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Epidemiology and Prediction Models of Injuries in Male Youth Football Players

Epidemiología y Modelos de Predicción de Lesiones en Jóvenes Jugadores de Fútbol

D. Francisco Javier Robles Palazón

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D.ª María del Pilar Sainz de Baranda Andújar
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UNIVERSIDAD DE MURCIA
DEPARTAMENTO DE ACTIVIDAD FÍSICA Y DEPORTE
Facultad de Ciencias del Deporte

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Doctora en Ciencias de la Actividad Física y del Deporte y Catedrática del Departamento de Actividad Física y Deporte de la Universidad de Murcia

AUTORIZA:

La presentación de la tesis doctoral titulada: **Epidemiología y modelos de predicción de lesiones en jóvenes jugadores de fútbol (*Epidemiology and prediction models of injuries in male youth football players*)**, realizada por **D. Francisco Javier Robles Palazón**, bajo mi inmediata dirección y supervisión, y que presenta para la obtención del Grado de Doctor por la Universidad de Murcia.

Y, para que surta los efectos oportunos al interesado, firmo la presente en Murcia, a tres de febrero de dos mil veintiuno.

D.ª María del Pilar Sainz de Baranda Andújar

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D. Enrique Ortega Toro

A mis padres, Ana y Francisco

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Abbreviations

2D	Two-dimensional
3D	Three-dimensional
ACL	Anterior cruciate ligament
ADF	Ankle dorsiflexion
ADF_{KF}	Ankle dorsiflexion with knee flexed
ADF_{KE}	Ankle dorsiflexion with knee extended
ANOVA	Analysis of variance
ASIS	Anterior superior iliac spine
AUC	Area under the receiver operating characteristic curve
BF	Bayesian factor
BIL	Bilateral ratio
BMI	Body mass index
CI	Confidence interval
cm	Centimetres
CMJ	Countermovement jump
CNS	Central nervous system
CPRD	Psychological Characteristics related to the Sport Performance
CT	Contact time
CV	Coefficient variation
DRF	Decrease in the RF over acceleration
DVJ	Drop vertical jump
ENN	Wilson’s edited nearest neighbor rule
F0	Theoretical maximal force
FIFA	Fédération Internationale de Football Association
FN	False negative
FP	False positive

FPPA	Frontal plane projection angle
FV	Slope of the force-velocity relationship
GRADE	Grading of recommendations assessment, development and evaluation
h	Hours
H	Height
H_0	Null hypothesis
H_1	Alternative hypothesis
HF	Hip flexion
IC	Initial contact
ICC	Intra-class Correlation Coefficient
KASR	Knee-to-ankle separation ratio
KF	Knee flexion
kg	Kilograms
KMD	Knee medial displacement
KNN	k-Nearest Neighbor
KSD	Knee separation distance
LE-ST	Lower extremity soft-tissue
m	Meters
MDC_{95}	Minimal detectable change at a 95% CI
mm	Millimetres
ms	Milliseconds
N	Newton
NOS	Newcastle Ottawa scale
PF	Peak flexion
PHABD	Passive hip abduction with hip neutral
$PHABD_{HF90^\circ}$	Passive hip abduction with hip flexed 90°
$PHAD_{HF90^\circ}$	Passive hip adduction with hip flexed 90°

PHE	Passive hip extension
PHER	Passive hip external rotation
PHF$_{KE}$	Passive hip flexion with knee extended
PHF$_{KF}$	Passive hip flexion with knee flexed
PHIR	Passive hip internal rotation
PHV	Peak height velocity
PKF	Passive knee flexion
PNF	Peripheral nervous system
POMS	Profile of Mood States
PRISMA	Preferred reporting items for systematic reviews and meta-analysis
pLFT	Peak landing force timing
Pmax	Maximal power
pVGRF	Peak vertical ground reaction force
RF	Ratio of force
ROC	Receiver operating characteristic
ROS	Random oversampling
RSI	Reactive strength index
RUS	Random undersampling
s	Seconds
SHAP	Shapley Additive exPlanations
SHD	Single hop for distance
SLCMJ	Single-leg countermovement jump
SLJ	Standing long jump
SMOTE	Synthetic minority oversampling technique
STAI	State-Trait Anxiety Inventory
STROBE	Strengthening the reporting of observational studies in epidemiology
STROBE-SIIS	Strengthening the Reporting of Observational Studies in Epidemiology checklist extension for Sports Injury and Illness Surveillance

TEE_{ST}	Standardised typical error of estimate
TEM_{ST}	Standardised typical error of measurement
TJA	Tuck jump assessment
TN	True negative
TP	True positive
TRIPOD	Transparent Reporting of a multivariable prediction model for Individual Prognosis or Diagnosis
ROM	Range of motion
U	Under
V(0)	Theoretical maximal velocity
Vmax	Maximal velocity
W	Watt
y	Years

Preface

The doctoral thesis that the reader is holding in his/her hands is the result of the last five years of research on the exciting topic of injury risk reduction in young athletes by all the members of the research group *E0B5-07 Aparato Locomotor y Deporte* from the University of Murcia. Given the importance of promoting the safe practice of sport during childhood and adolescence, as well as the promising results obtained from similar projects carried out with professional football and futsal players by members of our group, this project has generated a remarkable scientific and social interest since its conception in 2015. Firstly, our challenging research proposal received some grants to support the necessary training for the proper development of our project, such as mobility grants to enable the leaders of this line of investigation to undertake stays in the United States. Afterwards, the author of this thesis was awarded with a predoctoral contract, and our research group also obtained a R&D grant to fund part of this investigation. In order to meet the expectations generated, we have certainly had to make a great effort, but after all, the work could not have been more rewarding.

The thesis presented here is divided into four main parts. *Part I* is dedicated to provide an overview of the problem of football-related injuries in youth players, the issues that this thesis seeks to address, and the research objectives and hypotheses. *Part II* contains the five studies developed to address the research questions mentioned in *Part I*. This part is further divided into five chapters (numbers 3 to 7) which present each of the studies separately to the reader. *Part III* offers the main conclusions drawn from this thesis and sets out future lines of research. Finally, *Part IV* provides the reference list of the studies cited throughout the different chapters.

However, the scientific production of this research project is not limited to this document. During the five years up to the completion of this thesis, the author has also collaborated in 13 published manuscripts (different to the five included in this document) derived from this project (8 in journals indexed in JCR), and has presented oral communications in different International and National Congresses. Likewise, part of the results of this project has been shared with society in some scientific dissemination activities, which has attracted the attention of the media leading to several interviews in regional newspapers and radio stations. This period has enabled the author to complete also two international research stays in the United Kingdom (7 months abroad in total) to improve his scientific skills, allowing him at the same time to fulfil the necessary criteria to qualify for the International Mention in this thesis. Finally, the author and his research group have been awarded with different mentions and distinctions during these years thanks to their contributions to this line of investigation.

I hope you enjoy reading this thesis as much as I have enjoyed these years of work.

Abstract

Despite the multiple health benefits, participation in a physically demanding sport such as football, where players are required to repetitively perform sudden sprinting, tackling, cutting, and jumping and landing tasks, may also lead to an increased injury risk. In fact, football has been suggested as one of the top five injury-prone sports in youth regardless of the substantive effort made by the scientific community and physical trainer practitioners to reduce their number and severity. The inefficacy of the preventive measures implemented might be partly caused by the limitations present in the literature which hinder the accurate estimation of the most frequent football-related injuries as well as the identification of the factors (and their interactions) that may place youth football players at high risk of injury. To help overcome these limitations, the current doctoral thesis aims (a) to establish the extent of the injury problem in male youth football players, (b) to improve the understanding regarding the aetiology and mechanisms of injury through the analysis of the interaction between potential injury risk factors, and (c) to develop a robust prediction model to identify young football players at high or low risk of injury using a field-based screening battery. The five studies carried out to achieve these aims are briefly presented below.

The *first study* performed a systematic review and meta-analysis to quantify the overall, training and match injury incidences in youth football players. To this end, a systematic search was conducted in PubMed, Web of Science, Cochrane Library and SPORTDiscus databases. Studies were considered if they reported injury incidence rate among male and female youth (≤19 years) football players. Two reviewers extracted data and assessed trial quality using the STROBE statement and Newcastle Ottawa Scale assessment tools. The Grading of Recommendations Assessment, Development and Evaluation approach determined the quality of evidence. Studies were combined in pooled analyses (injury incidence) using a Poisson random effects regression model. Finally, a total of forty-three studies were selected. The main results revealed an overall incidence of 5.7 and 6.8 injuries per 1000 hours of exposure in males and females, respectively. Match injury incidence (14.4 [males] and 15.0 [females] injuries per 1000 hours of exposure) was significantly higher than training injury incidence rate (2.8 [males] and 2.6 [females] injuries per 1000 hours of exposure). Lower extremity had the highest incidence rates in both sexes (4.1 and 6.5 injuries per 1000 hours of exposure in males and females, respectively). The most common types of injuries were muscle/tendon for males (1.9 injuries per 1000 hours of exposure), and joint (non-bone) and ligament for females (2.4 injuries per 1000 hours of exposure). Minimal injuries (1–3 days of time loss) were the most common in both sexes. The incidence rate of injuries in males increased with advances in chronological age,

showing peak rates in U17-U19 football players. Elite male players presented higher match injury incidences than sub-elite players. In females, there was a paucity of data to compare across age groups and levels of play. The probability of sustaining a time-loss injury during a youth season was 47% and 43% for male and female youth players, respectively. The high injury incidence rates and the sex differences identified for the most common location and type of injury in this study reinforce the need for implementing different targeted injury risk mitigation strategies in male and female youth football players.

The objective of the *second study* was to describe the specific injury profile in young Spanish male football players. A total of 314 male youth football players from five different football clubs were prospectively followed during a 9-month season in two southeast regions of Spain. The study design and data collection followed both the consensus on definitions and data collection procedures for studies of football injuries outlined by the Union of European Football Associations and the consensus document for football injury surveillance studies. Injury incidence was calculated as the number of injuries divided by 1000 player-hours, and injury burden as the number of lay-off days/1000 hours of exposure. Post hoc probabilities of injury over a season were also determined. A spreadsheet for combining effect statistics was used to make clinically (qualitative) inference for paired-comparisons between incidence rates. During the 9-month follow-up season, a total of 146 time-loss injuries were sustained by 101 different youth football players, 72 injuries during training sessions and 74 injuries during matches. This resulted in an overall injury incidence of 3.1 injuries per 1000 hours of football exposure, 1.8 injuries per 1000 hours of training exposure and 11.2 injuries per 1000 hours of match exposure. The probability of players sustaining an injury over the season was 34%. Most of the injuries affected the lower extremity (especially the thigh) and were classified as muscle/tendon injuries, with hamstring muscle injuries representing the most burdensome diagnosis. The incidence of injuries increased with age and maturation, but a heightened risk of overuse injuries during periods around peak height velocity was also identified. These findings suggest a need for implementing specific injury prevention measures in Spanish youth football teams. Due to the high burden shown, these preventive measures should mainly focus on reducing the number and severity of hamstring muscle injuries. Likewise, the higher risk of overuse injuries reported during periods around the peak height velocity reinforce the need to routinely monitor young players' growth to adapt training interventions to their stage of maturation. Other relevant information such as the playing position and period of the season should be considered by practitioners when managing the injury risk.

The *third study* aimed to analyse and compare the influence of chronological age and maturational stage on several lower extremity range of motion (ROM) measures, as well as to describe the lower extremity ROM profile using a comprehensive approach in youth football players. A total of 286 male youth football players ROM was assessed including: passive hip (extension [PHE], adduction with hip flexed 90° [$PHAD_{HF90°}$], flexion with knee flexed [PHF_{KF}] and extended [PHF_{KE}], abduction with hip neutral [PHABD] and flexed 90° [$PHABD_{HF90°}$], external [PHER] and internal [PHIR] rotation), knee (flexion [PKF]) and ankle (dorsiflexion with knee flexed [ADF_{KF}] and extended [ADF_{KE}]) ROMs. Between-group differences for both chronological age (U12, U14, U16 and U19) and maturational stage (Pre-PHV, Circa-PHV and Post-PHV) were analysed using a one-way analysis of variance (ANOVA) and magnitude-based decisions. The results only report statistically significant ($p < 0.05$; $d > 0.5$) and clinically relevant differences (> 8°) for the PKF ROM between U12 vs. U19, and Pre-PHV vs. Post-PHV groups. Furthermore, approximately 40%, 35% and 20% of players displayed restrictions in their PHF_{KE}, PKF, and ADF_{KF} ROM values, respectively. Cumulatively, the findings of this study emphasise the necessity of prescribing compensatory measures (e.g., stretching exercises) across all periods of growth and maturation in the daily football training practices. As no bilateral differences between dominant and non-dominant legs were found, these exercises should be equally applied to both limbs with the aim of improving PHF_{KE}, PKF and ADF_{KF} ROM values.

The *fourth study* attempted (1) to determine the inter-rater and intra-rater reliability of frontal (frontal plane projection angle) and sagittal (hip, knee and ankle flexion angles at initial contact and peak flexion) plane landing kinematic measures during drop vertical jump (DVJ) and tuck jump assessment (TJA) tasks in male youth football players, (2) to assess the concurrent validity between DVJ and TJA tests for all landing kinematic measures, and (3) to evaluate the ability of both jumping tasks to detect differences between players' stage of maturation (pre-PHV, circa-PHV, and post-PHV). For these purposes, a cross-sectional observational design was used including a total sample of 223 male youth football players. Assessment sessions were carried out during the preseason period (September) of the years 2017 and 2018, and two-dimensional video cameras were used to capture the DVJ and TJA tests. Afterwards, knee displacement (frontal plane projection angle [FPPA]) in the frontal plane, and hip, knee and ankle flexion angles at initial contact and peak flexion in the sagittal plane were calculated for each video using a free available software (Kinovea 0.8.15, USA). The intra-class correlation coefficient (ICC), standardised typical error of measurement (TEM_{ST}), the typical percentage error (CV_{TE}), and the minimal detectable change (MDC_{95}) were used to determine the measurement reliability. To assess the concurrent validity, the Pearson's product-moment correlation coefficient (r) and the standardised typical error of estimate (TEE_{ST}) were reported. A Bayesian analysis of variance (ANOVA) was conducted to analyse potential differences among stages of maturation (pre-PHV vs. circa-PHV vs. post-PHV). The main findings of this study revealed good-to-excellent reliability data (ICC > 0.75; $TEM_{ST} < 0.3$; $CV_{TE} < 5\%$) for the knee FPPA as well as the hip and knee flexion angles during DVJ and TJA tasks when assessed by single or different testers. However, a low relationship between DVJ and TJA kinematic measures was found, demonstrating significant higher FPPA values and lower hip and knee flexion values at peak flexion during the TJA test. Furthermore, while the DVJ was not able to report strong evidence for supporting between group differences regarding the maturity status, the TJA displayed a higher ability to discriminate between developmental stages for all frontal and sagittal measures. Based on these results, the TJA may be viewed as a more informative tool for landing technique assessments. Given the deficits demonstrated in the frontal plane by players' at pre-PHV group and in the sagittal plane by players' at circa- and post-PHV groups, the implementation of neuromuscular strategies aimed to improve muscular strength, dynamic balance and plyometric skills is recommended from pre-puberty and across all periods of growth and maturation to mitigate the risk of injury in youth football.

Finally, the purpose of the *fifth study* was to develop a robust screening model based on pre-season measures to prospectively predict lower extremity soft-tissue (LE-ST) injuries after having applied supervised learning algorithms and resampling methods in non-elite young football players. To this end, a convenience sample of 301 young male football players from the academies of five different Spanish non-professional football clubs were recruited, of which a sample of 260 players completed the prospective follow-up. Players were required to attend their respective club's training facilities during the pre-season phase to undergo an evaluation of a number of personal characteristics (e.g., anthropometric measures), psychological constructs (e.g., trait-anxiety), and physical fitness and neuromuscular measures (e.g., range of motion, landing kinematics), most of them considered potential sport-related injury risk factors. Afterwards, all LE-ST injuries accounted for within the 9 months following the initial testing session were collected. A total of 45 LE-ST injuries were recorded over the season. The model developed (AUC = 0.700) allowed to successfully identify one out of every two (True Positive rate = 51.1%) and four out of every five (True Negative rate = 81.2%) youth male football players at high or low risk of suffering a LE-ST injury throughout the in-season phase, respectively, using a subset of six pre-season field-based measures (i.e., body mass index, knee medial displacement (knee valgus) in the DVJ, asymmetry in the peak vertical ground reaction force during landing, asymmetry in the FPPA assessed through the TJA, $ROM\text{-}ADF_{KE}$, and asymmetry in ROM-PHIR). Given that these measures require little equipment to be recorded and can be employed quickly (approximately 5 min) and easily by trained staff in a single player,

the model developed in this study should be included as an essential component of the injury management strategy in youth football.

Overall, the findings presented in this doctoral thesis may assist clinicians, grass-roots coaches and physical trainers in the decision-making process to reduce the high number and severity of injuries occurring in youth football.

Keywords: soccer, young, incidence, burden, landing, kinematic, neuromuscular control, range of motion, maturation, screening, prediction, learning algorithm, machine learning, artificial intelligence.

Resumen

La práctica del fútbol ha demostrado múltiples beneficios sobre el estado de salud de los niños y adolescentes. Sin embargo, la participación en un deporte tan exigente como éste, en el que los jugadores tienen que realizar repetidamente tareas de aceleración y desaceleración, cambios de dirección, entradas, saltos y aterrizajes, también puede incrementar el riesgo de sufrir una lesión deportiva. De hecho, el fútbol ha sido considerado uno de los cinco deportes más lesivos entre los jóvenes, pese a los grandes esfuerzos realizados por la comunidad científica y los profesionales del entrenamiento físico para reducir el número y la gravedad de las lesiones derivadas de este deporte. La ineficacia de las medidas preventivas aplicadas podría deberse, en parte, a las limitaciones existentes en la literatura científica publicada hasta la fecha, que dificultan tanto la estimación precisa de las lesiones que ocurren más frecuentemente en este deporte como la identificación de aquellos factores (y sus interacciones) que podrían situar a los jóvenes futbolistas en un posición de alto riesgo de lesión. Para ayudar a superar estas limitaciones, la presente tesis doctoral plantea los siguientes objetivos prioritarios: (a) establecer el alcance del problema de las lesiones en jóvenes futbolistas, (b) mejorar la comprensión respecto a la etiología y los mecanismos de lesión mediante el análisis de la interacción entre los posibles factores de riesgo, y (c) desarrollar un modelo de predicción que identifique aquellos jóvenes jugadores en situación de alto o bajo riesgo de lesión mediante la aplicación de técnicas estadísticas derivadas de la minería de datos y *Machine Learning*. A continuación, se describen brevemente los cinco estudios desarrollados para la consecución de estos objetivos.

Como *primer estudio*, se realizó una revisión sistemática con meta-análisis para cuantificar la incidencia de lesiones total, en entrenamientos y en partidos en jóvenes jugadores de fútbol. Para ello, se realizó una búsqueda sistemática en las bases de datos PubMed, Web of Science, Cochrane Library y SPORTDiscus, estableciendo como principal criterio de inclusión que los estudios originales reportaran la tasa de incidencia de lesiones en jóvenes jugadores (≤19 años) de fútbol. Dos revisores extrajeron de manera independiente todos los datos relevantes para cada estudio, y evaluaron la calidad de los ensayos a través de la declaración STROBE y la Newcastle Ottawa Scale. Además, se utilizó la Grading of Recommendations Assessment, Development and Evaluation para determinar la calidad de la evidencia generada en este meta-análisis. Para la obtención de los resultados agrupados (incidencia de lesiones) se empleó un modelo de regresión de efectos aleatorios de Poisson. Finalmente, 43 estudios formaron parte del análisis. Los resultados principales revelaron una incidencia global de 5,7 y 6,8 lesiones por 1000 horas de exposición en chicos y chicas, respectivamente. La incidencia de las lesiones en

los partidos (14,4 [chicos] y 15,0 [chicas] lesiones por 1000 horas de exposición) fue significativamente superior a la tasa de incidencia de las lesiones durante entrenamientos (2,8 [chicos] y 2,6 [chicas] lesiones por 1000 horas de exposición). Con respecto a la localización de las lesiones, las extremidades inferiores presentaron las tasas de incidencia más altas en ambos sexos (4,1 y 6,5 lesiones por 1000 horas de exposición en chicos y chicas, respectivamente). Los tipos de lesión más comunes fueron las musculares/tendinosas para los chicos (1,9 lesiones por 1000 horas de exposición), y las articulares (no óseas) y ligamentosas para las chicas (2,4 lesiones por 1000 horas de exposición). Las lesiones de gravedad mínima (1-3 días de baja) fueron las más comunes en ambos sexos. Las tasas de incidencia de lesiones incrementaron con el avance en la edad cronológica en los chicos, mostrando las mayores incidencias en jugadores pertenecientes a la categoría juvenil (sub-19). Igualmente, aquellos jugadores que competían a alto nivel (élite) presentaron mayores incidencias de lesiones durante los partidos que los jugadores considerados como sub-élite. La escasez de datos publicados hasta la fecha impidió comparar entre grupos de edad y niveles de juego para las chicas. La probabilidad de sufrir una lesión que conlleve ausencia de la práctica deportiva a lo largo de una temporada competitiva fue del 47% para los chicos y del 43% para las chicas. En conclusión, las altas tasas de incidencia y las diferencias identificadas en función del sexo de los jugadores para la localización y el tipo de lesión más común en este estudio refuerzan la necesidad de implementar diferentes estrategias para la reducción del riesgo de lesión de acuerdo al sexo de los jóvenes futbolistas.

El objetivo del *segundo estudio* fue describir el perfil específico de las lesiones en jóvenes jugadores de fútbol de España. Para ello, se realizó un seguimiento prospectivo durante una temporada (9 meses) a un total de 314 futbolistas pertenecientes a cinco clubes distintos de dos regiones del sureste español. El diseño del estudio y el proceso de recogida de datos siguieron tanto el consenso establecido por la UEFA en 2005 como el documento de consenso FIFA publicado en 2006. La incidencia de lesiones se calculó como el número de lesiones dividido por 1000 horas de participación en el deporte, mientras que las consecuencias de las lesiones (*injury burden*) fueron calculadas como el número de días de baja/1000 horas de exposición. Igualmente, se determinaron las probabilidades de lesión a lo largo de una temporada. A fin de realizar comparaciones pareadas entre tasas de incidencia que permitieran realizar inferencias a nivel clínico, se utilizó una hoja de cálculo propuesta por Hopkins. Durante la temporada de seguimiento, un total de 146 lesiones con ausencia de participación en el deporte fueron registradas en 101 jugadores distintos, 72 lesiones producidas en entrenamientos y 74 en partidos. Traducidos a incidencias, estos datos dieron lugar a una incidencia global de 3,1 lesiones por cada 1000 horas de exposición, 1,8 lesiones por cada 1000 horas de entrenamiento y 11,2 lesiones por cada 1000 horas de partido. La probabilidad de que los jugadores sufrieran una lesión a lo largo de la temporada fue del 34%. En cuanto a la localización de las lesiones registradas, la mayoría afectó a extremidades inferiores (especialmente al muslo) y fueron clasificadas como lesiones musculares/tendinosas. Además, las lesiones de la musculatura isquiosural representaron las peores consecuencias en términos de días de ausencia por cada 1000 horas. La incidencia de lesión aumentó con el avance en edad y maduración de los participantes, aunque también se identificó un mayor riesgo de lesiones por sobreuso durante los periodos cercanos al periodo de máxima velocidad de crecimiento (PHV). En definitiva, los hallazgos de este estudio sugieren la necesidad de implementar medidas específicas para la prevención de lesiones en equipos de fútbol infanto-juveniles de España. Dadas las grandes consecuencias evidenciadas, estas medidas preventivas deberían centrarse principalmente en reducir el número y la severidad de las lesiones musculares en isquiosurales. Asimismo, el incremento del riesgo de lesión por sobreuso mostrado durante los periodos cercanos al estirón puberal refuerza la necesidad de controlar rutinariamente el crecimiento de los jóvenes jugadores para adaptar las distintas intervenciones y entrenamientos a su correspondiente estado madurativo. Es importante que los entrenadores y preparadores físicos también tengan en cuenta otros datos relevantes, como la posición de juego y el periodo de la temporada, a la hora de gestionar el riesgo de lesión en sus equipos.

El *tercer estudio* trató de analizar y comparar la influencia de la edad cronológica y la etapa madurativa en varias medidas del rango de movimiento (ROM) articular de las extremidades inferiores, así como describir el perfil integral de ROM de las extremidades inferiores en jóvenes jugadores de fútbol. Con este objetivo, se evaluó el ROM a un total de 286 jugadores, incluyendo: el ROM de cadera (extensión [PHE], aducción con cadera flexionada 90° [$\text{PHAD}_{\text{HF}90^\circ}$], flexión con rodilla flexionada [PHF_{KF}] y extendida [PHF_{KE}], abducción con cadera neutra [PHABD] y flexionada 90° [$\text{PHABD}_{\text{HF}90^\circ}$], rotación externa [PHER] e interna [PHIR]), rodilla (flexión [PKF]) y tobillo (dorsiflexión con rodilla flexionada [ADF_{KF}] y extendida [ADF_{KE}]). Las diferencias entre grupos tanto para la edad (sub-12, sub-14, sub-16 y sub-19) como para la etapa madurativa (pre-PHV, circa-PHV y post-PHV) fueron analizadas mediante un análisis de la varianza (ANOVA) y decisiones basadas en la magnitud de los efectos (*magnitude-based decisions*). Los resultados informaron diferencias estadísticamente significativas ($p < 0{,}05$; $d > 0{,}5$) y clínicamente relevantes (> 8°) únicamente para el rango de movimiento de la flexión de rodilla (PKF ROM) y entre los grupos sub-12 vs. sub-19, y pre-PHV vs. post-PHV. Sin embargo, un 40%, 35% y 20% del total de los jugadores mostró restricciones en sus valores de ROM para la flexión de cadera con rodilla extendida (PHF_{KE}), flexión de rodilla (PKF) y dorsiflexión de tobillo con rodilla flexionada (ADF_{KF}), respectivamente. En consecuencia, los hallazgos de este estudio enfatizan la necesidad de prescribir medidas compensatorias (e.g., ejercicios de estiramiento) para todas las etapas de crecimiento y maduración como parte de su rutina habitual de entrenamiento de fútbol. Puesto que los resultados tampoco mostraron diferencias bilaterales entre piernas dominante y no dominante, estos ejercicios deberían aplicarse por igual a ambas extremidades con el objetivo de mejorar los valores de ROM de la flexión de cadera, rodilla, y dorsiflexión de tobillo.

