	5	+6
Edad		6	7	8	9	10	11	12	13	14	15	16	17	18
Categorías de fútbol * *(No cubrir)*		Pre-Benj		Benjamín		Alevín		Infantil		Cadete		Juvenil		

Deporte		**Federado**	Si	No	**Horas semanales**				1	2	3	4	5	+6
Edad		6	7	8	9	10	11	12	13	14	15	16	17	18
Categorías de fútbol * *(No cubrir)*		Pre-Benj		Benjamín		Alevín		Infantil		Cadete		Juvenil		

Deporte		**Federado**	Si	No	**Horas semanales**				1	2	3	4	5	+6
Edad		6	7	8	9	10	11	12	13	14	15	16	17	18
Categorías de fútbol * *(No cubrir)*		Pre-Benj		Benjamín		Alevín		Infantil		Cadete		Juvenil		

LESIONES

10.- ¿Has sufrido alguna/s lesiones, durante las 4 últimas semanas, que te hayan impedido participar en al menos 2 entrenamientos (o más)?

Si □ No □

(En caso afirmativo, contesta la siguiente pregunta)

10.1 Indica tipo de lesión y la zona del cuerpo en que la sufriste, así como el número de entrenos que te perdiste. *Observa el siguiente ejemplo:*

Tipo de Lesión/Zona	*Esguince de tobillo en el pie derecho*													
Entrenos perdidos	2	3	4	5	6	7	8	9	10	11	12	13	13	+14

Tipo de Lesión														
Entrenos perdidos	2	3	4	5	6	7	8	9	10	11	12	13	13	+14

11.- ¿Has sufrido alguna/s lesiones, que te hayan apartado de la competición durante al menos 1 mes?

Si □ No □

(En caso afirmativo, contesta la siguiente pregunta)

11.1 Indica tipo de lesión y la zona del cuerpo en que la sufriste, el número de meses de baja que estuviste sin competir en un partido oficial, y la edad que tenías durante ese tiempo. *Observa el siguiente ejemplo:*

Lesión	*Esguince de tobillo en el pie derecho*				**Meses de baja**				+1	+2	+3	+4	+5	+6
Edad		6	7	8	9	10	11	12	13	14	15	16	17	18
Categorías de fútbol * *(No cubrir)*		Pre-Benj		Benjamín		Alevín		Infantil		Cadete		Juvenil		

Lesión				**Meses de baja**				+1	+2	+3	+4	+5	+6
Edad	6	7	8	9	10	11	12	13	14	15	16	17	18
Categorías de fútbol * *(No cubrir)*	Pre-Benj		Benjamín		Alevín		Infantil		Cadete		Juvenil		

Lesión				**Meses de baja**				+1	+2	+3	+4	+5	+6
Edad	6	7	8	9	10	11	12	13	14	15	16	17	18
Categorías de fútbol * *(No cubrir)*	Pre-Benj		Benjamín		Alevín		Infantil		Cadete		Juvenil		

Lesión				**Meses de baja**				+1	+2	+3	+4	+5	+6
Edad	6	7	8	9	10	11	12	13	14	15	16	17	18
Categorías de fútbol * *(No cubrir)*	Pre-Benj		Benjamín		Alevín		Infantil		Cadete		Juvenil		

Lesión				**Meses de baja**				+1	+2	+3	+4	+5	+6
Edad	6	7	8	9	10	11	12	13	14	15	16	17	18
Categorías de fútbol * *(No cubrir)*	Pre-Benj		Benjamín		Alevín		Infantil		Cadete		Juvenil		

PREFERENCIA FUNCIONAL

Escritura

12.- ¿Con que mano escribes más a menudo?

Derecha □ Izquierda □

12.1 Escribes alguna vez con la otra mano

Si □ No □

Tiro a puerta

13.- ¿Con que pierna te sientes más competente cuándo tiras a portería? *(Cuál es tu pierna buena a la hora de tirar a portería)*

Derecha □ Izquierda □ Las dos □

Conducción

14.- ¿Con que pierna te sientes más competente cuándo conduces el balón? *(Cuál es tu pierna buena a la hora de realizar una rápida y segura conducción de balón)*

Derecha □ Izquierda □ Las dos □

OTRAS

15 ¿De qué talla fueron las últimas botas de fútbol que te compraste? *(Tacha con una "x" la talla de calzado según la numeración europea):*

32	32.5	33	33.5	34	34.5	35	35.5	36	36.5	37	37.5	38
38.5	39	39.5	40	40.5	41	41.5	42	42.5	43	43.5	44	44.5
45	45.5	46	46.5	47	47.5	48	48.5	49	49.5	50		