Los objetivos del *cuarto estudio* fueron (1) determinar la fiabilidad inter e intra-observador de las medidas cinemáticas de aterrizaje tras un salto en el plano frontal (ángulo de proyección de rodilla [FPPA]) y sagital (ángulos de flexión de la cadera, la rodilla y el tobillo en el contacto inicial y en el pico de máxima flexión) durante los test de salto vertical *drop jump* (DVJ) y *tuck jump* (TJA) en jóvenes jugadores de fútbol, (2) examinar la validez concurrente entre las pruebas DVJ y TJA para todas las medidas cinemáticas de aterrizaje, y (3) evaluar la capacidad de ambas pruebas para detectar diferencias de acuerdo al estado madurativo de los jugadores (pre-PHV, circa-PHV y post-PHV). Para ello, se utilizó un diseño observacional y transversal, incluyendo una muestra total de 223 jóvenes jugadores. Las sesiones de evaluación se llevaron a cabo durante la pretemporada (septiembre) de los años 2017 y 2018. Para la grabación de los saltos, dos cámaras de vídeo bidimensionales fueron utilizadas y, posteriormente, se calculó el desplazamiento de la rodilla (FPPA) en el plano frontal, y los ángulos de flexión de cadera, rodilla y tobillo en el momento de contacto inicial y en el de máxima flexión en el plano sagital para cada vídeo a través de un software disponible de manera gratuita (Kinovea 0.8.15, USA). Para determinar la fiabilidad de las medidas se utilizó el coeficiente de correlación intraclase (ICC), el error típico de la medida estandarizado (TEM_{ST}), el error típico en valores porcentuales (CV_{TE}) y el cambio mínimo detectable (MDC_{95}). Para evaluar la validez concurrente, se empleó el coeficiente de correlación de Pearson (*r*) y el error típico de estimación estandarizado (TEE_{ST}). Igualmente, un análisis de la varianza (ANOVA) bayesiano fue utilizado para analizar posibles diferencias entre las etapas madurativas (pre-PHV vs. circa-PHV vs. post-PHV). En general, los principales hallazgos de este estudio revelaron datos de fiabilidad categorizados como buenos-excelentes (ICC > 0,75; TEM_{ST} < 0,3; CV_{TE} < 5%) para el análisis del FPPA de rodilla, así como para los ángulos de flexión de cadera y rodilla durante las pruebas DVJ y TJA independientemente de que el análisis fuera realizado por un único evaluador o por evaluadores distintos. No obstante, una baja relación entre las medidas cinemáticas estudiadas para cada prueba fue encontrada, demostrando valores significativamente mayores para el FPPA y menores para la flexión de cadera y rodilla en el momento de máxima flexión para el test TJA. Además, mientras que el DVJ no fue capaz de encontrar diferencias entre grupos con respecto al estado madurativo, el TJA mostró una mayor capacidad para discriminar entre las distintas etapas del desarrollo para todas las medidas frontales y sagitales. Por tanto, el TJA podría considerarse como herramienta prioritaria para la valoración de la técnica de aterrizaje. Debido a los déficits demostrados en el plano frontal por los jugadores clasificados como pre-PHV y en el plano sagital por los jugadores categorizados como circa- y post-PHV, se recomienda la implementación de estrategias neuromusculares dirigidas a mejorar la fuerza muscular, el equilibrio dinámico y las habilidades pliométricas desde etapas prepuberales y a lo largo de todos los periodos madurativos para reducir el riesgo de lesión derivado de la práctica del fútbol.

Finalmente, el objetivo del *quinto estudio* fue desarrollar un modelo de predicción de lesiones del tejido blando (músculos, tendones y ligamentos) de las extremidades inferiores basado en medidas tomadas durante la pretemporada y mediante la aplicación de algoritmos de aprendizaje supervisado y métodos de remuestreo en jóvenes jugadores de fútbol. Para ello, una muestra de 301 jóvenes futbolistas de las canteras de cinco clubes de fútbol no profesionales españoles fue reclutada, de los cuales un total de 260 jugadores completó todo el estudio. Durante la pretemporada, los jugadores acudieron a las instalaciones de entrenamiento habitual de sus respectivos clubes para ser sometidos a la evaluación de una serie de características personales (e.g., medidas antropométricas), constructos psicológicos (e.g., ansiedad rasgo) y parámetros neuromusculares y del rendimiento motor (e.g., amplitud de movimiento, cinemática de aterrizaje). Posteriormente, se realizó un seguimiento prospectivo de todas las lesiones acontecidas en tejidos blandos de las extremidades inferiores durante los siguientes 9 meses. Un total de 45 lesiones fueron registradas a lo largo de la temporada competitiva. El modelo generado gracias a la aplicación de robustas técnicas estadísticas (AUC = 0,700) permitió identificar con éxito a uno de cada dos (tasa de Verdaderos Positivos = 51,1%) y a cuatro de cada cinco (tasa de Verdaderos Negativos = 81,2%) jóvenes jugadores de fútbol con alto o bajo riesgo de sufrir una lesión en tejidos blandos de extremidades inferiores a lo largo de la temporada, respectivamente. Para ello, el modelo desarrollado utilizó únicamente un subconjunto de seis variables medidas mediante tests de campo: desplazamiento medial de la rodilla (valgo de la rodilla) en el DVJ, índice de masa corporal, asimetría en el pico de fuerza reactiva durante la caída tras un salto (SLCMJ), asimetría en el FPPA evaluado a través del TJA, ROM de la dorsiflexión de tobillo y asimetría en el ROM de la rotación interna de cadera. Dado el escaso tiempo requerido para la valoración de estas variables (aproximadamente 5 minutos por jugador) y la facilidad de aplicación de cada uno de los test utilizados, se recomienda la inclusión del modelo generado en este estudio como componente esencial de las estrategias de prevención de lesiones implementadas en el fútbol infanto-juvenil.

En general, los hallazgos presentados en esta tesis doctoral podrían ayudar a médicos, entrenadores y preparadores físicos en el proceso de toma de decisiones para reducir el elevado número y la gravedad de las lesiones que se producen actualmente en el fútbol base.

Palabras clave: fútbol asociado, niños, adolescentes, incidencia, consecuencias, salto y aterrizaje, cinemática, control neuromuscular, rango de movimiento, maduración, identificación del riesgo, predicción, algoritmos de aprendizaje, aprendizaje automático, inteligencia artificial.

PART I

GENERAL INTRODUCTION, RESEARCH OBJECTIVES AND HYPOTHESES

1

GENERAL INTRODUCTION

Football (soccer) is the most popular sport in the world. According to the Fédération Internationale de Football Association (FIFA), there were 265 million male and female football players worldwide in 2006. Of these, 62 million (23%) were from Europe, which represent the second largest number of players after Asia (85 million, 33%) [1]. In Spain, data from the Royal Spanish Football Federation revealed more than 840,000 registered football players in the 2018/2019 season [2]. Furthermore, the majority of the registered football players worldwide (58%) and in Spain (83%) were youth (under 19 years of age), with boys accounting for more than four fifths of the total number of young players [1,2]. In fact, the number of youth football players has not ceased to increase during the last decades [2,3], perhaps encouraged by the multiple metabolic, cardiovascular and musculoskeletal health benefits derived from playing this sport [4–7].

However, participation in a physically demanding sport such as football, where young players are required to repetitively perform sudden sprinting, cutting, and jumping and landing tasks, alongside several tackling situations to keep or to win the ball, may also lead to an increased injury risk [8–10]. This risk of injury might be especially relevant during childhood and adolescence, when individual growth and maturation are not yet completed [11,12]. Indeed, football has been suggested as one of the top five injury-prone sports in youth [13,14]. Remaining injury free is a priority for youth football players as injuries can counter the health-related beneficial effects of sports participation at a young age if the child or adolescent is unable to continue to participate because of the residual effects of injuries [15]. Consequently, there is a need for implementing appropriated measures to prevent and reduce the number and severity of football-related injuries in youth players.

To develop an effective prevention strategy, van Mechelen et al. [16] proposed in 1992 what they called the *sequence of prevention* of sports injuries, a four-step model that outlines the different stages for implementing a scientifically based prevention measure. In the first step of this model, the extent of the injury problem must be identified and described in terms of incidence and severity. Next, the factors and mechanisms of the injury should be identified in the second step. Once the epidemiology of injuries and the aetiology and mechanisms have been determined, the third step is to introduce targeted preventive measures. Finally, the fourth step should be the assessment of the effectiveness of the injury prevention measures implemented by repeating again the first step. Over the years, the content of the steps of the classical *sequence of prevention* has been revisited and new perspectives have been added [17,18], resulting in a more comprehensive model that involves a total of seven steps. These new perspectives are briefly detailed below.

When establishing the extent of the problem (first step), the incidence and severity of injuries should be described using stardardised sport injury and exposure definitions, including data on when (match vs. training), where (location), and how (traumatic vs. overuse; contact vs. non-contact) the injuries usually occur in the studied population. However, the analysis of the injury incidence and severity in isolation may provide an incomplete picture of the injury phenomenon and thus, reporting also the injury burden (i.e., the combination of incidence and severity into a single concept) has been suggested [19]. Likewise, the importance of considering the individual, sociocultural and environmental context when described this first step of the sequence of prevention has been recently highlighted since they may provide a more comprehensive view and a deeper understanding of the injury problem [20].

To better address the multifactorial nature of the sports injuries aetiology (second step), the use of a complex system approach has been proposed [21]. This broader approach rests on analysing the injury mechanism (i.e., the event or pattern that led to damage a body structure) and then identifying potential interactions (i.e., relationships in a non-linear manner) within a web of determinants (i.e., injury predictors or risk factors) and clarifying how the interactions among factors contribute to the emergence of specific injuries. These complex interactions may also form observable regularities (repeated patterns) that enable the identification of risk profiles for an athlete or group. This knowledge forms the basis for developing screening models to prospectively identify athletes at high risk for sustaining an injury.

The third step involves the design and implementation of tailored preventive strategies to correct potentially hazardous movement patterns or regularities (e.g., abnormal kinematic pattern during landing tasks) in athletes and reduce the risk of injury. These measures should be based on information identified in the second step. The impact of certain contextual factors that may be increasing the injury risk should be also understood and considered when introducing these preventive measures into practice [20,22].

Once the intervention measures have been implemented, the fourth step of the sequence corresponds to the evaluation of their effectiveness by repeating the first step. Given that several factors such as intervention adherence, attitudes and beliefs may affect when translating efficacious preventive interventions into real world conditions [23], Finch [17] proposed in 2006 to include two additional steps to this sequence: 5) describe the intervention context to inform implementation strategies, and 6) evaluate the effectiveness of the scientifically proven preventive measures when implemented in a real-world context. Two years later, van Tiggelen et al. [18] complemented these modifications proposed by Finch by incorporating risk-taking behavior and compliance of the individual as limiting factors with a significant effect on the outcome of injury prevention measures. This expansion of van Mechelen's model gives a better insight into the different processes in injury prevention that can be used to decide whether to implement a preventive programme [18] (Figure 1).

The current doctoral thesis addresses the first and the second steps of this comprehensive seven-step model to assist the implementation of appropriated injury prevention strategies in male youth football players.

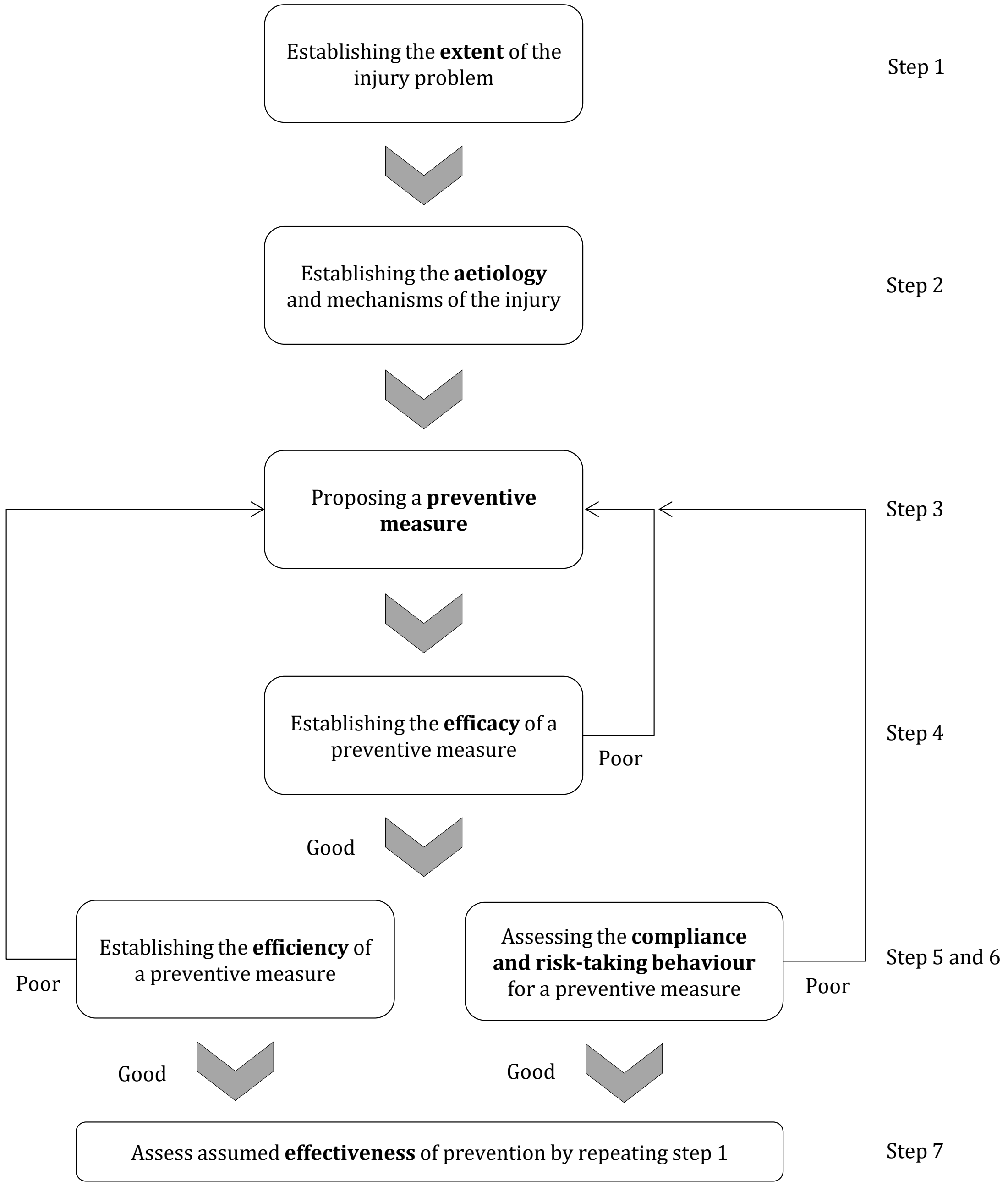


Figure 1. The sequence of prevention of sports injuries described by van Mechelen et al. [16] and later expanded by Finch [17] and van Tiggelen et al. [18]. Figure adapted from van Tiggelen et al. [18].

1.1 Epidemiology of injuries in youth football

As mentioned before, the first step to design an appropriated preventive measure is to describe the magnitude (incidence) of the problem and its severity. The extent of the injury problem in youth football has been the subject of an increasing volume of publications in the last years [12,24–35] (Figure 2). A range of prospective epidemiological investigations have been carried out to identify the injury profile of male youth football players worldwide: Asia [34,35], Europe [24–28,32], North America [36], South America [30], and Oceania [37]. The results of these studies have revealed a remarkable injury rate that varies from 1 [26] to 13 [25] injuries per 1000 hours of overall football exposure. Most of these injuries seems to occur during competition (range: 3-37 injuries per 1000 hours of match exposure)[31,38] compared to training sessions (range: 1-8 injuries per 1000 hours of training exposure)[26,34]. Likewise, the lower extremity, and especially the ankle, knee and thigh regions, appears to sustain the majority of the injury occurrences [12,26–29,32,38], with muscle and ligament representing the most frequent injury types [24,26–29]. Unlike adults, youth players have also to deal with unique injuries related to their immature skeletal structures, commonly known as growth-related injuries (e.g., growth plate fractures, apophysitis, apophyseal avulsion fractures, and green-stick fractures) [39,40]. Thus, coaches should be aware of the individuality of injuries throughout the different stages of young players' development and not base their prevention strategies on epidemiological data from adult football player cohorts.

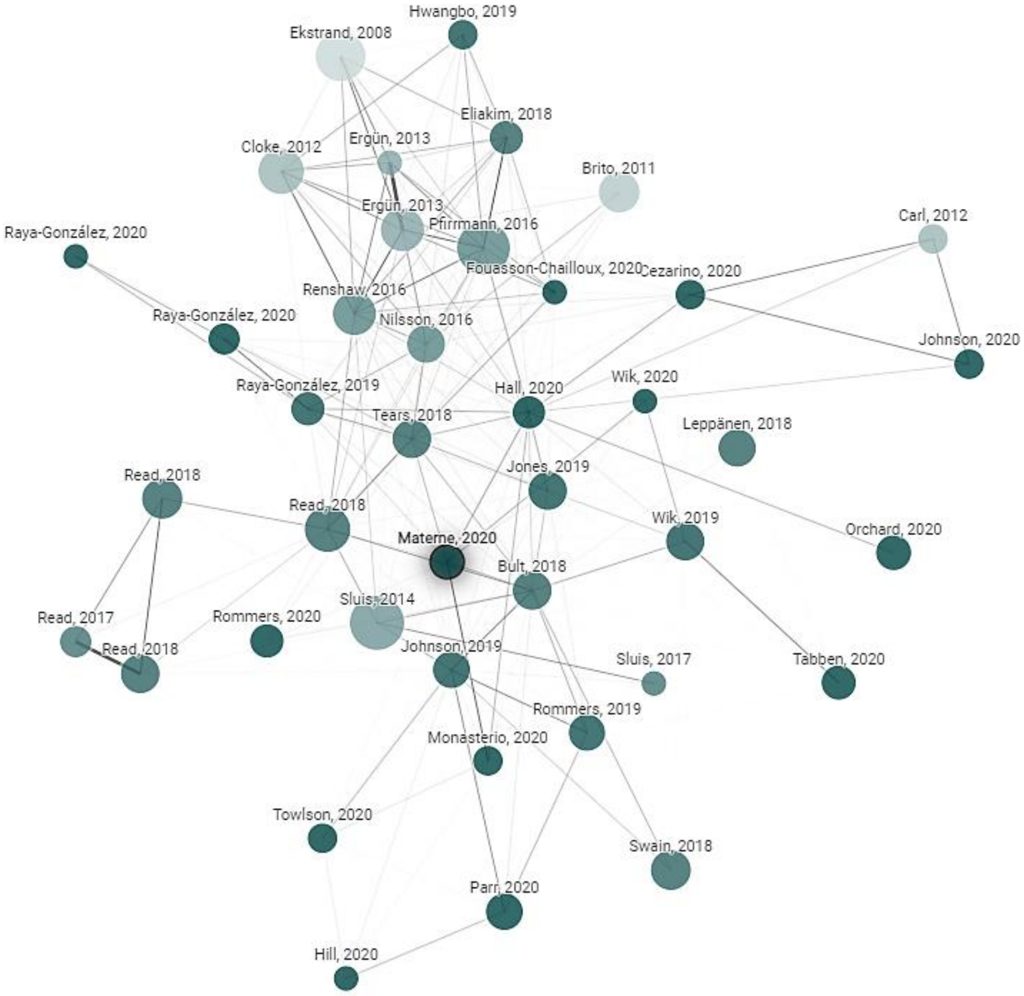


Figure 2. Visual overview of the volume of studies related to the epidemiology of injuries in youth football players published in the last years. Each circle represents an individual study while the lines link related publications. Graph created at *connected papers* website using the recent research of Materne et al. [35] as the main search criteria.

Some studies have reported injury incidence in youth football across a broad range of age groups [12,26,29,30,34,35,41,42], showing a trend towards increasing the injury incidence as players progress on a typical football academy [26,29,34,42]. Players in the older age groups are exposing themselves to higher physical demands and longer duration of match-play, which would mean more risk of injury during a game. Simultaneously, players transitioning to older age groups are likely to experience a large increase in training load, with spikes in workload suggested to contribute to injuries in youth football players [42]. This evolution in match and training physical demands is also couple with an increase in body size and shape, which can stress soft-tissue structures as a result of greater joint torques [43]. Consequently, it would seem reasonable that the vulnerability to sports injury increases with chronological age.

In addition, epidemiological data have also suggested that a heightened risk for sustaining an injury is evident around 13 to 16 year-old players compared to younger footballers [12,27,44]. These ages coincide with the period of maximum rate of growth (peak height velocity [PHV]), which is estimated about 14 years in males [45,46]. The rapid disproportional physical changes that occur during the peak growth spurt may lead to a temporary disruption in basic motor skill execution [46], and then predispose players to sports injuries. However, despite being a commonly held theory, most of the empirical evidence regarding the interaction between injury risk and maturation is extrapolated from analyses by chronological age. It is known that the biological maturation may differ considerably in level, timing, and tempo among individuals of the same chronological age [47,48]. In fact, it has been suggested that only two thirds of players might be within their normal maturity category in regards to their chronological age [49]. Therefore, the potential differences between adolescent players emphasise the limitations in using chronological age to study the influence of biological maturation on the injury risk [47]. To date, only a few published prospective cohort studies [12,50–52] have investigated the occurrence of injuries in football and its relation to maturity status. Furthermore, although all of them seem to suggest an increased risk for injury around the adolescent growth spurt, conflicting results regarding the incidence of traumatic (acute) and overuse injuries have been reported. While Materne et al. [51] and Johnson et al. [50] found higher incidence rates of overuse injuries in players around the PHV, Van der Sluis et al. [52] revealed greater incidences for traumatic injuries at this stage of maturation in comparison with pre- and post-PHV groups. Thus, further research is required on this topic.

On the other hand, injury burden (the product of severity [consequences] and incidence [likelihood]) has not been extensively investigated in youth football. Only a limited number of epidemiological studies have reported this information for Dutch [12], Belgian [53], English [54], Spanish [28] and Qatari [34,35] male youth players, highlighting some discrepancies in the worst burden age-groups. Additionally, only the recent studies of Materne et al. [35] and Wik et al. [34] have built a risk matrix illustrating the burden for most commonly type of injuries. This risk matrix plots the injury severity against the incidence, with criteria incorporated into the graph for evaluating the level of risk [55] (Figure 3). Both the injury burden and the risk matrix could help practitioners to identify which type of injury causes the greatest loss of time for players, and therefore which injuries should be prioritised in a risk management plan [19,55].

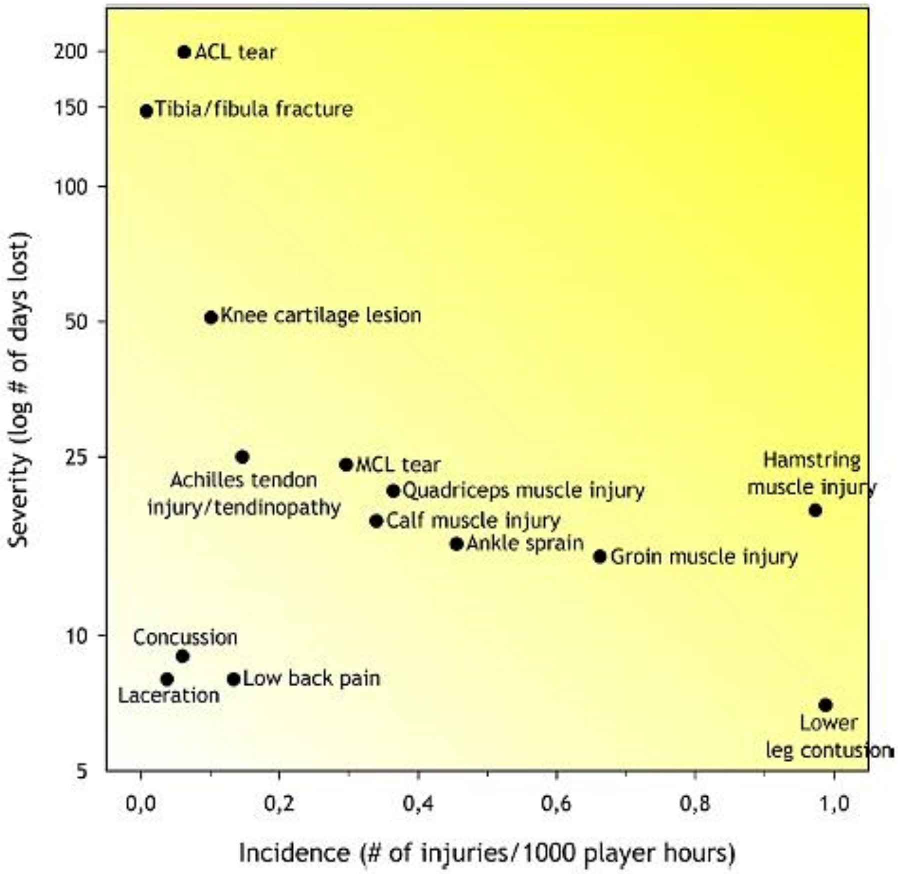


Figure 3. Quantitative risk matrix illustrating the relationship between the severity and incidence of the most commonly reported injury diagnoses. For each diagnosis, severity is presented as the average number of days lost from training and competition (log scale), and incidence as the number of injuries per 1000 hours of total exposure. Figure adapted from Bahr et al. [19].

The growing body of literature regarding the injury profile in youth football players that has been briefly presented in this section has also led to the publication of the first review articles in the last years. The epidemiology of injuries in sub-elite youth footballers was gathered by the review of Faude et al. [10], while the injury profile in elite youth footballers was analysed by the systematic reviews of Pfirrmann et al. [9] and Jones et al. [8]. Furthermore, this recent study of Jones et al. [8] made a step forward and combined and estimated pooled data for the overall incidence, reporting injury rates of 7.9 and 3.7 time-loss injuries per 1000 hours of exposure for elite players aged under (U) 17 to U21 and U9 to U16 years old, respectively. However, pooled estimates for training and competition incidences, as well as for injury patterns (location, type, severity, mechanism, and/or type of incident) have not been reported yet. Therefore, a meta-analytical investigation is required to accurately identify the most common and severe injuries, and where (anatomical location) and when (matches or training sessions) they usually occur in these paediatric cohorts. Additionally, the discrepancies presented by the limited studies that have analysed epidemiological data by maturity status warrant further prospective studies that inform about injury incidence, pattern and burden in youth football players.

1.2 Injury risk factors

The second step to design an effective preventive measure is to establish the aetiology and mechanisms of the injury. Research on injury risk factors has been recommended for two reasons: to help understand why injuries occur and to predict who is at high risk of injury [56]. Both the identification of the pattern of relationships (interactions) among specific risk factors in youth population as well as the development of robust screening models to predict the injury risk are therefore key elements in this step to improve the effectiveness of preventive strategies.

Although most of studies investigating injury risk factors in football players have been mainly focused on adults and female youth players [57,58], recent studies have also identified a range of personal, psychological, neuromuscular and biomechanical variables that could be incorporated into what Bittencourt et al. [21] defines as *web of determinants* for injury occurrences in male youth football players [53,59–74] (Table 1). Despite being a non-modifiable factor, one determinant that cannot be ignored in youth athletes is the individual growth and maturation process. This factor notably modulates the physical and physiological changes experienced by players throughout childhood and adolescence [46,75,76], playing a main role in the complex interaction between the different components of the web of determinants that can increase the injury risk. Thus, the identification of the influence of maturation on other potential risk factors is essential for understanding how susceptibility to injury may change along the youth participation in sport. Among modifiable factors, the adoption of aberrant lower extremity movement patterns during the execution of high intensity actions such as jumping and landing tasks has been suggested as a primary determinant for injuries in youth players [59,67]. Identifying abnormal landing patterns through a reliable and cost-effectiveness pre-participation screening test may then assist grass-roots coaches to detect players at high risk in the real framework of youth football practice.

Table 1. Potential injury risk factors in male youth football players.

Modifiable	Non-modifiable
Playing position [74]	Previous injury [72,73]
Skill level [60]	Age [59,67,71]
Deficits in muscle strength [61,62]	Growth and maturation [53,59,67–69]
Strength imbalances [59,63,67]	Anthropometric measures [67–69]
Abnormal movement patterns [59,67]	Leg dominance [70,71]
Flexibility [68]	
Dynamic balance [62,66,67]	
Fatigue [64,65]	
Stress and anxiety symptoms [77,78]	

1.2.1 Growth and maturation

Adolescent players are in a transitional period characterised by important somatic growth, and substantial musculoskeletal, physiological and sexual development that turn the child into a mature adult [79]. These changes promote the development of motor performance skills and physical fitness [46]; however, the non-linearity and complexity of the biological maturation has placed this process as a potential (and unique) risk factor for injury in paediatric populations.

Within the context of youth football, biological maturation can be defined as the status, timing and tempo of progress to achieving a mature state [45,80] (Figure 4). Firstly, maturity *status* refers to the state of maturation at the time of observation. As presented in the section 1.1 of the general introduction, the limited available research on maturity status seems to link periods around the PHV with an increased risk for injury in youth football [12,50–52]. Secondly, *timing* refers to the age at which specific maturational events occur. In contrast to maturity status, differences in injury incidence between earlier and later maturing groups have not been consistent among previous studies [11,50,81]. While Johnson et al. [50] did not reported differences between maturity timing groups, Le Gall et al. [81] and Van der Sluis et al. [11] found that earlier and later maturing players were at greater injury risk, respectively. Finally, *tempo* refers to the rate at which maturation progresses. A high tempo of maturation and high growth rates (>7.2 cm/year) have been proposed as increasing the risk in elite-standard youth football, which may also explain the high incidence of injuries found around the PHV [69]. Therefore, it is important to appreciate and understand changes in injury risk with biological maturation to be able to distinguish those players at greatest risk of injury.

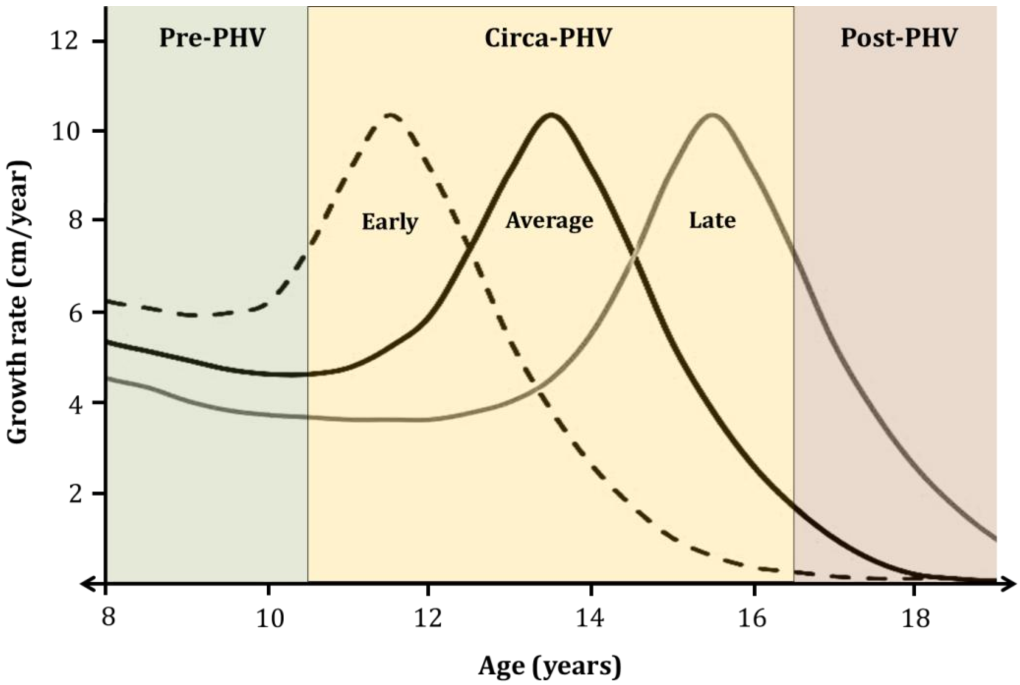


Figure 4. Change in growth rates with chronological age, maturity status, and maturity timing. Figure adapted from Lloyd et al. [47]

Several mechanisms have been hypothesised as to the cause of increased injury occurrence during adolescence. Temporary disruptions in motor performance due to the rapid growth of the whole body, as well as changes to limb proportions and moments of inertia during PHV [82,83] can derive in an increase injury risk [46,84]. In fact, a number of studies have investigated the influence of maturation on different parameters of physical performance (running speed and acceleration [85], jumping distance [86]), neuromuscular control (static and dynamic balance [66,87], landing kinematics [88]), and muscle strength (knee flexion and extension isokinetic strength [89]) in youth football players, reporting some adaptations or deficits that may contribute to this increased injury risk during the adolescent growth spurt. However, despite the possible differences in onset and rate of bones and muscles development during the growth spurt may result in significant restrictions on muscle-tendon flexibility [46], no studies have examined the impact of maturation on lower extremity joint ROMs in youth football players. The potentially restricted joint ROMs may lead adolescent football players to adopt altered movement strategies during the execution of high intensity dynamic tasks that increase the injury risk. Consequently, an understanding of the effect of maturation on lower extremity ROMs may help those working with youth football players to design tailored age and maturational stage-based training programs to both optimise flexibility performance and reduce injury risk.

1.2.2 Landing kinematics

Altered neuromuscular control strategies during landing tasks, commonly shown by players at years around the peak height velocity (PHV)[46,84], have been proposed as one of the potential risk factors for lower extremity injuries in football players. Particularly, dynamic valgus alignment, defined as a medial or valgus collapse of the knee in the frontal plane during tasks which involve hip and knee flexion [90], has been suggested as a main risk factor for non-contact medial collateral ligament (MCL) and anterior cruciate ligament (ACL) injuries [57]. Aberrant valgus positions during landing have shown to lead these passive joint structures to an excessive tension force and thus to increase the likelihood of tissue failure [91,92].

While a higher extent of dynamic valgus in postpubescent female compared to their male peers has been found [93,94], no significant differences in knee medial displacement values between prepubescent boys and girls have been reported [93,95]. Likewise, a large proportion of adolescent male football players with knee valgus alignment during landings have been recently identified [88], which might suggests a frequent manifestation of this potential injury mechanism also at some stages of the young male athletes' development. Due to the devastating consequences derived from severe knee injuries such as ACL tears [15], dynamic valgus assessments have been therefore placed on the front line of screening batteries and prevention strategies for injury reduction.

To this end, numerous jumping and landing tests have been designed and investigated. As a recent systematic review has shown [96], the drop vertical jump (DVJ) has been a popular test choice. Although some associations between DVJ landing kinematics and the occurrences of injuries in youth sport have been found [97], the limited external validity of this test has led to the emergence of new screening tests with performances closer to the competitive practice, such as the tuck jump assessment (TJA) [98]. Despite in the original protocol movement mechanics were qualitatively rated using a 10-item scoring sheet, quantitative assessment of important kinematic markers such as dynamic valgus has increased in the last years to solve the questionable reliability of data obtained through subjective analyses in the TJA [99,100]. However, the restricted testing time and human resources in youth football applied settings together with the multifactorial nature of sport injury may require coaches to prioritise between landing screening tools. Therefore, the knowledge of the reliability and potential relationships between DVJ and TJA tests, as well as their interaction with maturity status, may assist coaches' decision making to select the most informative jumping and landing assessment in youth football.

Although most studies analysing landing technique in youth football have mainly focused on frontal plane kinematic measures, the available literature has also suggested that sagittal plane biomechanics are a major mechanism of ACL loading [91]. Several studies have shown an increase in ACL loading as the knee flexion angle decreases, and reduced hip, knee and ankle joint flexion angles have been hypothesised to contribute to knee valgus as a compensatory strategy to modulate the ground reaction forces when landing [101,102]. Thus, the study of the lower extremity landing kinematic pattern would also require the assessment of potential deficits in the sagittal plane to provide a holistic view of the youth players' competency in landing tasks [96].

1.2.3 Injury prediction models

Lower extremity injuries are still very common incidents in youth team sports [103] and particularly in youth football [12,34], despite the substantive efforts made by the scientific community and sport practitioners to prevent these injuries. In fact, some recent investigations have revealed that the incidence rates have not been reduced during the last years [104–106]. One of the main reasons that has been suggested to explain why injury rates remain so high is the lack of available screening models, designed to identify athletes at high risk of suffering an injury, with adequate predictive properties (i.e., accuracy, sensitivity and specificity)[56].

Perhaps the lack of valid screening models to predict injuries in sport settings could be attributed to the use of statistical techniques (e.g., traditional logistic regression) that have not been specifically designed to deal with class imbalance problems, such as the injury phenomenon, in which the number of injured players (minority class) prospectively reported is always much lower than the non-injured players (majority class) [107–110]. Thus, in many scenarios including sport-related injury, traditional screening models are often biased (for many reasons) towards the majority class (known as the "negative" class) and therefore, there is a higher misclassification rate for the minority class instances (called the "positive" examples), which indeed represent the most important concern (i.e., the injured players). Other issue with the current body of the literature is that the external validity of the screening models available may be limited because they are built and validated using the same data set (i.e., cohort of athletes). Apart from resulting in overly optimistic models' performance scores, this evaluation approach does not indicate the true ability of the models to predict injuries in different data sets or cohort of athletes, which may be very low and consequently, not acceptable for injury prediction purposes. This appears to be supported by the fact that the injury predictors identified by some prospective studies have not been replicated by others using similar designs and assessment methodologies but with different samples of athletes [61–64,66,72,73]. These limitations alongside recent evidence demonstrating that incidence rates have not decreased over recent years have led some researchers to suggest that screening batteries may be of limited interest for injury prediction, and thus a waste of time and resources [56,63,64].

In Machine Learning and Data Mining environments, some methodologies (e.g., pre-processing, cost-sensitive learning and ensemble techniques) have been specially designed to deal with complex (i.e., non-lineal interactions among features or factors), multifactorial and class imbalanced scenarios [107–110]. These contemporary methodologies along with the use of resampling methods to assess models' predictive power (i.e., cross-validation, bootstrap and leave-one-out) may overcome the limitations inherent to the current body of knowledge and enable the ability to build robust, interpretable and generalisable models to predict sport-related injuries [111]. In fact, recent studies have used these contemporary methodologies and resampling methods to predict injuries in elite team sport athletes [111–119], including professional footballers [112,115,118,119].

Despite there seems to be some shared injury risk factors between adult and young male players (e.g., history of previous injuries [72,73,112,119], strength imbalances [59,63,67,120]), the documented anatomical and neuromuscular age- and maturation-related differences [75,83] might led, for example, young football players to adopt different movement patterns and neuromuscular control strategies during the execution of certain high intensity dynamic tasks that are inherent to the game of football (e.g., sprinting, cutting, and landing) compared to their more mature and adult peers [88,93]. This circumstance might elicit that, for the same type of injury (e.g., ACL tear), biomechanical differences (e.g., dynamic knee valgus motion) in predominant injury mechanisms (e.g., landings) could be identified between both adult and adolescent players and hence, not only the risk factors (e.g., lower extremity strength deficits) but also their impact or contribution (individual and collectively) on the likelihood of sustaining such injury could be significantly different. Thus, it seems important to develop specific models to profile youth football players' injury risk. To the authors' knowledge, there are only two recent studies that have built robust screening models using Machine Learning techniques in male youth football players [67,68]. Both screening models have been based on preseason anthropometric (e.g., stature, weight and sitting height) and motor coordination and physical fitness (e.g., strength, flexibility, speed, agility, endurance, balance) measures obtained through field-based tests. These studies have reported promising results such as 3.5-fold greater sensitivity scores than traditional logistic regression techniques [67] and an AUC score of 0.850 [68].

If Machine Learning techniques could build *user friendly* models, with adequate predictive properties and using a predominance of data obtained from questionnaires and field-based screening tests, injury prediction would be feasible for youth football teams. In case these techniques provided a trustworthy positive response, coaches and physical trainers may know whether any of the currently available questionnaires and field-based tests to predict injuries itself works and a hierarchical rank could be developed based on their individual predictive ability of those that showed reasonably high AUC, true positive and true negative scores [111]. Likewise, this knowledge might be used to analyse the cost-benefit (i.e., balance between the time required and the predictive ability of the data recorded) of including measures in the screening sessions for injury prediction.

1.3 Lines of action of this thesis

Based on everything stated above, there exists a need to reduce the number of injuries in youth football and, for this purpose, the several limitations presented in the available literature regarding the injury problem need to be solved. Therefore, the current doctoral thesis focuses on establishing the extent of the injury problem defining the incidence, burden, and pattern of injuries in youth football players (studies 1 and 2), improving the current understanding regarding the aetiology and mechanisms of injury through the analysis of the interaction between growth and maturation with other potential risk factors (studies 3 and 4) and the development of robust screening models for injury prediction (study 5) using contemporary Machine Learning techniques (Figure 5). The main findings of this thesis will help grass-root coaches and physical trainers in the decision-making process for injury prevention.

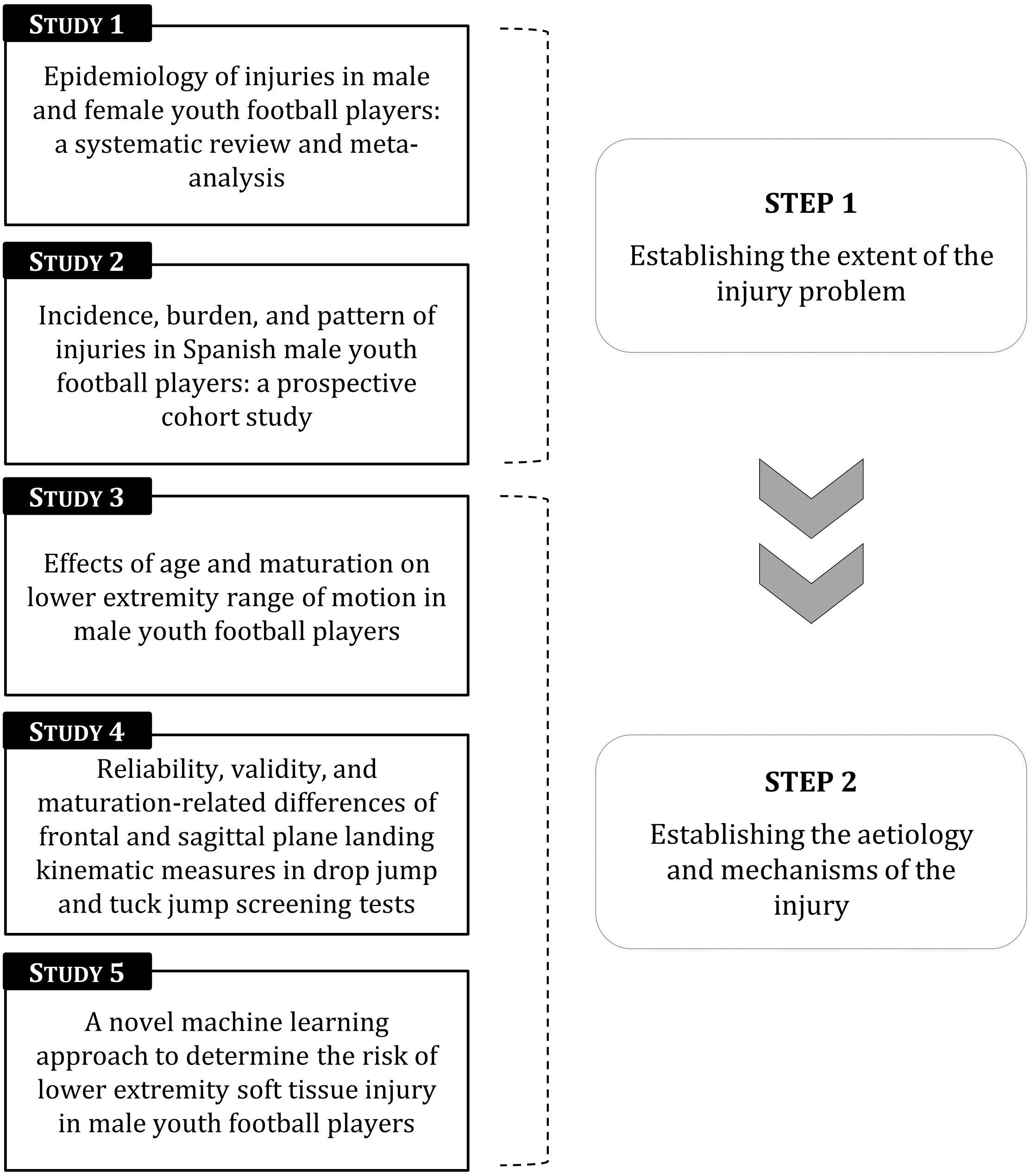


Figure 5. Lines of action of the studies presented in the current doctoral thesis.

2

RESEARCH OBJECTIVES AND HYPOTHESES

2.1 Aims and objectives of the thesis

The current doctoral thesis aims (a) to establish the extent of the injury problem in male youth football players, (b) to improve the understanding regarding the aetiology and mechanisms of injury through the analysis of the interaction between potential injury risk factors, and (c) to develop a robust prediction model to identify young football players at high or low risk of injury using preseason screening.

In order to achieve these aims, five studies were carried out. S*tudy 1* reviewed and meta-analysed the injury incidence previously reported in original studies to describe the injury profile of the young football player. Although the injury profile of female youth players was also explored in this first study, it should be clarified that the investigation of the epidemiology and aetiology of the injuries for this cohort of athletes is out of scope of the present doctoral thesis. Notwithstanding, it is not uncommon for girls to train and compete with boys in youth football context and thus, in this first investigation we aimed to provide grass-roots coaches with a comprehensive overview of injuries that can be expected when working with young players, analysing potential sex-related differences. *Study 2* utilised a prospective cohort design to examine the epidemiology of injuries over a competitive youth football season in Spain. *Study 3* explored the effects of chronological age and stage of maturation on several hip, knee and ankle range of motion measures in male players 10-19 years old. *Study 4* established the reliability and concurrent validity for frontal and sagittal plane landing kinematic measures in drop jump and tuck jump tasks, considering potential interactions between lower extremity kinematic patterns and players' maturity status. Finally, *Study 5* used Machine Learning and Data Mining techniques to predict male youth football players at high risk of injury.

In addition, the following specific objectives were established according to the five studies presented in this doctoral thesis:

Study 1. *Epidemiology of injuries in male and female youth football players: a systematic review and meta-analysis*.

1. To conduct a systematic review and meta-analysis quantifying the overall, training and match injury incidences in youth football players.
2. To determine the overall effects regarding location of injuries, type of injuries, severity of injuries, mechanism of injuries, type of incident, age group, and level of play.

Study 2. *Incidence, burden, and pattern of injuries in Spanish male youth football players: a prospective cohort study.*

3. To describe the specific injury profile in our cohort of Spanish male youth football players during a follow-up season.
4. To examine potential differences regarding the incidence rate and injury burden across different chronological age groups and stages of maturation.

Study 3. *Effects of age and maturation on lower extremity range of motion in male youth football players.*

5. To analyse and compare the influence of chronological age and peak height velocity (as an indicator of biological maturity) on lower extremity joints (hip, knee, and ankle) range of motion.
6. To describe the lower extremity range of motion profile using a comprehensive approach in youth football players.

Study 4. *Reliability, validity, and maturation-related differences of frontal and sagittal plane landing kinematic measures in drop jump and tuck jump screening tests.*

7. To determine the inter-rater and intra-rater reliability of 2-dimensional landing kinematic assessment for several frontal (frontal plane projection angle) and sagittal (hip, knee and ankle flexion angles at initial contact and peak flexion) plane measures during drop vertical jump and tuck jump tasks.
8. To assess the concurrent validity between the drop vertical jump and the tuck jump tests for all landing kinematic measures.
9. To evaluate the ability of both jumping tasks to detect differences between players' stage of maturation (pre-, circa-, and post-PHV).

Study 5. *A novel machine learning approach to determine the risk of lower extremity soft tissue injury in male youth football players.*

10. To analyse and compare the individual and combined ability of a range of personal, psychological, neuromuscular and motor performance measures obtained from a

preseason field-based screening battery to predict lower extremity soft-tissue injuries in male youth football players using supervised Machine Learning techniques.

2.2 Research hypotheses

The following hypotheses were established for each of the studies included in the current doctoral thesis:

Study 1. *Epidemiology of injuries in male and female youth football players: a systematic review and meta-analysis*.

1. Based on results from previous studies [28,32,34], the incidence of injury during matches is expected to be higher than during training sessions in youth football players.
2. Lower extremity (and especially thigh, knee, and ankle regions) will present the highest injury incidence in youth football [12,26–29,32], with muscle/tendon representing the most commonly injury type [24,26–29].
3. The incidence of injuries will probably increase with advances in chronological age [26,29,34,42].

Study 2. *Incidence, burden, and pattern of injuries in Spanish male youth football players: a prospective cohort study.*

4. Similar to the recent findings [28,29], a higher incidence and probability of injury over a competitive season is hypothesised in Spanish male football players.
5. A heightened risk will be observed at periods around the peak height velocity compared to prepubescent players [12,50–52], showing also these players the highest injury burden.
6. Most burdensome diagnoses will affect the hamstring and quadriceps muscles as well as ankle ligament structures [34,121].

Study 3. *Effects of age and maturation on lower extremity range of motion in male youth football players.*

7. Based on both the documented negative and temporary influence of maturation on essential motor performance [85–88], and the reported decrease in hip and knee ranges of motion with advancing age in young athletes [122–124], it is assumed that football players belonging to the younger age groups and whose predicted maturation status is categorised as “before PHV” will show higher hip and knee ranges of motion than their older counterparts that are immersed in the maturation years of “around” and “after PHV”.

Study 4. *Reliability, validity, and maturation-related differences of frontal and sagittal plane landing kinematic measures in drop jump and tuck jump screening tests.*

8. Bearing in mind reliability data from previous studies using 2-dimensional video-analysis to assess landing kinematics during drop vertical jumps [101,125] and tuck jumps [88,126], a good-to-excellent inter- and intra-rater reliability is presumed for all kinematic measures analysed in both jumping and landing screening tests.
9. Given that previous research has demonstrated a task-dependent nature of landing from a jump [127–129], low concurrent validity is likely to be found in frontal and sagittal kinematic measures in both drop vertical and tuck jump.
10. Considering its higher sensitivity to detect differences in dynamic valgus between maturation groups [126], a greater ability to discriminate between developmental stages is expected for the tuck jump assessment task.

Study 5. *A novel machine learning approach to determine the risk of lower extremity soft tissue injury in male youth football players.*

11. Since the sport-related injury has been defined as a multifactorial and complex phenomenon [21], the model built through the application of Machine Learning techniques will combine different personal, psychological and neuromuscular variables to predict youth football players at high or low risk of sustaining an injury.

PART II

MAIN STUDIES

3

EPIDEMIOLOGY OF INJURIES IN MALE AND FEMALE YOUTH FOOTBALL PLAYERS: A SYSTEMATIC REVIEW AND META-ANALYSIS

[STUDY 1]

3.1 Introduction

Football (soccer) is the most popular sport in the world [130]. Players are required to repetitively perform sudden accelerations and decelerations, rapid changes of directions, jumping and landing tasks, as well as being involved in several tackling situations to keep possession of or to win the ball [4,10]. These high-intensity situations alongside frequent exposure to collisions and contacts result in a notable increase in injury risk compared to other individual sports such as tennis [131] or gymnastics [132]. In fact, it has been suggested that football is among the top five injury-prone sports [13,14]. This increased risk is especially relevant in children and adolescents where individual growth and maturation may predispose youth players to sustain an injury [27,42,52,133]. Football-related injuries can counter the health-related beneficial effects of sports participation at a young age if a child or adolescent is unable to continue to participate because of the residual effects of injury [15].

There is a clear necessity to develop and implement measures aimed at preventing and reducing the number and severity of football-related injuries in youth players. However, before implementing any injury prevention measure it is essential to know the injury profile of youth football [16,17]. In the last two decades, a number of prospective studies have been published describing the incidence and pattern of injuries in youth football players [12,24,28–32,134–137]. Recently, a systematic review has combined and meta-analysed most of the incidences available in elite male youth football and has reported overall injury rates of 7.9 and 3.7 time-loss injuries per 1000 hours of exposure for players aged under (U) 17 to U21 and U9 to U16 years old, respectively [8]. Furthermore, this study has also proposed that a median of 18% (nearly one-fifth) of all reported injuries might be classified as severe (i.e., requiring more than

28 days recovery time) with muscle injuries accounting for 37% of all injuries sustained in elite male youth football, although the pooled incidences for injury patterns (i.e., location, type, mechanism, and severity of injuries) have not yet been provided.

The injury profile in youth male football should not be extrapolated to young female players due to the well-documented anatomical, hormonal and musculoskeletal sex-related differences [138,139]. In fact, epidemiological studies have pointed out that male youth footballers seem to be more prone to suffer muscle injuries [24,26–32,41,64,135,140] whereas ligament sprains are the most frequently diagnosed type of injury in female youth players [137,141]. Likewise, disparities in training workloads (volume, intensity and weekly frequency), medical and performance teams (e.g., number of members involved and level of education) and physical (e.g., number of high intensity actions performed during football play) and mental (e.g., expectations from coaches and parents) demands that often exist between elite and sub-elite players, and younger and older age groups, might also generate differences in injury incidence rates according to the level of competition and stages of development [10,24,26,142]. Indeed, some studies have showed that older adolescent football players who are approaching the professional-league level of play are more susceptible to sustaining injuries than their counterparts playing at a grass-roots level [33,143].

The potential for differences in injury profile in youth football by sex requires meta-analytical investigation to accurately identify the most common and severe injuries, as well as where (anatomical location) and when (matches or training sessions) they usually occur in these pediatric cohorts. However, to the best of the authors' knowledge, no systematic reviews and meta-analyses have been published describing the injury profile of youth football while analyzing potential sex-related differences. Likewise, disparities in training and match demands require the identification of those levels of play and age groups that may present a higher incidence of injury. Therefore, the main purpose of the current study was to conduct a systematic review and meta-analysis quantifying the incidence of injuries in male and female youth football players. The secondary purpose was to determine the overall effects regarding location of injuries, type of injuries, severity of injuries, mechanism of injuries, type of incident, age groups, and level of play.

3.2 Methods

This systematic review and meta-analysis was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [144]. The PRISMA checklist is presented in Appendix 1. The research protocol was registered with the PROSPERO

International prospective register of systematic reviews (http://www.crd.york.ac.uk/PROSPERO/), registration number CRD42019119279.

3.2.1 Study selection

Eligibility criteria were established and agreed upon by all authors based on the concept of population, intervention/indicator, comparator/control, outcome and study design (PICOS) [144,145] (for more information, please see Appendix 2).

Thus, to be included in this systematic review and meta-analysis studies had to fulfil the following criteria:

1) Participants had to be male or female football players younger than 19 years old.
2) Injury must be defined in terms of time loss (i.e., injury that results in a player being unable to take a full part in future football training or match play) [146,147].
3) The study had to be prospective cohort or randomised control trials (control groups), to minimise the occurrence of errors associated with recall [146,147], and the full-text article had to be published in a peer-reviewed journal before January 2021.
4) Eligible studies must report either injury incidence rate or prevalence among the surveyed players separately by sex or provide sufficient data from which these figures could be calculated through standardised equations.

Studies using injury definitions other than time loss were excluded. Literature reviews, abstracts, editorial commentaries and letters to the editor were also excluded. Finally, 22 authors were contacted for clarification on raw data extraction [24,26,27,31,34,54,63,64,68,121,141,148–154] and participant information [28,38,134,155]. Most of the authors contacted (18 out of 22) gave further details, where requested [26–28,31,34,38,41,54,64,68,134,148,150–155].

3.2.2 Search strategy

A systematic computerised search was conducted up to 31st December 2020 in the databases MEDLINE, PubMed, Web of Science, SPORTDiscus and Cochrane Library. In addition, a complementary search of the reference lists of included articles and a Google Scholar search were also performed. This was done using backward citation tracking (to manually search the reference list of a journal article), and forward citation tracking (scanning a list of articles that had cited a given paper since it was published) [156]. Citations were tracked using Google Scholar to make sure that studies were not missed inadvertently. When additional studies that met the inclusion criteria were identified, they were included in the final pool of studies.

Relevant search terms were used to construct Boolean search strategies, which can be found in Appendix 3.

Two reviewers independently (FJR-P and AL-V) selected studies for inclusion in a two-step process. First, studies were screened based on title and abstract. In a second stage, full-text studies were reviewed to identify those studies that met the eligibility criteria. A study was excluded immediately once it failed to meet a single inclusion criterion. Disagreements were resolved through consensus or by consulting a third reviewer (FA).

3.2.3 Data extraction

A codebook was produced to standardise the coding of each study in order to maximise the objectivity and each study was codified by two different reviewers. The moderator variables of the eligible studies were coded and grouped into three categories: 1) general study descriptors (authors, year of publication and study design), 2) study population (sample size, sex and level of play), 3) epidemiological data (injury [including it mains characteristics according to Fuller et al. [146]] and exposure data). If applicable, the authors of included studies were contacted to provide clarifications or access to raw data. Operational definitions used in this study are shown in Appendix 4. Appendix 5 also displays the moderator variables coded separately by category.

The purpose of the current meta-analysis was to determine the overall effects of: 1) football-related injury incidence (overall vs. training vs. match injuries rates) in male and female youth players, 2) location of injuries (lower extremity vs. trunk vs. upper extremity vs. head and neck), 3) type of injuries (fractures and bone stress vs. joint [non-bone] and ligament vs. muscle and tendon vs. contusions vs. laceration and skin lesion vs. central/peripheral nervous system vs. undefined/other), 4) severity of injuries (slight/minimal [1-3 days] vs. minor/mild [4-7 days] vs. moderate [8-28 days] vs. major/severe [>28 days]), 5) mechanism of injury (overuse vs. traumatic injuries), 6) new vs. recurrent injuries, 7) age groups (U17-U19: 16-19 years old; U13-U16: 12-16 years old; U12: lower than 12 years old), 8) level of play (sub-elite [low level] vs elite [high level]), and 9) probabilities of injuries over a season.

With regard to the category level of play, studies were classified into two different labels: sub-elite and elite. Elite youth football players were defined as follows: youth or adolescent elite youth football players between 8 and 19 years of age whose performance status was described as *football academy*, *high level*, or *elite* [8,9]. Players not described as belonging to a professional youth academy, playing at a high level or classified as elite were considered as sub-elite.

The age group category was classified into three different labels in order to reflect the taxonomy of children (U12 and below), pubertal adolescents (U13-U16) and post-pubertal adolescents (U17-U19).

3.2.4 Quality and risk of bias assessment

The reporting quality of included studies was assessed using an adapted version of the "Strengthening the Reporting of Observational Studies in Epidemiology" (STROBE) statement by Vom Elm et al. [157] Appendix 6 displays a description of the 22 criteria designed to assess quality of the studies included in the meta-analysis with the STROBE scale. Although STROBE statement was not developed to directly assess the quality of publications, compliance to the STROBE checklist has been recognised as a proxy for quality of the publications on observational studies since there is no validated instrument for this purpose [158,159]. The items and subitems of the STROBE statement were scored as 0 or 1, with a score of 1 provided for each checklist item that was properly completed. Using this checklist, a maximum score of 34 would indicate the article fulfilled requirements for a high-quality publication.

Furthermore, to assess risk of bias of external validity quality, an adapted version of the Newcastle Ottawa Scale (NOS) for cohort studies was used. The original NOS is a quality assessment tool for cohort and case-control studies which contains eight items categorised into three domains (selection, comparability and exposure) and uses a star rating system to indicate the quality of a study (maximum of eight stars) [160]. An article could be awarded a maximum of one star for each item if appropriate methods had been clearly reported. Thus, a total of 8 stars could be given to an article. The higher the number of stars given to an article, the lower the risk of bias. The instrument was modified for the purpose of this review (the incidence of injuries) and the population of football players as with previous meta-analysis [161]. Appendix 7 displays a brief description of each item of the adapted version of the NOS tool used in this study.

The data extraction and quality assessments (including risk of bias of external validity) were conducted by two reviewers (FJR-P and AL-V). To assess the inter-coder reliability of the coding process, these two reviewers (FJR-P and AL-V) coded 22 studies randomly (54%) (including quality assessment). For the quantitative moderator variables intra-class correlation coefficients ($ICC_{3,1}$) were calculated, while for the qualitative moderator variables Cohen's kappa coefficients were applied. On average, the ICC was 0.84 (range: 0.69-1.0) and the kappa coefficient was 0.89 (range: 0.79-1.0), which can be considered highly satisfactory, as proposed by Orwin et al. [162] Inconsistencies between the two coders were resolved by consensus, and when these were due to ambiguity in the coding book, this was corrected. As before, any disagreement was resolved by mutual consent in consultation with a third reviewer (FA).

3.2.5 Quality of the evidence

The quality of the evidence for the overall, training and match incidences of injuries in male and female youth football players was graded (high, moderate, low, or very low evidence) using a modified GRADE approach. Four of the five GRADE factors were used in this meta-analysis: risk of bias (i.e., the methodological quality of the studies), inconsistency (i.e., unexplained inconsistency of results across studies), imprecision (i.e., total sample size of the available studies), and indirectness (i.e., evidence from different populations than the population of interest in the review). The fifth factor, publication bias, is difficult to assess in observational studies due to a lack of registries for these types of studies [163]. Therefore, we did not take this factor into account in this meta-analysis. The starting point is always the assumption that the pooled or overall result is of high quality. The quality of evidence was subsequently downgraded by one or two levels per factor to moderate, low or very low when there was a risk of bias, inconsistency, imprecision, or indirect results [164].

3.2.6 Statistical analysis

Injury incidence rates per 1000 hours of player exposures were extracted from the included studies. If injury incidence rates were not specifically reported, they were, if possible, calculated from the available raw data using the following formulas:

$$\text{Incidence} = 1000 \times (\sum \text{injuries} / \sum \text{exposure hours})$$

$$\text{Incidence} = \text{nº of injuries} / (\text{nº of matches} \times 11 \text{ players} \times \text{match duration}) \times 1000$$

Similar to previous meta-analysis on epidemiology of injuries in sports [161,165,166], data were modelled by a random effects Poisson regression model, as previously described [167]. The response variable in each meta-analysis was the number of observed injuries, offset by the log of the number of exposure hours (injury incidence rates). A random effects term was included to account for the correlation arising from using multiple rows of data from the same study. Factors of interest were included as random effects. A weighting factor used was: study exposure time (hours) / mean study exposure time (hours). For injury incidence data, the overall estimated means for each random effect factor were obtained from the model and then back-transformed to give incidence rates, along with 95% CIs (CIs that showed negative values were adjusted to 0 for better interpretability). Heterogeneity was evaluated using the I^2 statistic, which represents the percentage of total variation across all studies due to between-study heterogeneity [168]. The possible influence of the following variables on the model was analysed independently through univariate and multivariate analyses: registration period, year of the study publication, age of the players, STROBE score, NOS stars, and number of teams included in the study. Sub-analyses separately by sex were carried out when there were at least three injury incidence rates (cohorts) coming from a minimum of two different studies and the sum of the number of participants involved was higher than 30 players.

Where match injury incidence was given per 1000h, post hoc probabilities of injury over a season were determined using the following equation developed by Parekh et al. [169]:

$$\mathrm{P}(\kappa) = \frac{(\lambda t)^{\kappa} \mathrm{e}^{-\lambda t}}{\kappa!}, \quad \text{for } \kappa = 1,\ 2,\ 3 \ldots$$

The equation shows the Poisson distribution model for youth football injury probability, where κ is the total number of injuries occurring in a squad of players and total time of match play exposure over a single season, t is the time-interval in hours, e is the base of the natural logarithm (e = 2.71828...), $\kappa!$ is the factorial of 'κ' and λt is the injury incidence multiplied by length of exposure.

The Poisson distribution for injury probability has previously been employed in football [8] and rugby [170] studies, and can describe the frequency of injuries occurring that is assuming these injuries occur independently and take place over time or space [171]. In order to calculate injury probability incidence rate, duration and number of matches played in a single season are required [169]. Therefore, to use Poisson distribution for injury probability it must be assumed that each player within the squad would have a similar risk of sustaining injury. Probability calculations were based on match duration being between 40 and 90 min as per Elite Player Performance Plan (EPPP), Royal Dutch Football Association (KNVB), French Football Federation (FFF), Royal Spanish Football Federation (RFEF), German Football Association (DFB) and Union of European Football Association (UEFA) youth regulations [172], a conservative 30 matches per season as per EPPP regulations, and injuries being independent events [8]. Injury probability was calculated separately for male and female players, and also by age groups.

All statistical analyses were performed using the statistical software package R Version 2.4.1 (The R Foundation for Statistical Computing) and the "metafor" package [173]. For injury incidence data, the overall estimated means for each random-effect factor were obtained from the model and then back-transformed to give incidence rates, along with 95% confidence intervals (CIs).

3.3 Results

3.3.1 Descriptive characteristics of the studies

A total of 2150 references were identified with all search strategies, of which 43 met the inclusion criteria (resulting in 111 cohort groups as 19 studies had more than one group) (Figure 6) [12,24–32,34,36–38,41,44,52,54,63,64,68,121,134–137,140,141,148,150–155,174–181]. These 43 studies were carried out between 1985 and 2020 and comprised male [12,24–32,34,36–38,41,44,52,54,63,64,68,121,135,140,148,151–155,174–179,181] and female [36,44,54,134,136,137,141,148,150,152,153,174,175,180] players from different countries, especially in Europe. Table 2 provides a descriptive summary of the included studies.

With regards to the reporting quality of the studies, the mean score obtained with the STROBE quality scale was 23 (minimum: 11, maximum: 32). Regarding NOS scale, the mean score obtained was 6.5 (minimum: 5, maximum: 8). The quality of evidence according to GRADE was downgraded to moderate (risk of bias and inconsistency) and low (risk of bias, inconsistency, indirectness, and imprecision) for overall, training and match injury incidence outcomes in males and females, respectively. The detailed data for STROBE, NOS and GRADE scales are presented in Appendix 8, 9 and 10, respectively.

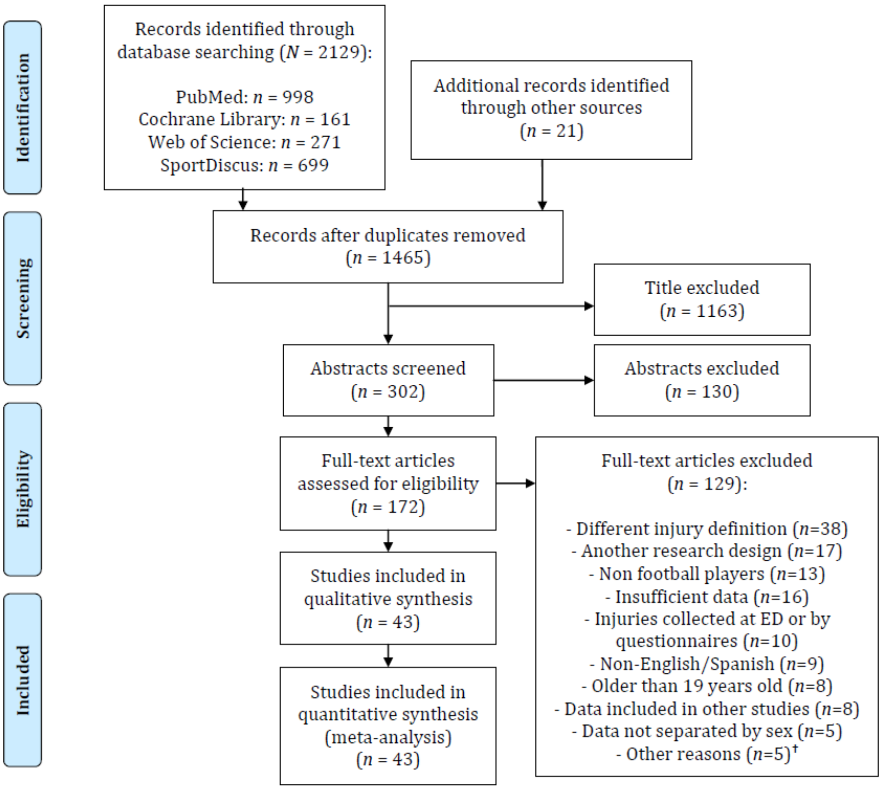


Figure 6. Flow chart of the selection of studies for the meta-analysis. †No injury definition (*n*=2), full-text not available (*n*=2), and incidence reported jointly with other sports (*n*=1).

Table 2. Characteristics of the studies included in the meta-analysis.

Reference	Study duration (weeks)	Participants			Exposure (hours)			Injuries			Incidence			STROBE - /34 (reporting quality)	NOS - /8 (methodological quality)
Continent (or event)/ Year/Level of play		Sex (cohort)	Age (range)	Teams (players)	Overall	Training	Match	Overall	Training	Match	Overall	Training	Match		
Andreasen et al. [174] IT / 1991 / EL	1	M	U19 (10-19)	- (9586)	-	-	25527	-	-	92	-	-	3.6	16	5
		F	U19 (10-19)	- (3321)	-	-	8890	-	-	39	-	-	4.4		
Azuma et al. [154] [F] Control AS / 2018-19 / SEL	40	M	U18 (15-18)	- (60)	25188	21408	3780	94	49	45	3.7	2.3	11.9	28	7
Backous et al. [36] NA / - / MI	3	M	U17 (6-17)	- (681)	14931.5	-	-	109	-	-	7.3	-	-	15	5
		F	U17 (6-17)	- (458)	10094.3	-	-	107	-	-	10.6	-	-		
Bianco et al. [31] [F] EU / 2012-13 / EL	44	M (a)	U16 (13-16)	- (54)	59058	53616	5442	72	60	12	1.2	1.2	2.2	20	6
		M (b)	U19 (17-19)	- (23)	24302	21984	2318	35	25	10	1.4	1.1	4.3		
		M (T)	U19 (13-19)	- (80)	83360	75600	7760	107	85	22	1.3	1.2	2.8		
Brito et al. [41] [F] EU / 2009 / SEL	6	M	U19 (12-19)	40 (741)	23364	20847	2517	53	37	16	2.5	1.8	6.8	21	5
Brito et al. [26] [F] EU / 2008-09 / SEL	43	M (a)	U12 (11-12)	- (179)	41666.7	-	-	25	-	-	0.6	-	-	22	7
		M (b)	U14 (13-14)	- (169)	37272.7	-	-	41	-	-	1.1	-	-		
		M (c)	U16 (15-16)	- (165)	40714.3	-	-	57	-	-	1.4	-	-		
		M (d)	U18 (17-18)	- (161)	44705.9	-	-	76	-	-	1.7	-	-		
		M (T)	U18 (11-18)	28 (674)	161850	149803	12047	199	139	60	1.2	0.9	4.7		
Bult et al. [12] [F] EU / 2013-16 / EL	117	M (a)	U12 (U12)	- (17)	3583	-	-	21	-	-	5.9	-	-	26	7
		M (b)	U13 (U13)	- (50)	9965	-	-	51	-	-	5.1	-	-		
		M (c)	U14 (U14)	- (54)	11332	-	-	84	-	-	7.4	-	-		
		M (d)	U15 (U15)	- (54)	11175	-	-	139	-	-	12.4	-	-		
		M (e)	U16 (U16)	- (53)	13066	-	-	113	-	-	8.7	-	-		
		M (f)	U17 (U17)	- (38)	11761	-	-	119	-	-	10.1	-	-		
		M (g)	U19 (U19)	- (43)	13475	-	-	93	-	-	6.9	-	-		
		M (T)	U19 (U12-19)	- (170)	74358	-	-	620	-	-	8.3	-	-		

Reference	Study	Participants			Exposure (hours)			Injuries			Incidence			STROBE - /34	NOS - /8
Continent (or event)/ Year/Level of play	duration (weeks)	Sex (cohort)	Age (range)	Teams (players)	Overall	Training	Match	Overall	Training	Match	Overall	Training	Match	(reporting quality)	(methodological quality)
Cezarino et al. [30] ^{F} SA / 2017 / EL	52	M (a)	U11 (10-11)	- (23)	4883.8	4516.7	367.1	2	1	1	0.4	0.2	2.7	29	8
		M (b)	U12 (11-12)	- (22)	4456.1	3908	548	8	8	0	1.8	2	0		
		M (c)	U13 (12-13)	- (25)	8120.4	7572.2	548.1	6	3	3	0.7	0.4	5.5		
		M (d)	U14 (13-14)	- (28)	12834.8	12394.8	440	21	17	4	1.6	1.4	9.1		
		M (e)	U15 (14-15)	- (28)	13176.4	12420.5	755.8	12	10	2	0.9	0.8	2.6		
		M (f)	U16 (15-16)	- (25)	12386.4	11731.2	655.2	27	24	3	2.2	2	4.6		
		M (g)	U17 (16-17)	- (28)	15084.9	14060.2	1024.7	46	32	14	3	2.3	13.7		
		M (h)	U18 (17-18)	- (16)	10359	9864	495	18	14	4	1.7	1.4	8.1		
		M (T)	U18 (10-18)	- (195)	81301.7	76467.8	4833.9	140	109	31	1.7	1.4	6.4		
Chena-Sinovas et al. [29] ^{F} EU / - / SEL	40	M (a)	U9 (7-9)	- (68)	8337.4	7492.8	844.7	19	12	7	2.3	1.6	8.3	15	6
		M (b)	U11 (10-11)	- (80)	14830.3	13290.3	1540	23	17	6	1.6	1.3	3.9		
		M (c)	U13 (12-13)	- (114)	22518	19681.9	2836.2	55	52	3	2.4	2.6	1.1		
		M (d)	U15 (14-15)	- (71)	14973.8	12905.8	2068	69	41	28	4.6	3.2	13.5		
		M (e)	U18 (16-18)	- (69)	18121.4	16058.9	2062.5	102	63	39	5.6	3.9	18.9		
		M (T)	U18 (7-18)	- (402)	78781	69429.6	9351.3	268	185	83	3.4	2.7	8.9		
Clausen et al. [136] ^{F} EU / 2012 / MI(T), EL(a), SEL(b)(c)	20	F (a)	U18 (15-18)	- (-)	6434	-	-	59	-	-	9.2	-	-	27	6
	20	F (b)	U18 (15-18)	- (-)	6811	-	-	63	-	-	9.2	-	-		
	20	F (c)	U18 (15-18)	- (-)	13761	-	-	140	-	-	10.2	-	-		
	20	F (T)	U18 (15-18)	32 (438)	27746	-	-	269	-	-	9.7	-	-		
Delecroix et al. [155] ^{F} EU / 2013-17 / EL	156	M	U19 (16-19)	- (52)	23947.4	-	-	182	-	-	7.6	-	-	25	7
Ërgun et al. [140] ^{F} EU / 2005-08 / EL	117	M	U19 (U17-19)	- (52)	2390.2	1897	493.2	29	14	15	12.1	7.4	30.4	21	6
Fouasson-Chailloux et al. [121] ^{F} EU / 2011-16 / EL	195	M	U15 (13-15)	- (-)	44436	-	-	417	-	-	9.4	-	-	23	6

Reference	Study duration (weeks)	Participants			Exposure (hours)			Injuries			Incidence			STROBE - /34 (reporting quality)	NOS - /8 (methodological quality)
Continent (or event)/ Year/Level of play		Sex (cohort)	Age (range)	Teams (players)	Overall	Training	Match	Overall	Training	Match	Overall	Training	Match		
Frisch et al. [64] [F] EU / 2007-08 / SEL	44	M	U19 (13-19)	- (67)	15673.1	12519.3	3153.7	163	89	74	10.4	7.1	23.5	27	7
Hägglund et al. [148] (a) [F] EC / 2006 / EL	2	M	U19 (U19)	8 (144)	1253	762	490	8	0	8	6.4	0	16.3	25	6
Hägglund et al. [148] (b) [F] EC / 2007 / EL	2	M	U19 (U19)	8 (147)	1158	654	504	15	1	14	13	1.5	27.8	25	6
Hägglund et al. [148] (c) [F] EC / 2008 / EL	2	M	U19 (U19)	8 (145)	1461	957	504	13	2	11	8.9	2.1	21.8	25	6
Hägglund et al. [148] (d) [F] EC / 2006 / EL	2	M	U17 (U17)	8 (144)	1316	834	482	11	1	10	8.4	1.2	20.7	25	6
Hägglund et al. [148] (e) [F] EC / 2007 / EL	2	M	U17 (U17)	8 (145)	1161	685	477	7	1	6	6	1.5	12.6	25	6
Hägglund et al. [148] (f) [F] EC / 2008 / EL	2	M	U17 (U17)	8 (144)	1354	899	455	18	5	13	13.3	5.6	28.6	25	6
Hägglund et al. [148] (g) [F] EC / 2006 / EL	2	F	U19 (U19)	8 (144)	1707	1210	497	19	6	13	11.1	5	26.2	25	6
Hägglund et al. [148] (h) [F] EC / 2007 / EL	2	F	U19 (U19)	8 (144)	1407	906	501	12	1	11	8.5	1.1	22	25	6
Hägglund et al. [148] (i) [F] EC / 2008 / EL	2	F	U19 (U19)	8 (145)	1635	1121	514	8	2	6	4.9	1.8	11.7	25	6

Reference	Study duration (weeks)	Participants			Exposure (hours)			Injuries			Incidence			STROBE - /34 (reporting quality)	NOS - /8 (methodological quality)
Continent (or event)/ Year/Level of play		Sex (cohort)	Age (range)	Teams (players)	Overall	Training	Match	Overall	Training	Match	Overall	Training	Match		
Hawkins et al. [38] EU / 1994-97 / EL	117	M	U18 (16-18)	- (30)	16832.5	13902.4	2930.1	166	57	109	9.9	4.1	37.2	17	5
Imai et al. [151] ^{F} Control AS / 2014-15 / SEL	32	M	U14 (12-14)	- (38)	7888	6126	1762	39	28	11	4.9	4.6	6.2	20	7
Junge et al. [175] (a) ^{F} WC / 1999-2011 / EL	19	M	U17 (U17)	136 (2856)	-	-	9124.5	-	-	259	-	-	28.4	23	6
Junge et al. [175] (b) ^{F} WC / 2008-12 / EL	9	F	U17 (U17)	48 (1008)	-	-	3168	-	-	68	-	-	21.5	23	6
Junge et al. [176] OC / 2001 / SEL	24	M	U18 (14-18)	12 (145)	9352.5	5727.5	3639.5	80	21	59	8.6	3.7	16.2	21	7
Junge et al. [37] Control EU / 1999-00 / SEL	52	M	U19 (14-19)	7 (93)	13094.4	-	-	100	-	-	7.6	-	-	22	6
Kakavelakis et al. [177] EU / 1999-00 / -	40	M	U15 (12-15)	24 (287)	52250	33333.3	17678.6	209	110	99	4	3.3	5.6	17	6
Kuzuhara et al. [152] AS / 2013-14 / SEL	52	M	U12 (≤12)	5 (86)	10838.4	8447.7	2390.8	25	12	13	2.3	1.4	5.4	22	7
		F	U12 (≤12)	- (3)	377.7	278.4	99.3	1	0	1	2.6	0	10.1		
Le Gall et al. [137] ^{F} EU / 1998-06 / EL	312	F	U19 (15-19)	- (119)	97325	87530	9795	619	400	219	6.4	4.6	22.4	24	7
Lislevand et al. [134] ^{F} AF / 2008 / SEL	0.3	F (a)	U13 (≤13)	37 (433)	-	-	431	-	-	5	-	-	11.6	27	5
		F (b)	U16 (13-16)	14 (213)	-	-	403	-	-	1	-	-	11.7		
		F (T)	U16 (≤16)	51 (646)	-	-	834	-	-	6	-	-	7.2		
Nielsen et al. [178] EU / 1986 / MI	44	M	U18 (16-18)	2 (30)	4554	3564	990	27	13	14	5.9	3.6	14.4	15	8
Nilsson et al. [135] ^{F} EU / 2013-14 / EL	88	M	U19 (15-19)	- (43)	10367	7678.6	1161.3	61	43	18	6.8	5.6	15.5	22	8

Reference	Study duration (weeks)	Participants			Exposure (hours)			Injuries			Incidence			STROBE - /34 (reporting quality)	NOS - /8 (methodological quality)
Continent (or event)/ Year/Level of play		Sex (cohort)	Age (range)	Teams (players)	Overall	Training	Match	Overall	Training	Match	Overall	Training	Match		
Nogueira et al. [32] [F] EU / 2015-16 / SEL	26	M (a)	U16 (15-16)	11 (290)	33673	28598.5	5074.5	138	73	65	3.7	2.1	12.6	29	7
		M (b)	U19 (17-19)	10 (239)	28389	24561	3828	110	46	64	4	2	16		
		M (T)	U19 (15-19)	21 (529)	62062	53159.5	8902.5	248	119	129	3.9	2.1	14.2		
Owoeye et al. [179] [F] Control AF / 2012-13 / EL	24	M	U19 (14-19)	10 (204)	61045	57448	3597	94	22	73	1.5	0.4	20.3	27	7
Raya-González et al. [28] EU / 2014-18/ EL	156	M (a)	U14 (13-14)	2 (-)	35064	31236	3828	84	61	23	2.4	2	6	23	7
		M (b)	U16 (15-16)	2 (-)	40300	35475	4825	111	67	44	2.8	1.9	9.1		
		M (c)	U19 (17-19)	2 (-)	49679	45318	4361	142	94	48	2.9	2.1	11		
		M (T)	U19 (13-19)	6 (257)	125043	112029	13014	337	222	115	2.7	2	8.8		
Renshaw et al. [27] [F] EU / 2012-13 / EL	39	M (a)	U11 (U9-11)	- (68)	11259.8	8695.7	2564.1	7	6	1	0.6	0.7	0.4	25	8
		M (b)	U15 (U15)	- (17)	97325	87530	150	-	-	12	-	-	80		
		M (c)	U16 (U16)	- (17)	-	-	343.8	-	-	11	-	-	32		
		M (d)	U18 (U18)	- (20)	-	2500	-	-	15	-	-	6	-		
		M (T)	U18 (9-18)	- (181)	29346	-	-	127	-	-	4.3	-	-		
Rommers et al. [68] [F] EU / 2017-18 / EL	39	M	U15 (U10-15)	- (734)	129206	112745	16464	389	229	160	3	2	9.7	20	7
Schmidt-Olsen et al. [44] IT / 1984 / EL	1	M (a)	U11 (9-11)	- (497)	-	-	1139.2	-	-	3	-	-	2.6	11	5
		M (b)	U13 (12-13)	- (1554)	-	-	3737.4	-	-	15	-	-	4		
		M (c)	U16 (14-16)	- (1932)	-	-	5729.2	-	-	45	-	-	7.8		
		M (d)	U19 (17-19)	- (1292)	-	-	3543.7	-	-	37	-	-	10.4		
		F (e)	U13 (9-13)	- (361)	-	-	13043.5	-	-	7	-	-	0.5		
		F (f)	U16 (14-16)	- (732)	-	-	1943	-	-	49	-	-	25.2		
		F (g)	U19 (17-19)	- (232)	-	-	635.6	-	-	13	-	-	20.9		
		M (T)	U19 (9-19)	- (5275)	-	-	14223.6	-	-	100	-	-	7.4		
		F (T)	U19 (9-19)	- (1325)	-	-	3913	-	-	69	-	-	17.6		

Reference	Study	Participants			Exposure (hours)			Injuries			Incidence			STROBE - /34	NOS - /8
Continent (or event)/ Year/Level of play	duration (weeks)	Sex (cohort)	Age (range)	Teams (players)	Overall	Training	Match	Overall	Training	Match	Overall	Training	Match	(reporting quality)	(methodological quality)
Sieland et al. [63] EU / 2015-17 / EL	78	M	U19 (U12-19)	- (205)	46296.3	40434.8	6400	125	93	32	2.7	2.3	5	24	7
Söderman et al. [141] EU / 1996 / SEL	28	F	U19 (14-19)	10 (153)	11689.2	-	-	79	-	-	6.8	-	-	20	7
Soligard et al. [150] F Control EU / 2007 / -	32	F	U17 (13-17)	- (837)	45428	31086	14342	215	74	138	4.7	2.4	9.6	32	8
Soligard et al. [153] F ET / 2005-08 / EL	4	M (a)	U13 (13)	- (-)	-	-	9095	-	-	20	-	-	2.2	24	5
		M (b)	U14 (14)	- (-)	-	-	12154	-	-	45	-	-	3.7		
		M (c)	U16 (15-16)	- (-)	-	-	16945	-	-	68	-	-	4		
		M (d)	U19 (17-19)	- (-)	-	-	6028	-	-	38	-	-	6.3		
		F (e)	U13 (13)	- (-)	-	-	2601	-	-	15	-	-	5.8		
		F (f)	U14 (14)	- (-)	-	-	4576	-	-	22	-	-	4.8		
		F (g)	U16 (15-16)	- (-)	-	-	8163	-	-	29	-	-	3.6		
		F (h)	U19 (17-19)	- (-)	-	-	3036	-	-	35	-	-	11.5		
		M (T)	U19 (13-19)	- (-)	-	-	44222	-	-	171	-	-	5.8		
		F (T)	U19 (13-19)	- (-)	-	-	18376	-	-	101	-	-	5.5		
Sprouse et al. [54] F EU / 2012-20 / EL	312	M (a)	U15 (U15)	- (-)	7958	7159	799	56	23	33	7	3.2	41.3	22	7
		M (b)	U16 (U16)	- (-)	9911	8435	1476	106	44	62	10.7	5.2	42		
		M (c)	U17 (U17)	- (-)	8702	6771	1931	65	20	45	7.5	2.9	23.3		
		M (d)	U18 (U18)	- (-)	6504	5332	1172	43	21	22	6.6	3.9	18.8		
		M (e)	U19 (U19)	- (-)	10689	9055	1634	49	25	24	4.6	2.8	14.7		
		F (f)	U15 (U15)	- (-)	7852	7531	321	61	52	9	7.8	6.9	28		
		F (g)	U16 (U16)	- (-)	7612	6633	979	48	28	20	6.3	4.2	20.4		
		F (h)	U17 (U17)	- (-)	15146	13651	1495	100	46	54	6.6	3.4	36.1		
		F (i)	U19 (U18-19)	- (-)	20541	18347	2194	117	67	50	5.7	3.6	22.8		

Reference	Study	Participants			Exposure (hours)			Injuries			Incidence			STROBE - /34	NOS - /8
Continent (or event)/ Year/Level of play	duration (weeks)	Sex (cohort)	Age (range)	Teams (players)	Overall	Training	Match	Overall	Training	Match	Overall	Training	Match	(reporting quality)	(methodological quality)
		M (T)	U19 (U15-19)	8 (-)	43764	36752	7012	319	133	186	7.3	3.6	26.5		
		F (T)	U19 (U15-19)	9 (-)	51151	46162	4989	326	193	133	6.4	4.2	26.7		
Steffen et al. [180] [F] Control EU / 2005 / -	32	F	U17 (13-17)	51 (947)	65725	-	-	241	-	-	3.7	-	-	29	7
Tears et al. [24] [F] EU / 2009-15 / EL	234	M	U18 (11-18)	- (-)	352800	-	-	778	-	-	2.2	-	-	25	6
van der Sluis et al. [52] [F] EU / 2002-07 / EL	117	M	U13 (-)	- (26)	33628.9	-	-	108	-	-	3.2	-	-	22	6
Waldén et al. [25] [F] EC / 2005 / EL	2	M	U19 (U19)	8 (144)	1394	899	495	17	2	15	13.4	2.9	30.4	25	6
Wik et al. [34] [F] AS / 2016-20 / EL	144	M (a)	U13 (U13)	- (-)	17072	15094	1978	133	91	42	7.8	6	21.2	28	7
		M (b)	U14 (U14)	- (-)	19245	16726	2519	164	105	59	8.5	6.3	23.4		
		M (c)	U15 (U15)	- (-)	17865	14803	3062	194	109	85	10.9	7.4	27.8		
		M (d)	U16 (U16)	- (-)	15719	12903	2816	215	114	101	13.7	8.8	35.9		
		M (e)	U17 (U17)	- (-)	13738	11203	2535	234	123	111	17	11	43.8		
		M (f)	U18 (U18)	- (-)	9188	7340	1848	171	97	74	18.6	13.2	40		
		M (T)	U18 (U12-18)	- (301)	92827	78069	14758	1111	639	472	12	8.2	32		
Zarei et al. [181] [F] Control AS / 2017 / EL	39	M	U14 (7-14)	17 (519)	32113	29716	2397	60	36	24	1.9	1.2	10	31	7

[F] Study was implemented according to the 2006 consensus statement for epidemiological studies in football.

(a);(b);(c): indicate different cohorts in the same study; (T) indicate the total sample of the study.

EL: Elite; SEL: Sub-elite; MI: Mixed (elite and sub-elite); M: Male; F: Female; U: Under.

EU: Europe; NA: North America; SA: South America; AS: Asia; AF: Africa; OC: Oceania; EC: European Championship; ET: European Tournament; IT: International Tournament; WC: World Championship.

3.3.2 Meta Analyses

In the different meta-analyses carried out, the effect sizes exhibited a moderate to large heterogeneity (based on the Q statistics and the I^2 indices), supporting the decision of applying random-effects models.

Neither registration period (i.e., the period of time/year when the data collection process was carried out), nor the year of publication of the study, age, STROBE score, NOS stars, and number of teams' variables had an impact on injury incidence rates and hence, the subsequent sub-analyses were not adjusted to these variables.

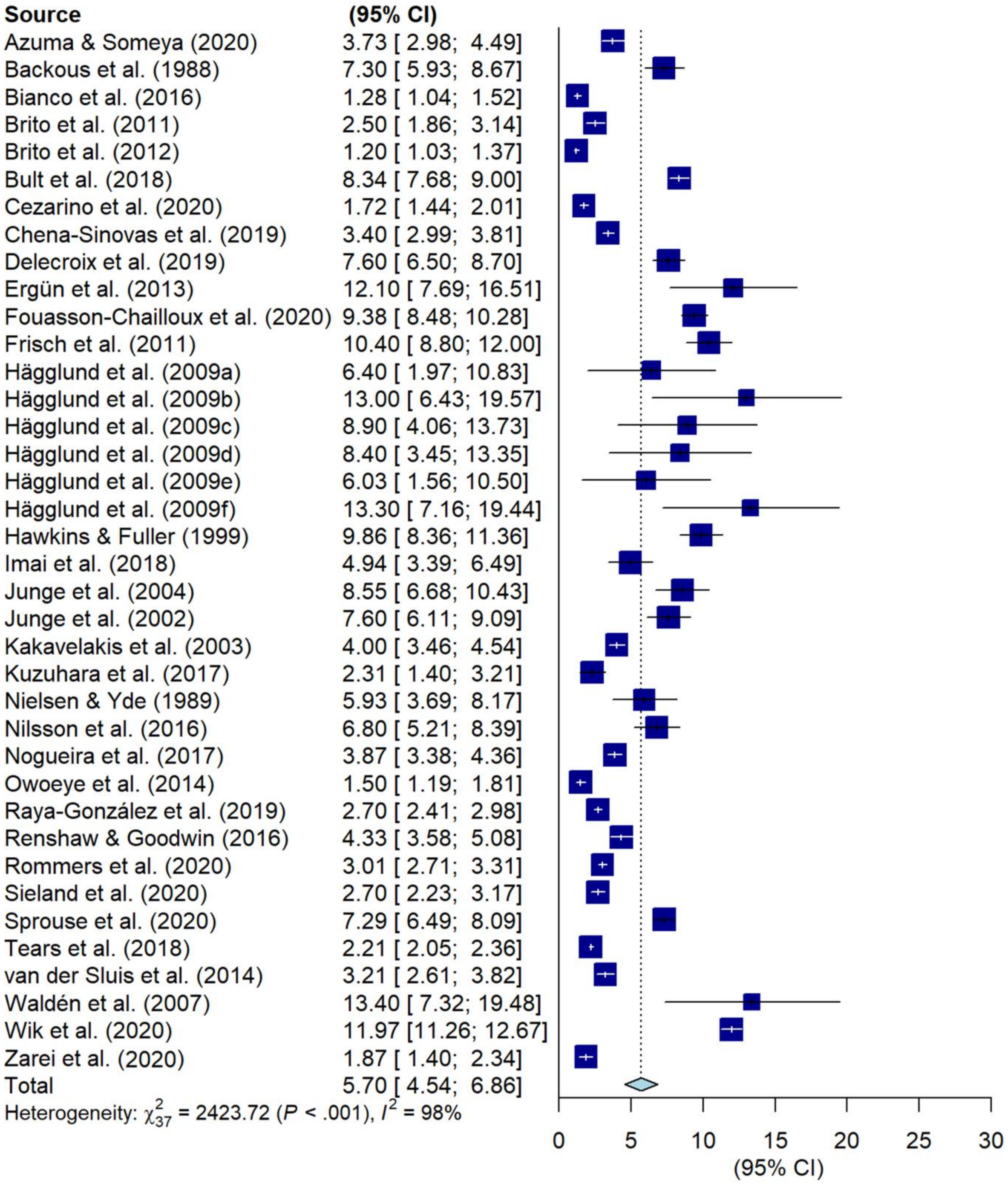
3.3.2.1 Injury incidence: overall, training and match

Males

Thirty-three studies (38 cohorts) reporting overall injury incidence [12,24–32,34,36–38,41,52,54,63,64,68,121,135,140,148,151,152,154,155,176–179,181], 25 studies (30 cohorts) reporting training injury incidence [25,26,28–32,34,37,38,41,54,63,64,68,135,140,148,151,152,154,177–179,181] and 29 studies (34 cohorts) reporting match injury incidence [25,26,28–32,34,37,38,41,44,54,63,64,68,135,140,148,151–154,174,175,177–179,181] in male youth football players were included in this meta-analysis, comprising a total of n = 6873 injuries and around 25600 different players. The random effect models for injury incidence showed an overall incidence of 5.7 injuries/1000h of total exposure (95%CI = 4.5-6.9, I^2 = 98.0%, quality of evidence = moderate), a training incidence of 2.8 injuries/1000h of training (95%CI = 2.0-3.5, I^2 = 97.0%, quality of evidence = moderate) and a match incidence of 14.4 injuries/1000h of match (95%CI = 11.0-17.8, I^2 = 97.0%, quality of evidence = moderate). Figures 7-9 display the forest plots with the overall, training and match incidence of the analysed studies.

Females

Nine studies (11 cohorts) reporting overall injury incidence [36,54,136,137,141,148,150,152,180], five studies (7 cohorts) reporting training injury incidence [54,137,148,150,152] and ten studies (12 cohorts) reporting match injury incidence [44,54,134,137,148,150,152,153,174,175] in female youth football players were included in this meta-analysis, comprising a total of n = 1896 injuries and around 9600 different players. The random effect models showed an overall incidence of 6.8 injuries/1000h of total exposure (95%CI = 5.0-8.5, I^2 = 94%, quality of evidence = low), a training incidence of 2.6 injuries/1000h of training (95%CI = 1.2-4.1, I^2 = 90%, quality of evidence = low) and a match incidence of 15.0 injuries/1000h of match (95%CI = 9.7-20.2, I^2 = 96%, quality of evidence = low). Figures 10-12 display the forest plots with the training and match incidence of the analysed studies.



Source	(95% CI)
Azuma & Someya (2020)	3.73 [2.98; 4.49]
Backous et al. (1988)	7.30 [5.93; 8.67]
Bianco et al. (2016)	1.28 [1.04; 1.52]
Brito et al. (2011)	2.50 [1.86; 3.14]
Brito et al. (2012)	1.20 [1.03; 1.37]
Bult et al. (2018)	8.34 [7.68; 9.00]
Cezarino et al. (2020)	1.72 [1.44; 2.01]
Chena-Sinovas et al. (2019)	3.40 [2.99; 3.81]
Delecroix et al. (2019)	7.60 [6.50; 8.70]
Ergün et al. (2013)	12.10 [7.69; 16.51]
Fouasson-Chailloux et al. (2020)	9.38 [8.48; 10.28]
Frisch et al. (2011)	10.40 [8.80; 12.00]
Hägglund et al. (2009a)	6.40 [1.97; 10.83]
Hägglund et al. (2009b)	13.00 [6.43; 19.57]
Hägglund et al. (2009c)	8.90 [4.06; 13.73]
Hägglund et al. (2009d)	8.40 [3.45; 13.35]
Hägglund et al. (2009e)	6.03 [1.56; 10.50]
Hägglund et al. (2009f)	13.30 [7.16; 19.44]
Hawkins & Fuller (1999)	9.86 [8.36; 11.36]
Imai et al. (2018)	4.94 [3.39; 6.49]
Junge et al. (2004)	8.55 [6.68; 10.43]
Junge et al. (2002)	7.60 [6.11; 9.09]
Kakavelakis et al. (2003)	4.00 [3.46; 4.54]
Kuzuhara et al. (2017)	2.31 [1.40; 3.21]
Nielsen & Yde (1989)	5.93 [3.69; 8.17]
Nilsson et al. (2016)	6.80 [5.21; 8.39]
Nogueira et al. (2017)	3.87 [3.38; 4.36]
Owoeye et al. (2014)	1.50 [1.19; 1.81]
Raya-González et al. (2019)	2.70 [2.41; 2.98]
Renshaw & Goodwin (2016)	4.33 [3.58; 5.08]
Rommers et al. (2020)	3.01 [2.71; 3.31]
Sieland et al. (2020)	2.70 [2.23; 3.17]
Sprouse et al. (2020)	7.29 [6.49; 8.09]
Tears et al. (2018)	2.21 [2.05; 2.36]
van der Sluis et al. (2014)	3.21 [2.61; 3.82]
Waldén et al. (2007)	13.40 [7.32; 19.48]
Wik et al. (2020)	11.97 [11.26; 12.67]
Zarei et al. (2020)	1.87 [1.40; 2.34]
Total	5.70 [4.54; 6.86]

Heterogeneity: $\chi^2_{37} = 2423.72$ ($P < .001$), $I^2 = 98\%$

Figure 7. Overall injury incidence in male youth football players with 95% confidence intervals.

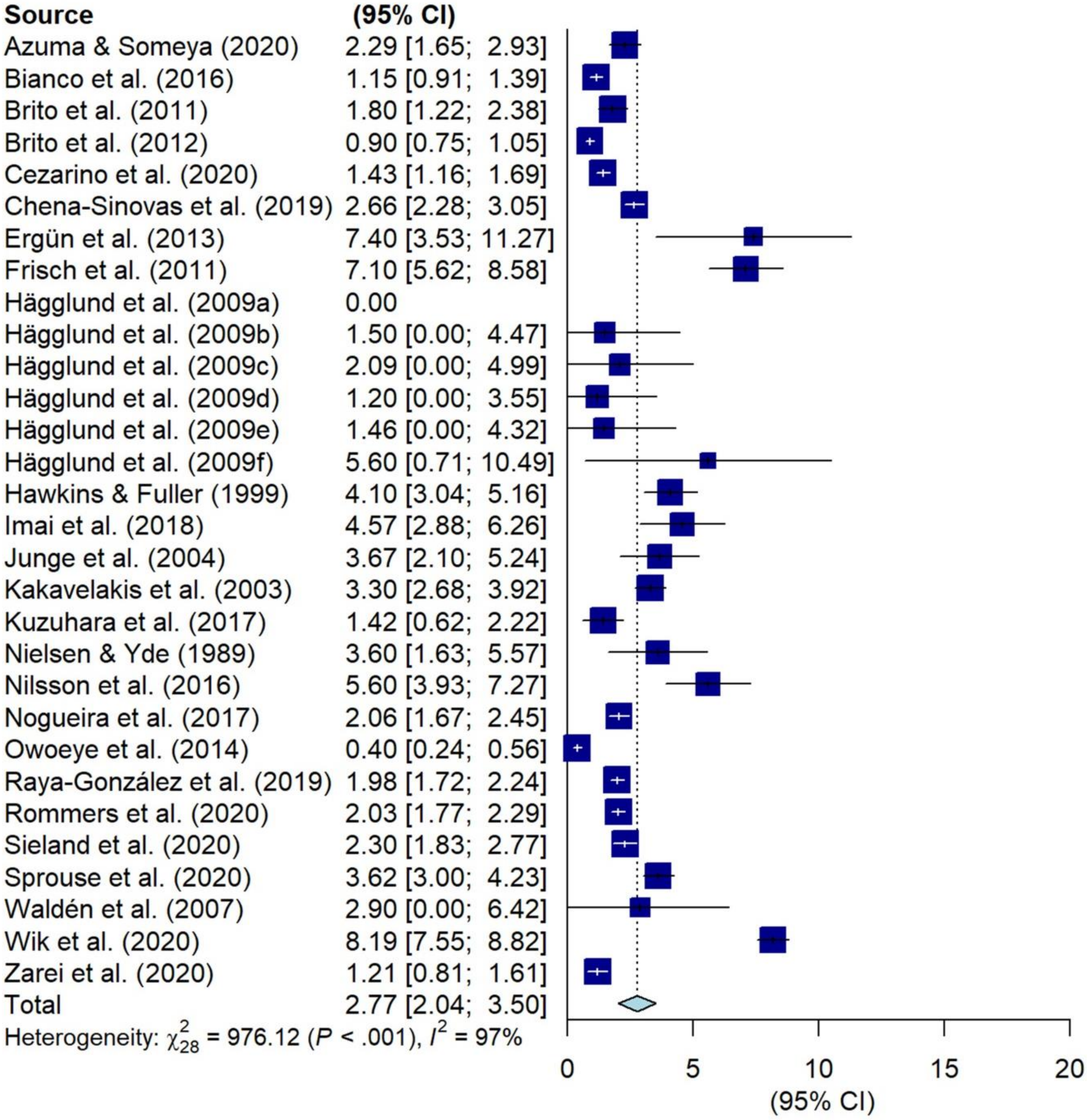


Figure 8. Training injury incidence in male youth football players with 95% confidence intervals.

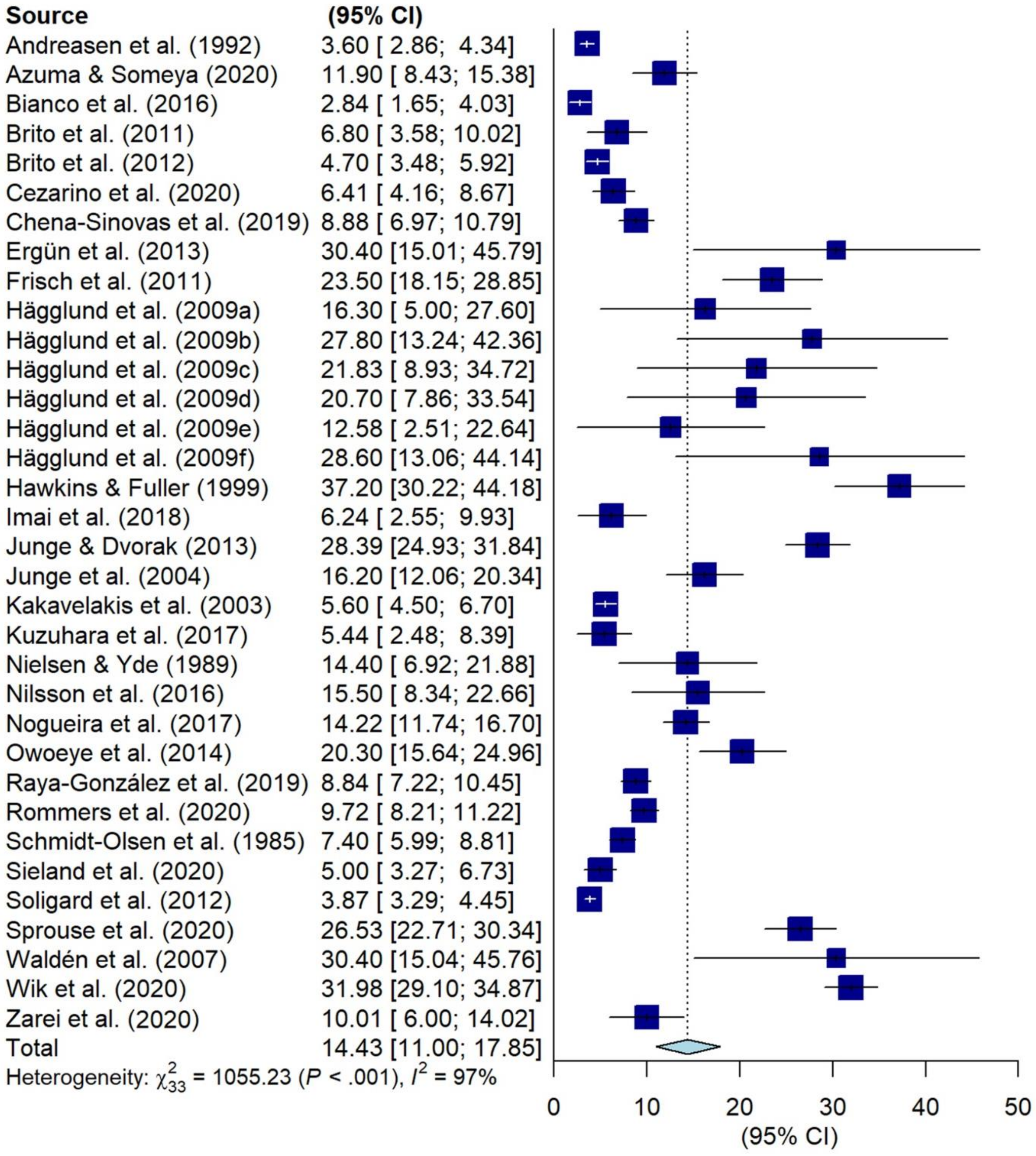
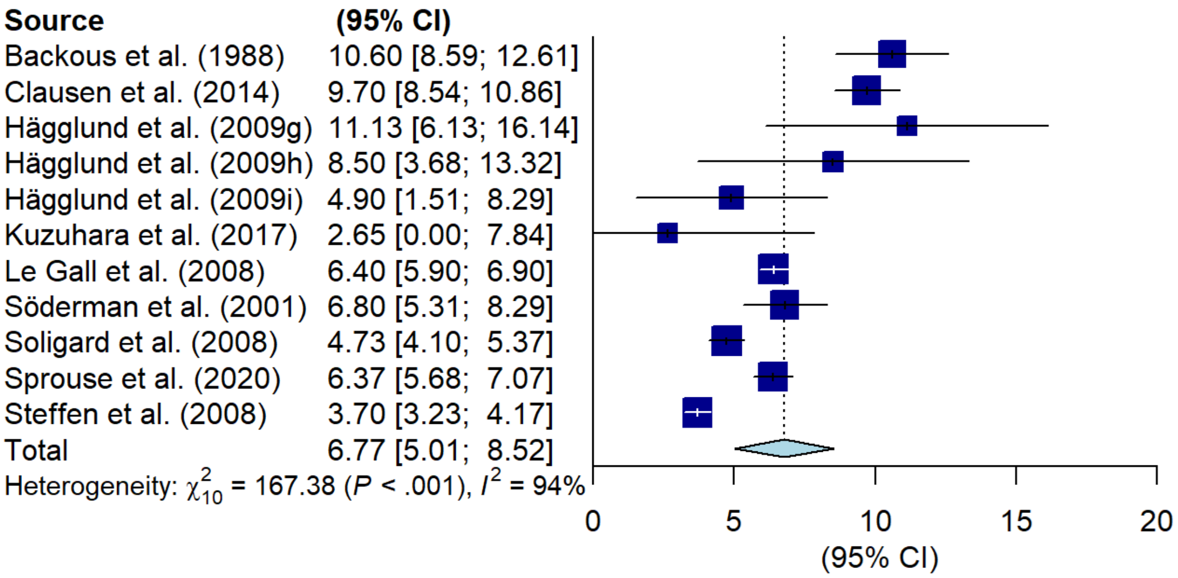


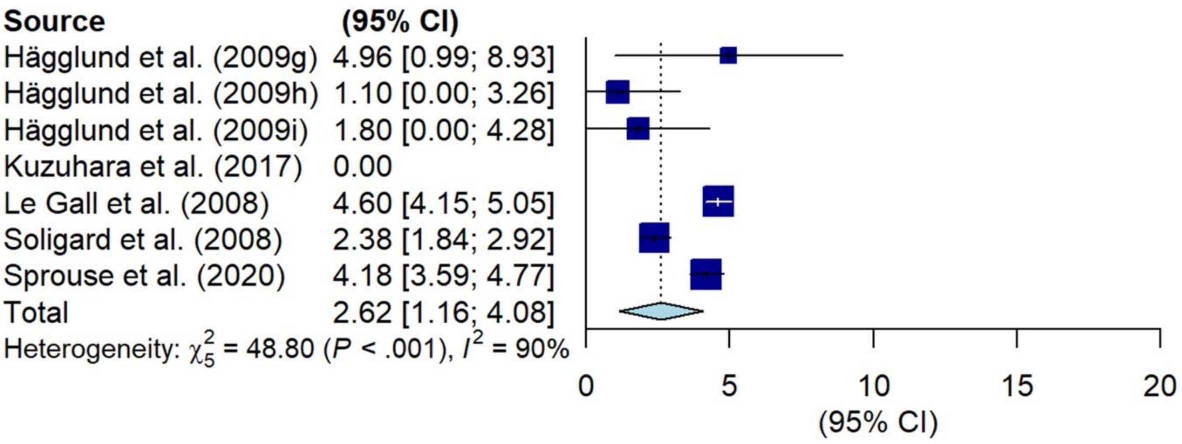
Figure 9. Match injury incidence in male youth football players with 95% confidence intervals.



Source	(95% CI)
Backous et al. (1988)	10.60 [8.59; 12.61]
Clausen et al. (2014)	9.70 [8.54; 10.86]
Hägglund et al. (2009g)	11.13 [6.13; 16.14]
Hägglund et al. (2009h)	8.50 [3.68; 13.32]
Hägglund et al. (2009i)	4.90 [1.51; 8.29]
Kuzuhara et al. (2017)	2.65 [0.00; 7.84]
Le Gall et al. (2008)	6.40 [5.90; 6.90]
Söderman et al. (2001)	6.80 [5.31; 8.29]
Soligard et al. (2008)	4.73 [4.10; 5.37]
Sprouse et al. (2020)	6.37 [5.68; 7.07]
Steffen et al. (2008)	3.70 [3.23; 4.17]
Total	6.77 [5.01; 8.52]

Heterogeneity: $\chi^2_{10} = 167.38$ ($P < .001$), $I^2 = 94\%$

Figure 10. Overall injury incidence in female youth football players with 95% confidence intervals.



Source	(95% CI)
Hägglund et al. (2009g)	4.96 [0.99; 8.93]
Hägglund et al. (2009h)	1.10 [0.00; 3.26]
Hägglund et al. (2009i)	1.80 [0.00; 4.28]
Kuzuhara et al. (2017)	0.00
Le Gall et al. (2008)	4.60 [4.15; 5.05]
Soligard et al. (2008)	2.38 [1.84; 2.92]
Sprouse et al. (2020)	4.18 [3.59; 4.77]
Total	2.62 [1.16; 4.08]

Heterogeneity: $\chi^2_5 = 48.80$ ($P < .001$), $I^2 = 90\%$

Figure 11. Training injury incidence in female youth football players with 95% confidence intervals.

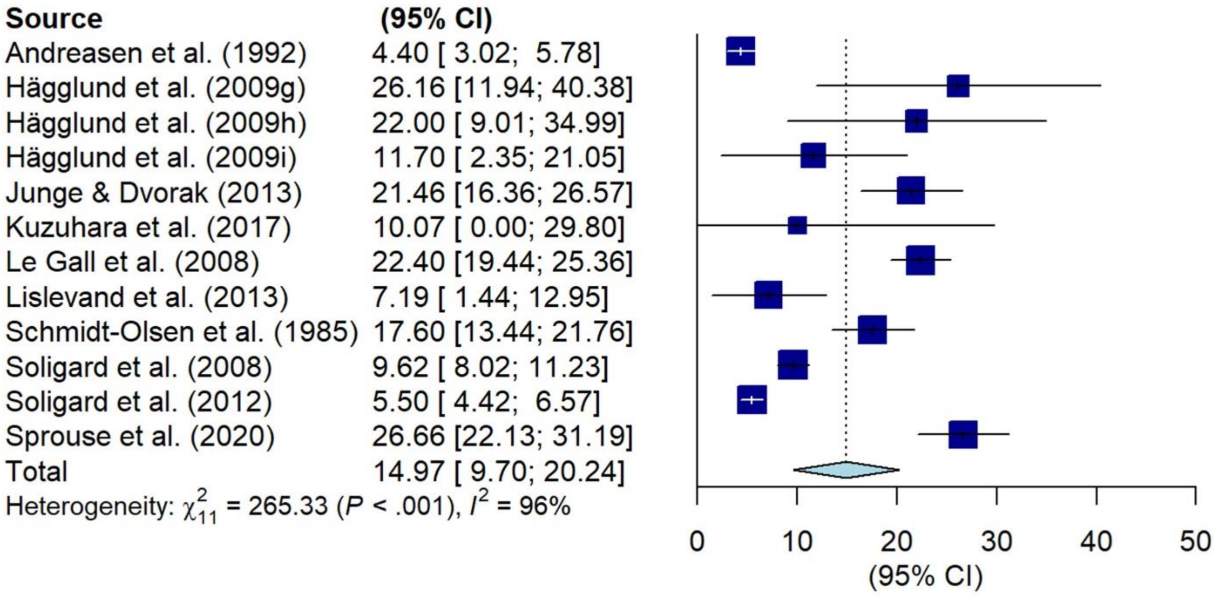


Figure 12. Match injury incidence in female youth football players with 95% confidence intervals.

3.3.2.2 Location of injury

Males

Twenty-four studies reported injury location and lower extremities region categories in males according to Fuller et al.[146]. [12,24–29,31,32,34,38,41,63,64,68,135,140,151,152,154,177–179,181] Lower extremity injuries had the highest incidence rates (4.1/1000h, 95%CI = 2.9-5.2, I^2 = 99.5%) compared to the other body regions. Upper limbs was the second most commonly injured region (0.3/1000h, 95%CI = 0.2-0.4, I^2 = 94.7%), trunk was the third most commonly injured region (0.3/1000h, 95%CI = 0.2-0.3, I^2 = 92.9%) and head and neck injuries had the lowest incidence rates (0.1/1000h, 95%CI = 0.0-0.1, I^2 = 88.5%). Regarding lower extremity injuries, thigh showed the highest incidence rate (1.2, 95%CI = 0.7-1.7, I^2 = 99.1%), followed by ankle (0.9, 95%CI = 0.6-1.2, I^2 = 97.6%), knee (0.7, 95%CI = 0.5-1.0, I^2 = 96.6%), hip/groin (0.7, 95%CI = 0.5-1.0, I^2 = 98.1%), lower leg/Achilles tendon (0.4, 95%CI = 0.2-0.5, I^2 = 94.4%), and foot/toe (0.3, 95%CI = 0.2-0.4, I^2 = 94.9%).

Females

Only five studies reported injury location and lower extremities region categories in female youth footballers [136,137,141,150,152]. The trend was similar to the one showed in males, with lower extremities having the highest incidence (6.5/1000h, 95%CI = 4.7-8.4, I^2 = 91.4%), followed by trunk (0.7/1000h, 95%CI = 0.5-0.8, I^2 = 0%), upper limbs (0.3/1000h, 95%CI = 0.1-0.4, I^2 = 51.0%), and with the lowest incidence head and neck injuries (0.1/1000h, 95%CI = 0.0-

0.3, I^2 = 68.2%). With regards to lower extremity injuries, ankle (1.5, 95%CI = 1.2-1.9, I^2 = 64.0%) and knee (1.5, 95%CI = 0.9-2.1, I^2 = 89.3%) showed the highest incidence rates, followed by thigh (1.1, 95%CI = 0.5-1.6, I^2 = 91.0%), lower leg/Achilles tendon (0.7, 95%CI = 0.3-1.1, I^2 = 90.2%), hip/groin (0.6, 95%CI = 0.2-1.0, I^2 = 91.9%), and foot/toe (0.4, 95%CI = 0.3-0.5, I^2 = 0%) (Figure 13).

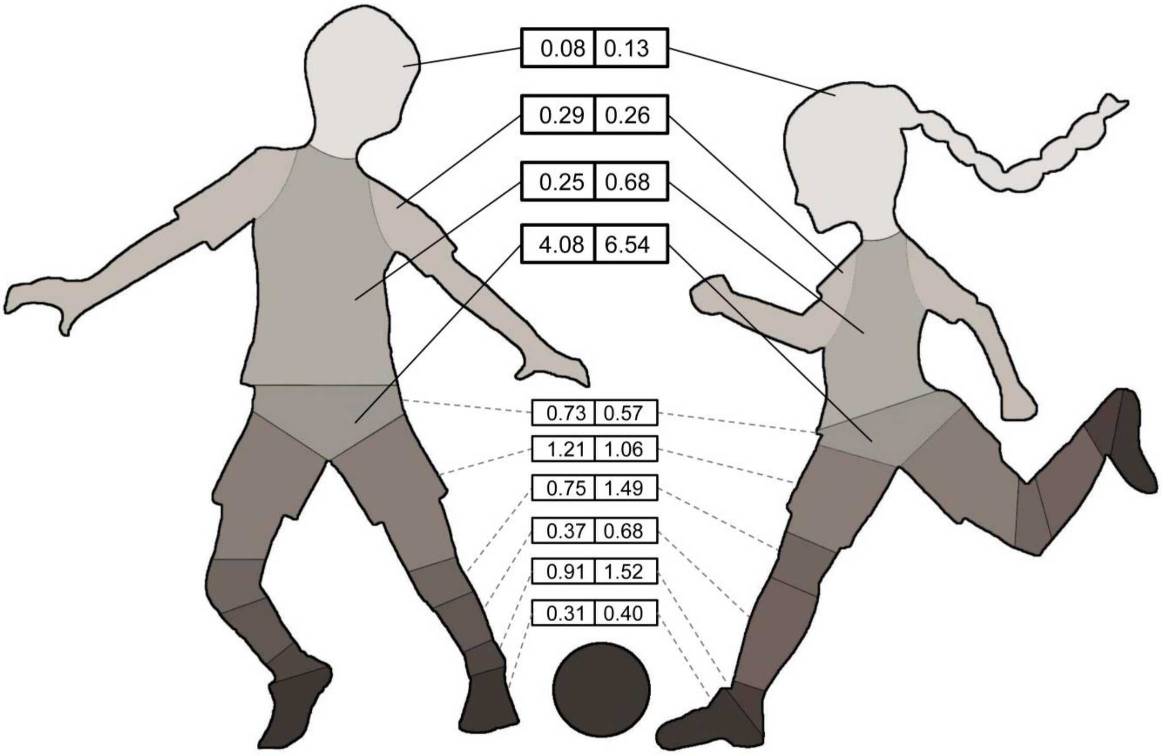


Figure 13. Location of injury in male (left side) and female (right side) youth football players. The upper boxes (solid lines) represent the incidence of injury for main groups, whereas the lower boxes (dashed lines) represent the incidence of injury for lower extremities categories.

3.3.2.3 Type of injury

Males

Fifteen studies reported type of injury in male players [24–29,31,32,34,41,64,68,140,152,154]. The most common type of injury grouping was muscle/tendon (1.9, 95%CI = 1.3-2.6, I^2 = 99.0%), followed by joint (non-bone) and ligament (1.0, 95%CI = 0.6-1.3, I^2 = 97.4%), and contusions (0.8, 95%CI = 0.4-1.3, I^2 = 99.3%). Fracture and bone stress (0.4, 95%CI = 0.0-0.8, I^2 = 99.7%), undefined/other (0.3, 95%CI = 0.0-0.5, I^2 = 99.5%), central/peripheral nervous system (0.06, 95%CI = 0.0-0.1, I^2 = 95.6%), and laceration and skin lesions (0.03, 95%CI = 0.0-0.1, I^2 = 66.0%) were the least common types of injury.

Females

Only three studies were pooled in the meta-analysis [137,141,152]. Unlike male, joint (non-bone) and ligament injuries (2.4, 95%CI = 1.6-3.1, I^2 = 59.0%) were the most common type of injury, followed by muscle and tendon injuries (2.0, 95%CI = 1.7-2.3, I^2 = 0%), contusions (0.9, 95%CI = 0.6-1.2, I^2 = 44.6%), undefined/other (0.8, 95%CI = 0.5-1.2, I^2 = 57.0%), and fracture and bone stress injuries (0.3, 95%CI = 0.2-0.4, I^2 = 0%). No laceration and skin lesions or central/peripheral nervous system injuries were registered (Figure 14).

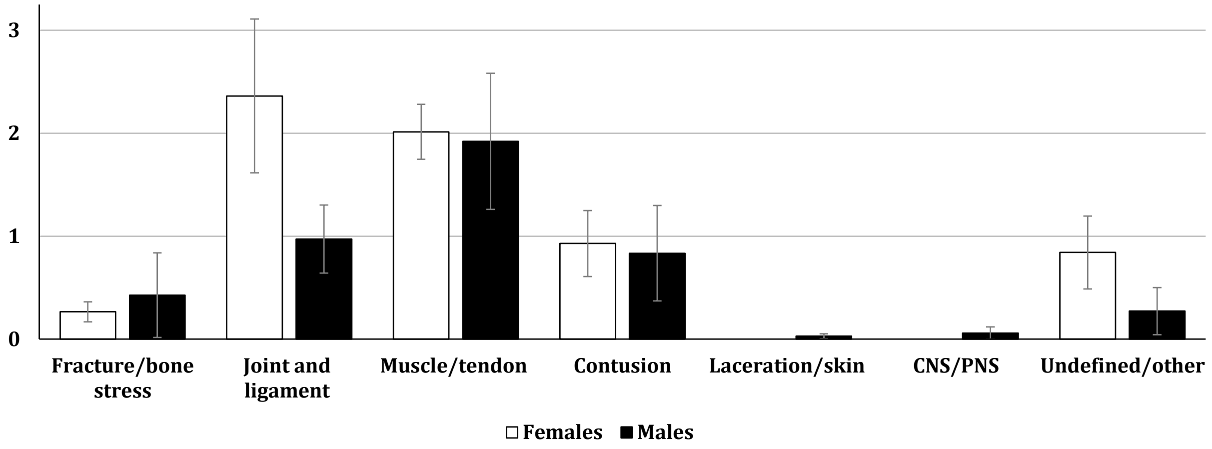


Figure 14. Type of injury in male and female youth football players.

3.3.2.4 Severity of injury

Males

Twenty-one studies (26 cohorts) reported severity of injury in males [12,24–29,32,34,38,41,63,64,68,121,135,140,148,154,179,181]. Minimal injuries (1.9/1000h, 95%CI = 1.1-2.6, I^2 = 99.8%) were the most usual injuries, followed by moderate (1.7/1000h, 95%CI = 1.3-2.2, I^2 = 98.0%), mild (1.1/1000h, 95%CI = 0.8-1.5, I^2 = 98.5%) and severe (0.8/1000h, 95%CI = 0.6-1.0, I^2 = 96.4%) injuries. Additionally, a total of eleven studies [12,26–28,31,32,41,64,121,140,181] reported an average of 15.5 days lost per injury in male footballers and an overall injury burden of 96.5 injury days per 1000 hours of football exposure (95%CI = 49.9-143.1, I^2 = 100%).

Females

Only three studies (5 cohorts) reported severity in females [134,148,150]. Minimal injuries (3.6/1000h, 95%CI = 0.7-6.5, I^2 = 82.3%) were also the most usual injuries in females, followed by moderate injuries (1.5/1000h, 95%CI = 1.2-1.9, I^2 = 0%), severe injuries (1.3/1000h, 95%CI = 0.6-1.9, I^2 = 43.1%) and mild injuries (0.8/1000h, 95%CI = 0.5-1.0, I^2 = 0%). The paucity of data prevented the calculation of pooled estimates for the injury burden (Figure 15).

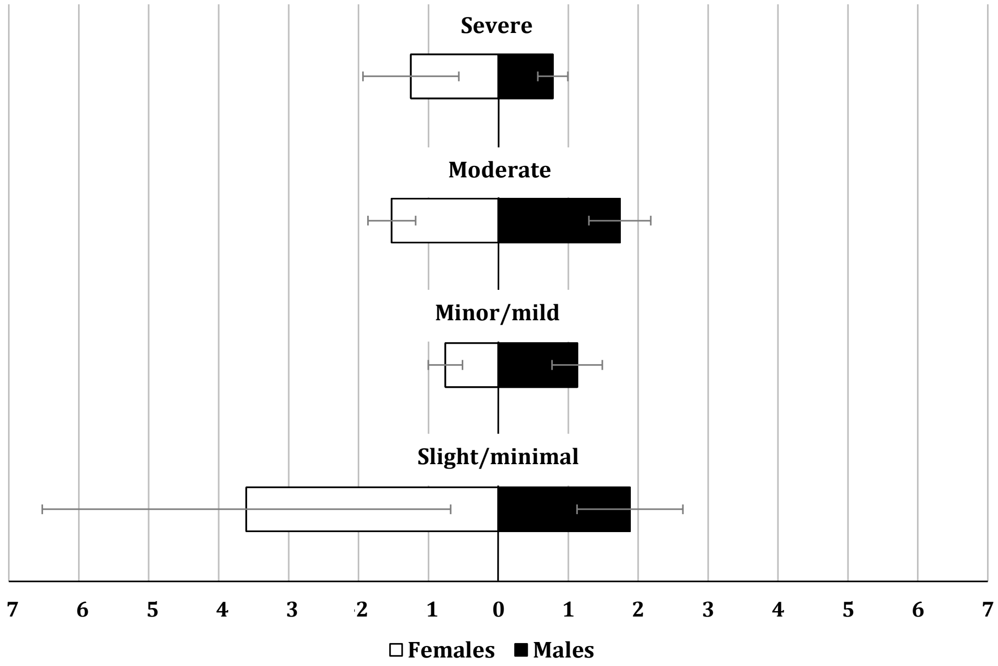


Figure 15. Severity of injury in male and female youth football players.

3.3.2.5 Mechanism of injury

Males

Sixteen studies (19 cohorts) were involved in the meta-analysis to compare overuse injuries versus traumatic (acute) injuries in males [12,25–29,32,34,38,54,64,135,140,148,151,179]. The incidence in traumatic injuries (5.5, 95%CI = 4.0-7.0) was higher than in overuse (1.1, 95%CI = 0.7-1.5). In relation with mechanism of injury, fifteen studies (18 cohorts) reported data to compare contact versus non-contact injuries in males [25–27,29,32,34,38,54,63,64,140,148, 154,155,179]. Males showed a slightly higher incidence of non-contact (3.5, 95%CI = 2.3-4.6) than contact injuries (2.8, 95%CI = 1.9-3.6).

Females

Eight studies (9 cohorts) were involved in the meta-analysis to compare overuse injuries versus traumatic injuries in females [54,134,136,137,141,148,150,180]. Similar to males, the incidence in traumatic injuries (4.5, 95%CI = 3.7-5.4) was higher than in overuse (1.6, 95%CI = 0.8-2.3) in females. Four studies (5 cohorts) reported data to compare contact versus non-contact injuries in females [54,148,150,180]. Similar incidence rate for non-contact (2.4, 95%CI = 1.8-3.0) and contact injuries (1.9, 95%CI = 1.7-2.2) was found.

3.3.2.6 New vs. recurrent injuries

Males

Eleven studies (14 cohorts) were included in an analysis aimed at comparing the incidence of new versus recurrent injuries in males [26,27,31,32,34,38,41,64,68,140,148]. The incidence rate of new injuries (5.9, 95%CI = 3.9-7.8) was higher than recurrent injuries (0.8, 95%CI = 0.4-1.3).

Females

Five studies (6 cohorts) compared the incidence of new versus recurrent injuries in females [136,137,141,148,180]. Similar to males, the incidence rate of new injuries (5.1, 95%CI = 3.6-6.6) was higher than recurrent (1.4, 95%CI = 0.3-2.5) in female footballers.

3.3.2.7 Age groups

Males

Concerning the football players' age, studies were gathered in three groups: U12 and below, U13-U16 and U17-U19. In males, a total of 20 studies (58 cohorts) was included to compare overall injury incidence [12,25–32,34,38,54,121,140,148,151,152,155,177,178], 16 studies (46 cohorts) and 19 studies (55 cohorts) to compare training [25,27–32,34,38,54,140,148,151,152,177,178] and match [25,27–32,34,38,44,54,140,148,151–153,175,177,178] injury incidences, respectively. U17-U19 male age group showed the highest overall injury incidence (7.5/1000h, 95%CI = 5.6-9.5, I^2 = 97%), followed by U13-U16 male (5.3/1000h, 95%CI = 3.7-7.0, I^2 = 98%), and U12 male (1.6/1000h, 95%CI = 0.8-2.4, I^2 = 85%) age groups. In particular, the mean incidence rates in training decreased from U17-U19 (3.5/1000h, 95%CI = 2.1-4.9, I^2 = 91%) to U13-U16 (3.4/1000h, 95%CI = 2.2-4.6, I^2 = 95%), and U12 age groups (1.1/1000h, 95%CI = 0.4-1.7, I^2 = 72%). In match, the incidence rates per age group were, in descending order: U17-U19 (20.0/1000h, 95%CI = 15.5-24.6, I^2 = 93%), U13-U16 (13.7/1000h, 95%CI = 8.5-18.9, I^2 = 95%), and U12 (2.6/1000h, 95%CI = 0.6-4.6, I^2 = 77%).

Females

Only two studies (5 cohorts) were included to compare overall and training injury incidences [54,148], and six studies (15 cohorts) to compare match injury incidence [44,54,134,148,153,175]. U17-U19 female age group showed an overall injury incidence of 6.2/1000h of total exposure (95%CI = 4.7-7.8, I^2 = 38%), a training injury incidence of 3.1/1000h of training (95%CI = 2.2-4.0, I^2 = 40%) and a match injury incidence of 20.9/1000h of match (95%CI = 14.3-27.6, I^2 = 78%). U13-U16 female age group reported a match injury incidence of 12.7 injuries/1000h (95%CI = 5.4-19.9, I^2 = 89%). The scarcity of studies reporting overall, training and match injury incidence rates in the female U12 and below group, and overall and training incidences in the U13-U16 prevented further sub-analyses for these age groups.

3.3.2.8 Level of play

Males

Regarding the level of play, studies were classified into two groups: sub-elite and elite. Ten studies reported overall injury incidence [26,29,32,37,41,64,151,152,154,176], 9 studies reported training injury incidence [26,29,32,37,41,64,151,152,154] and 9 studies reported match injury incidence [26,29,32,37,41,64,151,152,154] in sub-elite players. The random effect models showed an overall incidence of 4.8 injuries/1000h of exposure (95%CI = 2.6-6.9, I^2 = 98%), a training incidence of 2.8 injuries/1000h of training (95%CI = 1.4-4.3, I^2 = 96%) and a match incidence of 10.6 injuries/1000 hours of match (95%CI = 6.0-15.3, I^2 = 93%).

For its part, elite level was represented by 20 (25 cohorts) overall injury incidence studies [12,24,25,27,28,30,31,34,38,52,54,63,68,121,135,140,148,155,179,181], 14 (19 cohorts) training injury incidence studies [25,28,30,31,34,38,54,63,68,135,140,148,179,181] and 16 studies (21 cohorts) from competition [25,28,30,31,34,38,54,63,68,135,140,148,153,175, 179,181]. The random effect models showed an overall incidence of 6.2 injuries/1000h of exposure (95%CI = 4.6-7.8, I^2 = 99%), a training incidence of 2.7 injuries/1000h of training (95%CI = 1.6-3.7, I^2 = 98.0%) and a match incidence of 17.9 injuries/1000h of match (95%CI = 13.0-22.8, I^2 = 98%).

Females

Three studies (4 cohorts) reported overall injury incidence [136,141,152], with the random effect models displaying an overall incidence of 7.9 injuries/1000h of exposure (95%CI = 3.3-12.4, I^2 = 78%). Not enough studies were found to estimate training and match incidences in sub-elite female players.

On the other hand, 4 studies (6 cohorts) reported overall [54,136,137,148], 3 studies (4 cohorts) reported training [54,137,148], and 5 studies (6 cohorts) presented match [54,137,148,153,175] injury incidence rates in elite female players. The overall incidence was 6.5 injuries/1000h of exposure (95%CI = 5.8-7.2, I^2 = 50%), 3.2 injuries/1000h of training (95%CI = 1.6-4.9, I^2 = 79%) and 18.1 injuries/1000h of match (95%CI = 9.4-26.8, I^2 = 98%).

3.3.2.9 Probability of Injury

The overall injury probability over one season was 47% and 43% for male and female youth players, respectively. Independent of sex, the highest injury probability was found for the U17-U19 age groups (56% in males and 58% in females), and lowest for U12 (7% in males and 18%

in females) and U13-U16 (39% and 30% for males and females, respectively) age groups. Appendix 11 provides a descriptive summary of the probabilities of injury by individual studies in both male and female cohorts.

3.4 Discussion

The primary purpose of this study was to perform a systematic review and meta-analysis quantifying the incidence of injuries in male and female youth football. The secondary purpose was to determine the overall effects regarding location of injuries, type of injuries, severity of injuries, overuse and traumatic injuries, new and recurrent injuries, age groups, and level of play.

Both the methodology and statistical analyses used in the current study were identical to those in the systematic reviews and meta-analyses conducted by Lopez-Valenciano et al. [161,182] in adult men (elite players) and women (sub-elite and elite players) football players and hence, comparisons in injury profile are possible. However, these injury profile comparisons between youth and adult footballers should be interpreted with a certain degree of caution due to inter-meta-analyses differences in the number of cohorts and quality of the studies included in each analysis.

3.4.1 Injury incidence: overall, training and match

The main findings of the current study indicate that the overall, training and match injury incidence rates in male (5.7, 2.8 and 14.4 injuries/1000h of overall, training and match exposure, respectively) and female (6.8, 2.6 and 15.0 injuries/1000h of overall, training and match exposure, respectively) youth football players are higher than the injury incidence rates provided by previous studies in other youth team sports such as: handball (2.9, 0.9 and 9.9 injuries/1000h of overall, training and match exposure, respectively) [183], basketball (1.3, 0.5, 11.2 injuries/1000h of overall, training and match exposure, respectively) [184] and volleyball (2.4 injuries/1000h of match exposure) [185]. Furthermore, the probability of youth football players sustaining a time-loss injury during a season was 47% for male and 43% for female players. These probability of injury scores are higher than the 28% reported for child and adolescent rugby players involved in a rugby match playing season [170]. The high injury incidence rates and probability scores found for youth footballers in the present meta-analysis reinforce the need for implementing targeted injury risk mitigation strategies in youth football.

In line with adult football players [161,182] and other youth team sports (independent of the sex of the players) such as handball [183], basketball [184], volleyball [185], and rugby [170], match injury incidence is always significantly higher than training incidence. A number of studies have attributed these differences in injury incidence rates between match and training to several factors, including: the higher physical playing demands during matches in comparison with training sessions, the match selection policy, the variability and uncertainty generated by players when competing against rivals, the number of contacts and collisions accounted for during matches, and the fatigue generated during the course of the match [33,186,187]. In addition, Koutures & Gregory [188] have suggested that to reduce the high injury rate in matches at youth level, preventive interventions, such as adequate rule enforcement and focusing on fair play, must be analysed and developed.

3.4.2 Location and type of injuries

Similar to what was found in adult footballers, in both male and female youth football players, lower extremity injuries had the highest incidence rates compared to the other body regions (3.8 and 6.5 injuries/1000h for males and females, respectively).

The location of the most frequently reported injuries in male and female youth footballers was slightly different. In male players the thigh (1.2/1000h) and ankle (0.9/1000h) were the anatomical regions where injuries occurred most whereas the knee (1.5/1000h) and ankle (1.5/1000h) were the regions most frequently injured in females. These higher knee and ankle injury incidence rates documented in female youth football players may be explained by the fact that females sustain twice as many joint (non-bone) and ligament injuries than their male counterparts (2.4 [females] vs 1.0 [males] injuries/1000h). This higher susceptibility for sustaining joint and ligament injuries observed in youth female players in comparison with their male counterparts has also been found in adult football players. Sex-related differences in core and lower extremity neuromuscular control, joint laxity, hormonal regulation, biomechanics and anatomy [138,139,189,190] have been suggested (among other factors) to explain why female athletes are more prone to suffer more joint (non-bone) and ligament injuries, mainly around knee and ankle joints. Due to the lack of epidemiological studies reporting incidence rates in youth footballers separately for joints (non-bone) and ligaments (e.g., anterior cruciate ligament [ACL] of the knee, anterior inferior tibiofibular ligament of the ankle) a sub-analysis aimed at identifying the most injured joint (non-bone) and ligament was not possible. However, previous studies have consistently reported that ankle sprains were the most frequent joint and ligament injuries diagnosed in youth football, independently of the sex of the players [28,42,137,141].

Unlike females, the area most frequently injured in male football players was the thigh. However, no sex-related differences were found in the magnitude of thigh injury incidence (~1.1/1000h for both male and female players). This circumstance strongly correlates with the fact that both male and female youth football players also presented analogous muscle injury incidence rates (~2/1000h). The link between these two incidence rates can be found in the fact that hamstring and quadriceps muscle injuries, both operationally located in the thigh [146], have been consistently reported as the most frequently diagnosed injuries in youth football (also in adult players) [33,42,191]. By contrast, it should also be highlighted in this regard the fact that, in adult football, men and women did not report similar muscle injury rates. In particular, male footballers presented muscle incidence rates that were twice as high as women (4.6 vs. 1.8 injuries/1000h), which might be attributed to the larger inter-sex differences in physical match demands (e.g., number of high intensity actions performed) that are evident in elite football [192].

Interestingly, the incidences of trunk injuries were almost three times greater for female than male footballers (0.7 vs. 0.3 injuries/1000h), but still relatively low for both sexes. A more erect posture during landing has been evidenced in females, which could overload not only lower limbs but also trunk areas [189] and, consequently, this may increase the risk of trunk injuries (e.g., spondylolisthesis). Therefore, it would be advisable that prevention programs in females also focus on core strength.

3.4.3 Severity and mechanism of injuries

Although injuries occur frequently in youth football players, fortunately the majority appear to be of minimal (1–3 days lost) severity. However, it should be highlighted that moderate (1.7 [males] and 1.5 [females] injuries/1000h) but mainly severe (0.8 [males] and 1.3 [females] injuries/1000h) injury rates showed in this meta-analysis for both sexes may be considered problematic due to the fact that in applied settings, it might imply that in a typical youth football squad comprised of 20 players, a coach could expect two high burdensome injuries (> 28 days of time loss) per season (value calculated using the data provided in original studies [12,25–29,32,34,38,41,63,64,68,135,140,148,150,154,179,181]). Results of this study have revealed that a great proportion of injuries in male and female youth football might have a traumatic and non-contact mechanism, and as such they could be regarded as preventable. The implementation of comprehensive injury prevention programs aimed at improving movement competency and physical fitness in youth football have demonstrated to be a successful approach to reducing the number of moderate and severe non-contact injuries in children and adolescents [150,193]. In this sense, previous studies have demonstrated that 10–15 min of neuromuscular training activities two to three times weekly is sufficient in reducing non-contact injuries by 45% in youth football players [194].

While injury at adult levels can have negative effects on the team and its success rate [195], the impact of injury on development within youth football is yet to be established. However, it may be assumed that at young ages being away from football play for more than 28 days may not only negatively influence short-term tactical, technical and physical performance but also impair the long-term athlete development, health outcomes and future career opportunities [15]. As previous studies have only reported incidence rates and not the average number of days lost from football (time loss) by location and type of injury, it was not possible for us to calculate the injury burden (the cross-product of severity [consequences] and incidence [likelihood]) to build a risk matrix. The risk matrix would have helped to identify the importance (i.e., burden) of each football-related injury and may provide information to help prioritise injury prevention measures used in applied football environments. However, and based on the findings shown in previous studies [35,121], the most burdensome injuries in youth football may be quadriceps and hamstring muscle injuries and knee ligament injuries, alongside growth related injuries (ACL tears as well as Osgood-Schlatter and Sinding-Larsen diseases). This injury pattern in terms of severity and mechanism of injury described for youth players is very similar to the one reported by Lopez-Valenciano et al. [161,182] for adult footballers.

3.4.4 New vs. recurrent injuries

As expected, and similar to what has been reported in adult football players [161,182], recurrent injury incidence in youth football is lower than the new injury rate (0.8 [males] and 1.4 [females], vs. 5.9 [males] and 5.1 [females] injuries/1000h, respectively). Likewise, there are no sex-related differences in new and recurrent injuries either in youth nor in adult football players. However, it should be highlighted that the ratio of new versus recurrent injuries is higher in youth players (7.4 [male youth] vs. 5.4 [male adult] [161], and 3.6 [female youth] vs. 2.6 [female adult] [182]).

On the one hand, the lower incidence of recurrent injuries in youth players in comparison with their adult counterparts may indicate that at young ages there is not such a high pressure to return to play as soon as possible, contributing to improved rehabilitation [9]. On the other hand, having a previous history of injury is one of the few evidence-based predictors available in the literature for the most common football-related injuries (i.e., hamstring and knee injuries) [72,196,197]. As a consequence of having a larger experience in football play, adult footballers may present a higher likelihood of having suffered previous injuries compared with their youth players and hence, they may be at a higher risk of injury recurrence [119,198]. This circumstance has led some researchers to suggest that another main purpose of the injury risk mitigation strategies that should be implemented in youth football should be to delay as much as possible the appearance of the first injury event [119,199]. Longitudinal studies tracking injury incidence through the academy setting and into professional environments might help to elucidate if there is a consequence of repeated injury incidence during growth and maturation [200].

3.4.5 Age groups

Results from the different age groups, representing different periods of childhood and adolescence, suggest potential interactions between maturity, sex, training and competition with injury incidence. In males overall incidences increased between players who are likely to be pre-pubertal (U12), circa-pubertal (U13-U16) and post pubertal (U17-U19) [201], with overall injury rates of 1.6, 5.3 and 7.5 respectively. This was driven by a high incidence of match injury rates that increased by approximately ten injuries between each consecutive age interval (2.6 vs. 13.7 vs. 20.0). The changing profile of injury incidence is likely attributable to both maturation effects and increasing demands of training and competition in older age groups. Young children have an immature neuromuscular and metabolic system, with a lower muscle mass, more compliant muscle-tendon structures, and being less able to recruit fast twitch fibres, with an underdeveloped anaerobic system and with a greater reliance on aerobic metabolism [202]. All these factors will mean that immature players will work less explosively, generating and having to tolerate lower levels of force, exposing themselves to lower levels of risk, while they will also experience lower levels of fatigue during intermittent work and will able to recover from fatigue more quickly [203]. This is reflected in the U12 players having a low overall and low match incidence of injury. Adolescent players will experience a period of rapid physical development that will result in gains in both size and fitness, but this period can be accompanied with temporarily disrupted motor co-ordination [46]. Consequently, adolescent players may begin to expose themselves to a greater intensity and volume of exercise within training and match-play and may display abhorrent movement mechanics while also being more susceptible to growth and overuse injuries [42,52,69], and having a reduced ability to recover between matches [204], likely contributing to a greater injury incidence compared to prepubertal players.

Players will continue to physically develop into late adolescence and early adulthood and will likely continue to increase their abilities to work at a high intensity, completing more accelerations, decelerations and greater total distances during competition compared to younger players [205]. The increased physical demands and longer duration of match-play will mean players in the older age groups are exposing themselves to more risk during a game. Simultaneously, players transitioning to older age groups (U17-U19) are likely to experience a large increase in training load as they begin to train on full-time professional contracts [42], with spikes in workload suggested to contribute to injuries in youth football players [42,206]. These increases in injury rates across players' age groups are also evident when compared with the results reported by López-Valenciano et al. [161] for adult football players, where injury incidences reach up to 8.1, 3.7 and 36.0 injuries/1000h of overall, training and match exposure, respectively.

There was a paucity of data available to compare injury incidence across age groups in female players. From the available data, girls who were U17-U19 experienced a higher incidence of match related injuries than U13-U16 females (20.9 vs. 12.7), which is similar to the increase described in males. However, more research with females is needed to confirm potential differences between age groups, especially across a range of maturational stages.

3.4.6 Level of play

The findings of this study also indicate that elite (high-level) male players present higher match injury incidences (17.9) than their sub-elite (less skilled) peers (10.6). These observed differences according to the level of play may be partially explained by the fact that elite players may perform more high-intensity actions during competitions and, as it has been mentioned before, this would potentially increase their risk of sustaining an injury. In addition, players skilled at receiving the ball, passing, shooting, and decision-making with the ball at their feet have more ball possession and, consequently, are exposed to more tackles and other contact situations [207]. Furthermore, apart from playing with their respective teams, highly skilled young players are often required to play up age groups and compete in teams of older players. This scenario not only forces these players to compete against more mature and physically bigger players but also to potentially play two matches within a very short time interval (usually less than 36 hours), which may overload their immature musculoskeletal system and thus, significantly increase their risk of injury [208]. In this sense, Dupont et al. [209] found that decreased recovery time between matches leads to an increase in injury incidences. Finally, the professionalisation of youth football has meant that many youngsters in professional academies become single-sport specialists [8]. High weekly training volumes associated with early specialisation may promote limited participation in other sports, decreasing motor skill development, and increasing injury risk as players transition development cycles [210,211]. Elite young football players who strive to be professional players may also be exposed to high levels of pressure.

On the other hand, no differences in training injury incidences were found regarding the level of play for males. It is reasonable to suggest that elite players have access to better resources compared to their sub-elite peers, including better equipment, comprehensive medical support and expert coaches to control match/training loads, which may have contributed to the reduction of injury risk despite their expected greater exposure to training [24].

Although elite female youth footballers showed similar injury incidence rates than males, there was a lack of data for training and matches in sub-elite players. Future studies should analyse the injury profile in this cohort of football players, reporting the number of injuries sustained in matches and training sessions separately.

3.4.7 Level and quality of the evidence

The pooled results of more than 25 epidemiological studies provided a moderate quality of evidence that supports the overall, training and match injury rates estimated for male youth football players in this systematic review and meta-analysis. On the contrary, the quality of evidence for overall, training and match injury incidences in females was low, coming from only 5 (training) to 10 (match) studies. Therefore, future research should be focused on injury incidences in youth female football players for a broader comparison with the incidences presented by males.

3.4.8 Limitations

Although this novel study was conducted following the international guidelines for systematic reviews and meta-analyses, some limitations should be acknowledged. Variations in injury definition and data collection procedures used in the different studies might partly explain the heterogeneous estimates obtained in our main meta-analysis, like in previous meta-analysis conducted in Sport Medicine [8,161,170,182]. To mitigate it, only those studies that rigorously and clearly followed the time-loss injury definition described by Fuller et al. [146] and Hägglund et al. [147] were included in the sub-analyses. Surely, the additional inclusion of medical attention injuries might have led to a higher injury incidence. However, this could also intensify the differences between data collection procedures since non-time loss injury incidence has been shown to be especially sensitive to different recording settings, and a research-invested clinical recorder might report almost nine times greater incidence compared to other non-involved recorders (i.e., non-involved physiotherapists) [212]. Thus, and based on the reality of injury surveillance in youth football players, where coaches are frequently the responsible person for recording injuries [36,141,152,153,178,193,213,214] due to the lack of medical staff, time-loss definition was used. Furthermore, when different epidemiological data were presented (e.g., hours of athlete exposure, total number of injuries or number of matches played), we applied standardised formulas to account for this discrepancy. Nevertheless, even when these inclusion criteria and standardised formulas were applied, the degree of inconsistency of the main results (overall, training and match incidences) across studies was still very high. Consequently, other aspects such as differences existing between the geographic areas (or time of year) regarding the climatic conditions for football practice (cooler vs. warmer regions/months) [215], the monitoring period of the season (pre-season vs. competitive season) [26,41], the number of exposure hours and match congestion [24], or the skill level of youth footballers [60] may have constituted other sources of inconsistency. The limited studies reporting the location and type of injuries for elite and sub-elite players by sex made further sub-analyses to identify potential for differences regarding the level of play impossible. However, and based on previous results for elite [24,25,27,28,34,140] and sub-elite [26,29,32,41,64] male and elite [137] and sub-elite [141] female players, large differences in these injury patterns might not be expected. Finally, albeit another important focus would have been the estimation of physical maturation status and the influence of the growth spurt on injury incidence, as well as the incidence of growth-related injuries in young players, the sample size of studies included was also not sufficient to investigate interactive effects within these factors.

3.5 Conclusions

The high injury incidence rates and probability scores found for youth footballers in the present meta-analysis reinforce the need for implementing targeted injury risk mitigation strategies in youth football, irrespective of sex. As incidence rates are higher during match play for both sexes it is important that training prescription mimics match demands as closely as possible to provide the robustness and readiness needed for competitive play. The sex differences identified for the most common location and type of injury reinforce the need for different targeted management strategies in male and female youth players. As males tend to sustain predominantly muscle injuries to the thigh and females sustain joint and ligament injuries to the knee and ankle, strategies should focus on neuromuscular conditioning in male players and movement mechanics as well as core strength and joint stability in female players. However, there is still a paucity of data in female players, especially in younger and less mature players, and thus longitudinal studies are needed to fully explore the age and maturation related changes in incidence, severity, location, and type.

3.6 Appendices

Appendix 1. PRISMA checklist.

Section/topic	#	Checklist item	Page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	69
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	33
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	69, 70
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	70
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	71
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	71 (App 2)
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	71, 72
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	72 (App 3)
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	71
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	71-72 (App 5)
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	72 (App 4)
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	73 (App 6 and 7)
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	74, 75

Section/topic	#	Checklist item	Page #
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	74, 75
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	73-74
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	74-75
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	76 (Fig 6)
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	77-83 (Table 2)
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	76 (App 8 and 9)
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	84-89 (Fig 7-12)
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	84-89
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	116 (App 10)
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	84-94
DISCUSSION			
Summary of evidence	24	Summarise the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	95-101
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	101
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	100
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	5

Appendix 2. Inclusion/exclusion criteria for young football players' injuries literature search.

	Inclusion criteria	**Exclusion criteria**	**Rationale for these criteria**
Publication type	Peer-reviewed original research articles only.	Non-peer-reviewed articles, newspapers, opinion pieces, systematic reviews and meta-analysis, editorials, commentaries and letters to the editor. Conference proceedings/abstracts. Book chapters.	For reasons of practicality, it was deemed acceptable to include only studies published in peer-reviewed journals.
Language	English and Spanish	Non- English and Spanish.	For reasons of practicality, it was deemed acceptable to include only studies published in English or Spanish.
Publication date	Up to 31st December 2020.	-	All articles were included regardless of the time period.
Study design	Multi-centre studies, randomised control trials, and prospective cohort studies	Descriptive studies, anecdotal. Case-controlled studies and cross-sectional studies. Case studies or expert opinion.	Based on the evidence hierarchy as a guide, ONLY study designs ranked 'good' and 'excellent' were included in this systematic review and meta-analysis. This was to ensure high methodological rigour and offer reasonable empirical support for the incidence and aetiology of injuries among young footballers.
Sex and age	Male and female football players younger than 19 years old (U19).	Studies with no football players, where the footballers are older than 19 years old or participants' age is not specified, and studies that do not report injury incidences separately by sex.	The primary outcome of interest was the incidence, nature and anatomical location of the injuries sustained in young male and female football players. Studies that compared injury rates between young and adult players and present injury incidences separately were included. Similarly, studies that analyse injury incidences in several sports but present incidence in young footballers separately were also included.
Playing level	Participating in elite and/or sub-elite level.	Non-competitive football activities.	The inclusion of injuries associated with such a range of different populations might result in a vague aetiology due to differences in playing/training conditions. Therefore, only studies with young football players participating in games/training in a competitive setting (elite and sub-elite) were included, to be consistent with the aims of this systematic review and meta-analysis. Elite involved professional youth academies, national teams and international tournaments. Players not described as belonging to a football academy, playing at a high level or classified as elite were considered as sub-elite (e.g., community, regional and inter-provincial playing levels).
Injury definition	Time-loss definition.	Non-Time-loss definition.	Time-loss injury, defined as any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention, allows to compare statistically data between different studies reducing inconsistencies between data collection procedures. Studies with other definitions would not meet the methodological criteria of the meta-analysis.

Appendix 3. Search strategies.

Search strategy in PubMed -998 results

#1 (soccer[tiab] OR “soccer”[MeSH Terms] OR football[tiab] OR “football”[MeSH Terms]) AND (injury[tiab] OR “injury”[MeSH Terms] OR injuries[tiab] OR “injuries”[MeSH Terms] OR incidence[tiab] OR “incidence”[MeSH Terms] OR prevalence[tiab] OR “prevalence”[MeSH Terms] OR epidemiology[tiab] OR “epidemiology”[MeSH Terms]) AND (youth[tiab] OR “youth”[MeSH Terms] OR children[tiab] OR “children”[MeSH Terms] OR adolescents[tiab] OR “adolescents”[MeSH Terms] OR kids[tiab] OR “kids”[MeSH Terms])

#2 #1 Filters: Published up to 31st December 2020.

Search strategy in the Cochrane Central Register of Controlled Trials – 161 results

#1 soccer [Title/Abstract/Key Word] OR football [Title/Abstract/Key Word] AND injur [Title/Abstract/Key Word] OR incidence [Title/Abstract/Key Word] AND youth [Title/Abstract/Key Word]

#2 soccer [Title/Abstract/Key Word] OR football [Title/Abstract/Key Word] AND injur [Title/Abstract/Key Word] OR incidence [Title/Abstract/Key Word] AND children [Title/Abstract/Key Word]

#3 soccer [Title/Abstract/Key Word] OR football [Title/Abstract/Key Word] AND injur [Title/Abstract/Key Word] OR incidence [Title/Abstract/Key Word] AND adolescent [Title/Abstract/Key Word]

#4 #1 AND #2 AND #3

#5 #4 Filters: Published up to 31st December 2020.

Search strategy in Web of Science - 271 results

#1 TITLE: (football OR soccer) AND TITLE: (injur* OR incidence OR prevalence OR epidemiology) AND TITLE: (youth OR children OR adolescent OR kid)

Search strategy in Sportdiscus - 699 results

#1 AB (football OR soccer) AND AB (injury OR injuries OR incidence OR epidemiolog* OR prevalence) AND AB (youth OR children OR adolescent OR kid)

Appendix 4. Definitions used to include studies in the meta-analysis.

Term	**Definition**
Injury	Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities.
Time loss injury	Injury that results in a player being unable to take a full part in future football training or match play.
Recurrent injury	An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.
Injury severity	The number of days that have elapsed from the date of injury to the date of the player's return to full participation in team training and availability for match selection. Injuries are grouped as: *Minimal* Absence (1-3 days) *Minor / Mild* Absence (4-7 days) *Moderate* Absence (8-28 days) *Major / Severe* Absence (>28 days)
Match exposure	Play between teams from different clubs.
Training exposure	Team-based and individual physical activities under the control or guidance of the team's coaching or fitness staff that are aimed at maintaining or improving players' football skills or physical condition.
Overuse injury	An injury caused by repeated microtrauma without a single, identifiable event responsible for the injury.
Traumatic injury	Injury with sudden onset and known cause.
Contact injury	An injury caused by external influence (i.e., any contact with another player or other object).
Non-contact injury	An injury happened without external influence.
Injury location	Head and neck (Head/face; Neck/cervical spine) Upper limbs (Shoulder/clavicula; Upper arm; Elbow; Forearm; Wrist; Hand/finger/thumb) Trunk (Sternum/ribs/upper back; Abdomen; Lower back/pelvis/sacrum) Lower limbs (Hip/groin; Thigh; Knee; Lower leg/Achilles tendon; Ankle; Foot/toe)
Type of injury grouping	Fractures and bone stress Joint (non-bone) and ligament (Dislocation/subluxation; Sprain/ligament injury; Lesion of meniscus or cartilage) Muscle and tendon (Muscle rupture/tear/strain/cramps; Tendon injury/rupture/tendinosis/bursitis) Contusions (Haematoma/contusion/bruise) Laceration and skin lesion (Abrasion; Laceration) Central/peripheral nervous system (Concussion [with or without loss of consciousness]; Nerve injury) Other (Dental injuries; Other injuries)
Injury incidence	Number of injuries per 1000 player hours ((Σ injuries/Σ exposure hours) ×1000).

Appendix 5. Moderator variables codded.

General study descriptors

- Authors
- Year of the study
- Continent / Tournament
- Sampling time (number of seasons)

Description of the study population

- Sample size
- Number of teams
- Age group
- Level of play (sub-elite or elite)
- Sex

Epidemiological descriptors

- Injury definition
- Number of injuries (total, match and training)
- Exposure time (total, match and training)
- Incidence (total, match and training)
- Injury burden or days lost per injury
- Injury location
- Type of injury
- Severity of injury
- Recurrence
- Injury mechanism (traumatic or overuse; contact or non-contact)
- Quality of the study (STROBE scale)
- Risk of bias (adapted NOS scale)

Appendix 6. Description of the 22 criteria designed to assess quality of the studies included in the meta-analysis with the STROBE scale.

	Item	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported
Objectives	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design	4	Present key elements of study design early in the paper
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	Describe any efforts to address potential sources of bias
Study size	10	Explain how the study size was arrived at
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed
		(*e*) Describe any sensitivity analyses
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)

	Item	Recommendation
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorised
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results	18	Summarise key results with reference to study objectives
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Appendix 7. Description of the 8 criteria designed to assess risk of bias of external validity quality in the studiesT. This instrument is an adapted version of the Newcastle Ottawa Scale (NOS) for cohort studies.

Criterion	**Description of criteria**
Description or type of football players.	There are several types of football players (sub-elite vs. elite, males vs. females). Without the description regarding to the type of football players it is impossible to conclude which population the incidence rates refer to. Studies that reported a description of the football players or informed the type of football players receive a star for this criterion. Studies conducted in football tournaments (which may determine the type of football players; e.g., World Cup tournaments) and which describe the race characteristics receive a star for this criterion as well. Studies that did not describe the characteristics or the type of football players, and studies conducted in football tournaments that did not describe the characteristics of the tournament did not receive a star for this criterion.
Definition of football-related injury.	Studies that aimed to investigate football-related injuries should present a definition of an injury informing what was considered as an injury in the study. Studies that present a definition of time-loss injury received a star for this criterion.
Representativeness of the exposed cohort.	(a) Truly representative of the average football players in the community*; (b) somewhat representative of the average football players in the community*; (c) selected group of users; (d) no description of the derivation of the cohort.
Ascertainment of exposure.	(a) Secure record*; (b) structured interview*; (c) written self-report; (d) no description
Demonstration that outcome of interest was not present at start of study.	(a) Yes*; (b) no. Studies that described that all football players included were injury-free at baseline received a star for this criterion.
Assessment of outcome.	(a) Independent blind assessment*; (b) record linkage*; (c) self-report; (d) no description.
Was follow-up long enough for outcomes to occur risk factors.	(a) Yes*; (b) no. Studies that carried out a follow-up period of at least 12 weeks received a star for this criterion.
Adequacy of follow-up of cohorts	(a) Complete follow-up of all subjects accounted for*; (b) subjects lost to follow-up unlikely to introduce bias (up to 20 % loss) or description provided of those lost*; (c) follow-up rate <80% and no description of those lost; (d) no statement. A loss to follow-up greater than 20 % may increase the risk of bias in prospective studies [216].

[T]: The articles could be awarded a maximum of one star for each item. A total of 8 stars could be given for the articles.

* Articles with this alternative received a star for this criterion.

Appendix 8. Analysis of the selected studies' methodological quality-STROBE (*n* = 43).

Study	1a	1b	2	3	4	5	6a	6b	7	8	9	10	11	12a	12b	12c	12d	12e	13a	13b	13c	14a	14b	14c	15	16a	16b	16c	17	18	19	20	21	22	**Score**
Andreasen et al. [174]	-	+	+	+	-	+	+	+	+	+	-	-	-	-	+	-	-	-	-	-	-	+	-	+	+	-	-	+	+	+	-	-	-	+	16
Azuma & Someya [154]	+	+	+	+	-	+	+	+	+	+	+	-	+	+	+	-	+	-	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	-	28
Backous et al. [36]	+	-	+	+	-	-	+	+	+	+	+	-	-	-	+	-	-	-	-	-	-	-	-	+	+	-	-	+	+	+	-	-	-	+	15
Bianco et al. [31]	+	+	+	+	-	+	+	+	+	+	+	-	-	-	+	-	-	-	-	-	-	+	-	+	+	-	-	+	+	+	+	+	-	+	20
Brito et al. [41]	+	+	-	+	+	+	-	+	+	+	-	-	+	-	+	-	-	-	+	-	-	-	-	+	+	+	+	+	+	+	+	+	-	+	21
Brito et al. [26]	+	+	+	+	-	+	-	+	+	+	-	-	+	-	+	-	-	-	+	+	-	+	-	+	+	+	+	+	+	+	-	+	-	+	22
Bult et al. [12]	+	+	+	+	-	+	+	+	+	+	-	-	+	+	+	-	-	-	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+	+	26
Cezarino et al. [30]	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	-	+	-	-	+	+	+	+	+	+	+	+	+	+	+	-	+	29
Chena-Sinovas et al. [29]	-	+	+	+	-	-	-	+	+	+	+	-	+	-	+	-	-	-	-	-	-	+	-	+	+	-	-	+	+	-	-	+	-	-	15
Clausen et al. [136]	+	+	+	+	+	+	+	+	+	+	-	-	-	+	+	+	+	-	+	+	+	+	-	+	+	+	+	+	+	+	-	+	-	+	27
Delecroix et al. [155]	+	+	+	+	+	+	+	+	+	+	-	-	-	+	+	+	+	-	+	-	-	+	-	+	+	-	+	+	+	+	+	+	-	+	25
Ergün et al. [140]	+	+	+	+	-	+	+	+	+	+	-	-	+	-	+	-	+	-	-	-	-	+	-	+	+	-	-	+	+	+	+	+	-	+	21
Fouasson-Chailloux et al. [121]	+	+	+	+	-	+	+	+	+	+	+	-	+	-	+	-	-	-	-	-	-	+	-	+	+	+	+	+	+	+	+	+	-	+	23
Frisch et al. [64]	+	+	+	+	+	+	+	+	+	+	-	-	+	+	+	-	+	-	+	+	-	+	-	+	+	+	+	+	+	+	+	+	-	+	27
Hägglund et al. [148]	+	+	+	+	+	+	+	+	+	+	-	-	+	+	+	-	-	-	+	-	-	+	-	+	+	+	-	+	+	+	+	+	+	+	25
Hawkins & Fuller [38]	+	+	+	+	+	+	+	+	+	+	-	-	+	-	+	-	-	-	-	-	-	-	-	+	+	-	-	+	+	+	-	-	-	-	17
Imai et al. [151]	-	+	+	+	-	+	-	+	+	+	-	-	+	+	+	-	-	-	-	+	-	-	-	+	+	+	-	-	+	+	+	+	+	+	20
Junge & Dvorak [175]	+	+	+	+	-	+	+	+	+	+	-	-	+	+	-	-	-	-	+	-	-	+	+	+	+	+	+	-	+	+	-	+	+	+	23
Junge et al. [176]	+	+	+	-	+	+	+	+	+	+	-	-	-	-	+	+	+	-	+	+	-	+	-	+	+	-	-	+	+	-	+	+	-	-	21
Junge et al. [37]	+	+	+	+	+	+	+	+	+	+	-	-	-	-	+	+	+	-	+	+	-	+	-	+	+	-	-	+	+	-	-	+	-	+	22
Kakavelakis et al. [177]	+	+	+	+	-	+	+	-	+	+	-	-	-	-	-	-	+	-	+	+	-	+	-	+	+	-	-	+	-	+	-	+	-	-	17
Kuzuhara et al. [152]	+	+	+	+	-	+	+	+	+	+	-	-	-	+	+	-	-	-	-	-	-	+	-	+	+	+	+	+	+	+	+	+	-	+	22
Le Gall et al. [137]	+	+	+	+	+	+	+	+	+	+	+	-	-	-	+	-	+	-	-	-	-	+	-	+	+	+	+	+	+	+	+	+	-	+	24
Lislevand et al. [134]	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	27
Nielsen & Yde [178]	+	+	+	+	-	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	+	-	+	+	-	-	+	+	-	-	-	-	-	15
Nilsson et al. [135]	+	+	+	+	+	+	+	-	+	+	+	-	+	-	-	-	+	-	+	+	-	+	-	+	+	-	-	+	-	+	+	+	-	+	22
Nogueira et al. [32]	+	+	+	+	-	+	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	-	+	+	+	+	+	+	+	+	+	-	+	29
Owoeye et al. [179]	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	-	+	+	-	-	+	+	+	+	+	-	-	27
Raya-González et al. [28]	+	+	+	+	+	+	+	+	+	+	-	-	+	+	+	-	-	-	-	-	-	+	-	+	+	+	+	+	+	+	+	+	-	-	23
Renshaw & Goodwin [27]	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	-	+	-	-	-	-	-	-	+	+	-	+	+	+	+	+	+	+	+	25
Rommers et al. [68]	+	+	+	+	+	+	+	+	+	+	-	-	+	-	-	-	-	-	-	-	-	+	-	+	+	-	-	-	+	+	+	+	+	+	20

Study	1a	1b	2	3	4	5	6a	6b	7	8	9	10	11	12a	12b	12c	12d	12e	13a	13b	13c	14a	14b	14c	15	16a	16b	16c	17	18	19	20	21	22	**Score**
Schmidt-Olsen et al. [44]	-	-	+	+	-	+	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	+	-	+	+	-	-	+	+	-	-	-	-	-	11
Sieland et al. [63]	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	-	-	-	-	-	-	+	-	+	+	-	-	+	+	+	+	+	+	+	24
Söderman et al. [141]	+	+	+	+	-	+	+	+	+	+	+	-	-	-	-	-	+	-	+	+	-	+	-	+	+	-	-	+	+	-	-	+	-	+	20
Soligard et al. [150]	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	32
Soligard et al. [153]	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	-	-	-	-	-	-	+	-	+	+	-	+	+	+	+	+	+	-	+	24
Sprouse et al. [54]	-	+	+	+	+	+	+	+	+	+	-	+	+	+	+	-	-	-	-	-	-	-	-	+	+	-	-	+	+	+	+	+	+	+	22
Steffen et al. [180]	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	-	-	+	+	+	+	-	+	+	+	+	+	+	+	+	+	-	+	29
Tears et al. [24]	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	-	-	-	-	-	-	+	+	-	-	+	+	+	+	+	+	+	25
van der Sluis et al. [52]	-	+	+	+	-	+	+	+	+	+	-	-	+	-	+	+	+	-	+	+	-	-	+	+	+	-	-	+	+	+	+	+	-	-	22
Waldén et al. [25]	+	+	+	+	+	+	+	+	+	+	-	-	+	+	+	-	-	-	+	-	-	+	+	+	+	-	-	+	+	+	+	+	+	+	25
Wik et al. [34]	+	+	+	+	+	+	+	+	+	+	-	-	+	-	-	+	+	-	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	28
Zarei et al. [181]	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	-	+	+	+	+	+	+	+	31

Appendix 9. Risk of bias assessment of the studies (Newcastle-Ottawa scale).

Study	**Criteria for assessing risk of bias**								**Total**
	1	2	3	4	5	6	7	8	
Andreasen et al. [174]	*	*	*			*		*	5
Azuma & Someya [154]	*	*	*		*	*	*	*	7
Backous et al. [36]	*	*	*			*		*	5
Bianco et al. [31]	*	*	*			*	*	*	6
Brito et al. [41]	*	*	*			*		*	5
Brito et al. [26]	*	*	*	*		*	*	*	7
Bult et al. [12]	*	*	*	*		*	*	*	7
Cezarino et al. [30]	*	*	*	*	*	*	*	*	8
Chena-Sinovas et al. [29]	*	*	*			*	*	*	6
Clausen et al. [136]	*	*	*			*	*	*	6
Delecroix et al. [155]	*	*	*		*	*	*	*	7
Ergün et al. [140]	*	*	*			*	*	*	6
Fouasson-Chailloux et al. [121]	*	*	*	*		*	*		6
Frisch et al. [64]	*	*	*	*		*	*	*	7
Hägglund et al. [148]	*	*	*	*		*		*	6
Hawkins & Fuller [38]		*	*			*	*	*	5
Imai et al. [151]	*	*	*	*		*	*	*	7
Junge & Dvorak [175]	*	*	*	*		*		*	6
Junge et al. [176]	*	*	*	*		*	*	*	7
Junge et al. [37]	*	*	*	*		*	*		6
Kakavelakis et al. [177]	*	*	*			*	*	*	6
Kuzuhara et al. [152]	*	*	*	*		*	*	*	7
Le Gall et al. [137]	*	*	*		*	*	*	*	7
Lislevand et al. [134]	*	*	*			*		*	5
Nielsen & Yde [178]	*	*	*	*	*	*	*	*	8
Nilsson et al. [135]	*	*	*	*	*	*	*	*	8
Nogueira et al. [32]	*	*	*	*		*	*	*	7
Owoeye et al. [179]	*	*	*	*		*	*	*	7
Raya-González et al. [28]	*	*	*	*		*	*	*	7
Renshaw & Goodwin [27]	*	*	*	*	*	*	*	*	8
Rommers et al. [68]	*	*	*	*	*	*	*		7
Schmidt-Olsen et al. [44]	*	*	*			*		*	5
Sieland et al. [63]	*	*	*	*	*	*	*		7
Söderman et al. [141]	*	*	*		*	*	*	*	7
Soligard et al. [150]	*	*	*	*	*	*	*	*	8
Soligard et al. [153]	*	*	*			*		*	5
Sprouse et al. [54]	*	*	*	*		*	*	*	7
Steffen et al. [180]	*	*	*		*	*	*	*	7
Tears et al. [24]	*	*	*			*	*	*	6
van der Sluis et al. [52]	*	*	*			*	*	*	6
Waldén et al. [25]	*	*	*	*		*		*	6

Study	**Criteria for assessing risk of bias**								**Total**
	1	2	3	4	5	6	7	8	
Wik et al. [34]	*	*	*	*		*	*	*	7
Zarei et al. [181]	*	*	*	*		*	*	*	7

Criteria for assessing risk of bias: (1) description or type of football players; (2) definition of injury; (3) representativeness of the exposed cohort; (4) ascertainment of exposure; (6) demonstration that outcome of interest was not present at start of study; (6) assessment of outcome; (7) was follow-up long enough for outcomes to occur; (8) adequacy of follow-up of cohorts.
*Star(s) awarded for each criterion.

Appendix 10. Summary of findings (GRADE).

Nº of studies	**Certainty assessment**					**Effect**			**Certainty**
	Study design	**Risk of bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Nº of events**	**Nº of individuals**	**Incidence (95% CI)**	
Overall injury incidence in youth male football players									
33 [12,24–32,34,36–38, 41,52,54,63,64,68,121,135,140,148, 151,152,154,155,176–179,181]	Observational studies	Serious [a]	Very serious [b]	Not serious [c]	Not serious	6873	7895	5.7 injuries/1000h (4.5 to 6.9)	⊕⊕⊕◯ MODERATE
Training injury incidence in youth male football players									
25 [25,26,28–32,34,37,38,41,54,63,64,68,135,140, 148,151,152,154,177–179,181]	Observational studies	Serious [a]	Very serious [b]	Not serious [c]	Not serious	2496	6692	2.8 injuries/1000h (2.0 to 3.5)	⊕⊕⊕◯ MODERATE
Match injury incidence in youth male football players									
29 [25,26,28–32, 34,37,38,41,44,54,63,64,68,135,140, 148,151–154,174,175,177–179,181]	Observational studies	Serious [a]	Very serious [b]	Not serious [c]	Not serious	2559	24409	14.4 injuries/1000h (11.0 to 17.8)	⊕⊕⊕◯ MODERATE
Overall injury incidence in youth female football players									
9 [36,54,136,137,141,148,150,152,180]	Observational studies	Serious [a]	Very serious [b]	Serious [d]	Not serious	1896	3388	6.8 injuries/1000h (5.0 to 8.5)	⊕⊕◯◯ LOW
Training injury incidence in youth female football players									
5 [54,137,148,150,152]	Observational studies	Not serious	Very serious [b]	Serious [d]	Serious [e]	676	1392	2.6 injuries/1000h (1.2 to 4.1)	⊕⊕◯◯ LOW
Match injury incidence in youth female football players									
10 [44,54,134,137,148,150,152,153,174, 175]	Observational studies	Serious [a]	Very serious [b]	Serious [d]	Not serious	804	7692	15.0 injuries/1000h (9.7 to 20.2)	⊕⊕◯◯ LOW

[a] Some studies [17,32,50,70,71,80] presented certain risk of bias (assessed with the Newcastle Ottawa Scale [NOS])

[b] High inconsistency (I^2 > 90%)

[c] Sub-analyses by age-group and level of play are presented, so indirectness was not downgraded

[d] Not enough data to carry out sub-analyses by age groups (U12 and U16) and level of play

[e] Limited sample size

Appendix 11. Probabilities of injury for males and females over a typical season*.

Reference	Age (range)	Match incidence	Match duration (min)	Average probability of injury to a player in a typical season (%)[†]
Males				
Azuma & Someya [154]	U18 (15-18)	11.9	90	41
Bianco et al. [31]	U16 (13-16)	2.2	80	8
	U19 (17-19)	4.3	90	18
	All groups (13-19)	2.8	80-90	11-12
Brito et al. [41]	U19 (12-19)	6.8	60-90	18-26
Brito et al. [26]	U18 (11-18)	4.7	60-90	13-19
Cezarino et al. [30]	U11 (10-11)	2.7	40	5
	U12 (11-12)	0.0	50	0
	U13 (12-13)	5.5	50	13
	U14 (13-14)	9.1	60	24
	U15 (14-15)	2.6	60	8
	U16 (15-16)	4.6	80	17
	U17 (16-17)	13.7	80	42
	U18 (17-18)	8.1	90	30
	All groups (10-18)	6.4	40-90	12-25
Chena-Sinovas et al. [29]	U9 (7-9)	8.3	40	15
	U11 (10-11)	3.9	60	11
	U13 (12-13)	1.1	70	4
	U15 (14-15)	13.5	80	42
	U18 (16-18)	18.9	90	57
	All groups (7-18)	8.9	40-90	16-33
Ërgun et al. [29] [140]	U19 (U17-19)	30.4	80-90	70-75
Hägglund et al. (a) [148]	U19 (U19)	16.3	90	52
Hägglund et al. (b) [148]	U19 (U19)	27.8	90	71
Hägglund et al. (c) [148]	U19 (U19)	21.8	90	63
Hägglund et al. (d) [148]	U17 (U17)	20.7	80	56
Hägglund et al. (e) [148]	U17 (U17)	12.6	80	40
Hägglund et al. (f) [148]	U17 (U17)	28.6	80	68
Hawkins et al. [38]	U18 (16-18)	37.2	90	81
Junge et al. (a) [175]	U17 (U17)	28.4	90	72
Junge et al. [176]	U18 (14-18)	16.2	90	52
Kuzuhara et al. [152]	U12 (<=12)	5.4	40	10
Nielsen et al. [178]	U18 (16-18)	14.4	90	48
Nilsson et al. [135]	U19 (15-19)	15.5	90	50
Nogueira et al. [32]	U16 (15-16)	12.6	80	40
	U19 (17-19)	16.0	90	51
	All groups (15-19)	14.2	80-90	43-47
Owoeye et al. [179]	U19 (14-19)	20.3	90	60
Raya-González et al. [28]	U14 (13-14)	6.0	80	21
	U16 (15-16)	9.1	90	34
	U19 (17-19)	11.0	90	39
	All groups (13-19)	8.8	80-90	30-33
Renshaw et al. [27]	U11 (U9-11)	0.4	40-60	1
	U15 (U15)	80.0	80	96
	U16 (U16)	32.0	80	72
Sieland et al. [63]	U19 (U12-19)	5.0	60-90	14-20
Soligard et al. [153]	U13 (13)	2.2	40	4
	U14 (14)	3.7	40	7

Reference	Age (range)	Match incidence	Match duration (min)	Average probability of injury to a player in a typical season (%)[†]
	U16 (15-16)	4.0	50	10
	U19 (17-19)	6.3	60	17
	All groups (13-19)	3.9	40-60	7-11
Sprouse et al. [54]	U15 (U15)	41.3	80	81
	U16 (U16)	42.0	80	81
	U17 (U17)	23.3	90	65
	U18 (U18)	18.8	90	57
	U19 (U19)	14.7	90	48
	All groups (U15-19)	26.5	80-90	65-70
Waldén et al. [25]	U19 (U19)	30.4	90	75
Wik et al. [34]	U13 (U13)	21.2	60	47
	U14 (U14)	23.4	70	56
	U15 (U15)	27.8	80	67
	U16 (U16)	35.9	90	80
	U17 (U17)	43.8	90	86
	U18 (U18)	40.0	90	83
	All groups (U13-18)	32.0	60-90	62-76
Total	U12 and below (6 cohorts)		40-60	7 (0-15)[a]
	U13-U16 (21 cohorts)		40-90	39 (4-96)
	U17-U19 (23 cohorts)		60-90	56 (17-86)
	All age-groups (30 cohorts)		40-90	47 (1-96)
	Females			
Hägglund et al. (g) [148]	U19 (U19)	26.2	90	69
Hägglund et al. (h) [148]	U19 (U19)	22.0	90	63
Hägglund et al. (i) [148]	U19 (U19)	11.7	90	41
Junge et al. (b) [175]	U17 (U17)	21.5	90	62
Kuzuhara et al. [152]	U12 (<=12)	10.1	40	18
Le Gall et al. [137]	U19 (15-19)	22.4	90	64
Lislevand et al. [134]	U16 (13-16)	11.7	50	25
	All groups (≤16)	7.2	30-50	10-16
Soligard et al. [150]	U17 (13-17)	9.6	40-50	18-21
Soligard et al. [153]	U13 (13)	5.8	40	11
	U14 (14)	4.8	40	9
	U16 (15-16)	3.6	50	8
	U19 (17-19)	11.5	60	29
	All groups (13-19)	5.5	40-60	10-15
Sprouse et al. [54]	U15 (U15)	28.0	80	67
	U16 (U16)	20.4	80	56
	U17 (U17)	36.1	90	80
	U19 (U18-19)	22.8	90	64
	All groups (U15-19)	26.7	80-90	66-70
Total	U12 and below (1 cohort)		40	18
	U13-U16 (6 cohorts)		40-80	30 (8-67)
	U17-U19 (7 cohorts)		60-90	58 (29-80)
	All age-groups (10 cohorts)		30-90	43 (13-69)

* Only studies (and cohorts) with sufficient data to estimate the probability of injury are presented.

[†] Average probability of injury to a player using the Poisson distribution model of Parekh et al. [65] assuming a player plays a whole season of 30 matches with each match 40-90 min in duration (according to youth football regulations).

[a] Total values are presented as means and ranges of probabilities.

4

INCIDENCE, BURDEN, AND PATTERN OF INJURIES IN SPANISH MALE YOUTH FOOTBALL PLAYERS: A PROSPECTIVE COHORT STUDY

[STUDY 2]

4.1 Introduction

Football is by far the most popular sport among young people worldwide [1]. In Spain, data from the last available report revealed that more than 840,000 players participated in registered football activities during the 2018/2019 season [2]. Four out of five of these participants were male youth (under 19 years of age) football players. In fact, the number of youth football players has not ceased to increase during the last decade [2,217], perhaps encouraged by the multiple metabolic, cardiovascular and musculoskeletal health benefits derived from playing this sport [4–7].

However, the participation in a physically demanding sport such as football during youth also entails a high risk of injury compared to other individual [131,132] and team [183–185] sports. The higher participation rates registered during the last years have increased the number of football-related injuries among the youth population, leading to a substantial increase in economic costs to the public healthcare systems as well [105,106,218]. Nevertheless, the importance of football-related injuries is not only explained by the economic burden that they involve. These injuries can cause important consequences for the sporting development and health status of adolescent players. Sustaining an injury reduces the players' availability for training and matches, and may also negatively influence his future performance [8,15]. Moreover, adverse events may discourage children from playing football or may lead parents to forbid their children to play this sport [10]. Therefore, injuries may compromise not only the future career opportunities of elite young footballers but also the maintenance of an active lifestyle as a future non-footballing adult [219]. Thus, it is essential to mitigate the impact of injuries in youth football, and the first step in reducing their incidence is to create a solid research base on the epidemiology of such injuries.

The previous chapter of this thesis has provided pooled estimates of the incidence of injuries in youth football based on data from a wide range of prospective epidemiological studies conducted around the world (Asia [34,152], Europe [24,27,32], North America [36], South America [30], and Oceania [37]). This meta-analysis has reported a significantly higher injury risk during matches in comparison with training sessions, as well as a tendency to sustain muscle/tendon injuries that affect predominantly to the thigh in male youth football players. Likewise, an increase in the incidence rate with advances in chronological age has been shown. However, this systematic review has also highlighted the need to address some knowledge gaps that exist in the field of the epidemiology of injuries in young football players.

On the one hand, despite previous research has suggested that rapid changes that occur during the adolescent growth spurt may heighten the injury risk of youth footballers [58], the number of studies that have investigated the influence of the maturity status on injury incidence is scarce [12,50–52]. Most of the empirical evidence regarding the interaction between injury risk and maturation is extrapolated from analyses by chronological age. However, the potential differences among individuals of the same chronological age in the level, timing, and tempo of biological maturation [48] emphasise the need for further epidemiological studies using appropriate estimations of physical maturation status as opposed to chronological age. On the other hand, previous original studies exploring the location and type of youth football-related injuries have mainly reported incidence rates and not the average number of days lost (lay-off) from football by injury diagnosis, which prevented the calculation of the injury burden (the cross-product of severity [consequences] and incidence [likelihood]) to build a risk matrix. A risk matrix (i.e., a graph of injury severity plotted against injury incidence) would help to identify the most burdensome injuries on which to prioritise preventive measures in youth football environments [55].

Despite the large number of young football players registered in Spain and the success of Spanish players and clubs, only two previous epidemiological investigations have covered young Spanish players [28,29]. The study of the injury profile in Spanish youth football clubs may offer a specific picture of this phenomenon that can be compared with epidemiological data from other nations (and pooled estimates of *Chapter 3*) to suggest areas of improvement on injury prevention policies in this country. Therefore, the main purpose of this study was to describe the injury profile in young Spanish male football players. Additional analyses were included to examine the incidence rate and injury burden across different chronological age groups and stages of maturation.

4.2 Methods

To report this descriptive epidemiological study on youth football injuries, the Strengthening the Reporting of Observational Studies in Epidemiology checklist extension for Sports Injury and Illness Surveillance (STROBE-SIIS) was followed [220]. The STROBE-SIIS checklist is presented in Appendix 12.

4.2.1 Participants

A total of 314 male youth (range: 10-19 years) football players from five different football clubs (20 teams) were prospectively followed during a 9-month season in two southeast regions of Spain. The data collection was carried out during two different competitive years: 2017/18 (15 teams) and 2018/19 (5 teams). The seasons started after the school summer break (September) and lasted until the beginning of the subsequent summer holidays (May-June), with two holiday breaks during the competitive period: one in winter (two weeks corresponding to the last of December and the first of January) and another one in spring (one week in April). The players had on average 3 training sessions (90 min each one) and 1 match (U11-12: 60 min; U13-14: 70 min; U15-16: 80 min; U17-19: 90 min match duration) per week. All teams competed in their respective highest regional leagues of youth football. Players who left the team during the season (e.g., due to transfer) were included in the analysis according to their time on the team. Also, players injured when the follow up started were included in this study, but this injury was not taken into account. Those individuals who were still injured at the end of the study period were included in the statistical analyses based on the estimated duration of the recovery period established by their respective medical staff [146]. Descriptive statistics for each chronological age and maturation group are displayed in Table 3.

Prior to the beginning of the study, experimental procedures were fully explained to both parents and children in verbal and written forms, and written informed consent was obtained from parents or legal guardians. The experimental procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the Ethics and Scientific Committee of the University of Murcia (Spain) (ID: 1551/2017).

Table 3. Descriptive anthropometric values (mean ± standard deviation) and exposure time by age-group and maturity status.

Group	***N***	**Age (years)**	**Body mass (kg)**	**Stature (cm)**	**Leg length (cm)**	**Maturity offset**	**Training exposure (h)**	**Match exposure (h)**	**Overall exposure (h)**	**Match exposure ratio[†]**
U11-12	92	11.2 ± 0.5	39.7 ± 7.1	147.7 ± 6.5	72.4 ± 4.2	-2.4 ± 0.6	10666.5	1595.9	12262.4	0.130
U13-14	82	13.2 ± 0.5	51.6 ± 8.7	161.8 ± 7.9	80.5 ± 5.2	-0.8 ± 0.7	9774.0	1642.1	11416.1	0.144
U15-16	69	14.9 ± 0.5	61.7 ± 7.9	172.3 ± 6.1	84.5 ± 3.8	0.9 ± 0.6	8037.0	1554.1	9591.1	0.162
U17-19	71	17.4 ± 0.8	68.4 ± 8.2	176.7 ± 7.1	86.6 ± 5.6	2.5 ± 0.7	11385.0	1832.2	13217.2	0.139
Pre-PHV	120	11.6 ± 0.9	40.9 ± 7.2	149.3 ± 6.9	73.6 ± 4.8	-2.2 ± 0.7	13906.5	2115.4	16021.9	0.132
Circa-PHV	43	13.9 ± 0.7	57.2 ± 7.0	167.4 ± 4.8	82.8 ± 4.5	0.0 ± 0.3	5116.5	932.3	6048.8	0.154
Post-PHV	103	16.7 ± 1.3	67.7 ± 7.9	176.7 ± 6.3	86.4 ± 5.0	2.2 ± 0.8	15262.5	2566.2	17828.7	0.144

N: number of players; kg: kilograms; cm: centimeters; h: hours.

[†] Match hours/total hours of exposure.

4.2.2 Procedures

4.2.2.1 Anthropometry and maturity status

Body mass in kilograms was measured on a calibrated physician scale (SECA 799, Hamburg, Germany). Standing and sitting heights in centimeters were recorded on a measurement platform (SECA 799, Hamburg, Germany). Stage of maturation was calculated in a noninvasive manner using the regression equation proposed by Mirwald et al. [221] (Equation 1). This equation has been used to predict maturation status with a standard error of approximately 6 months in pediatric population [221]. To account for the reported error, players were grouped into discrete bands based on their maturational offset (pre-PHV [<-1], circa-PHV [-0.5 to 0.5], post-PHV [>1]), and players with a maturity offset from -1 to -0.5 and 0.5 to 1 were removed from the dataset when players were analysed by stage of maturation. All anthropometric measures for predicting the PHV were assessed at the beginning of the season.

> *- 9.236 + [0.0002708*leg length and sitting-height interaction] – [0.001663*age and leg-length interaction] + [0.007216*age and sitting-height interaction] + [0.02292*weight by height ratio*100]* [equation 1]

4.2.2.2 Data collection

The study design and data collection followed both the consensus on definitions and data collection procedures for studies of football injuries outlined by the Union of European Football Associations [147] and the consensus document for football injury surveillance studies [146]. All injuries were diagnosed by the physiotherapists of each football club. To minimise data collection bias, the clubs' medical staff received a standardised and detailed injury report form to ensure uniform documentation of all injury relevant data throughout the study period. Likewise, a time-loss injury definition [146,147] was used to reduce potential differences in injury recording between medical teams [212]. A player was considered injured until the medical staff allowed him to fully participate in training sessions and was available for match selection.

For all time-loss injuries, team medical staff recorded the following details: date of injury, moment (training or competition), player's tactical position (goalkeeper, defender, midfielder, forward), player's age-group (U11-12, U13-14, U15-16, U17-19), injury location, type of injury (with specific diagnoses), mechanism (traumatic vs. overuse, contact vs. non-contact), severity of injury (minimal [1–3 days], mild [4–7 days], moderate [8–28 days], severe [>28 days]), type of incident (new vs. recurrent), and date of return to full training and competition. Illnesses and any other physical or mental complaint that did not result from a football match or training were excluded. Individual player exposure time in matches was recorded by the official match reports available at the regional football association, while training exposure was registered at a team level by the coach. Missed training exposure as a result of an injury or illness was recorded and extracted from the total training hours. Both physiotherapists and coaches were routinely contacted (at least once a month) by the principal investigator (FJR-P) to collect data of injuries and exposures. Operational definitions used in this study are shown in Appendix 13.

4.2.2.3 Data analysis

Descriptive data are presented as means with standard deviations (SD), proportions (%), incidence rates and 95% confidence intervals (CI). The overall injury incidence, match injury incidence and training injury incidence were the number of injuries divided by 1000 player-hours in total, match and training, respectively [146]. For incidence rates, 95% CIs were calculated as the incidence ±1.96 times the incidence divided by the square root of the number of injuries (CIs that showed negative values were adjusted to 0 for better interpretability) [175]. The injury burden was calculated as the number of lay-off days/1000 hours of exposure [19]. Player overall hours were calculated by adding match and training hours. Player match hours were calculated by adding individual match hours, and player training hours were calculated by multiplying the total training sessions per the average duration of training and per the average number of players attending each training session (warm up of the matches was not included).

Post hoc probabilities of injury over a season were also determined using the following equation developed by Parekh et al. [169]:

$$\mathrm{P}(\kappa) = \frac{(\lambda t)^{\kappa} \mathrm{e}^{-\lambda t}}{\kappa!}, \quad \text{for } \kappa = 1,\ 2,\ 3 \ldots$$

The equation shows the Poisson distribution model for youth football injury probability, where κ is the total number of injuries occurring in a squad of players and total time of match play exposure over a single season, t is the time-interval in hours, e is the base of the natural logarithm (e = 2.71828...), $\kappa!$ is the factorial of 'κ' and λt is the injury incidence multiplied by length of exposure. The Poisson distribution for injury probability has previously been employed in football [8] and rugby [170] studies, and can describe the frequency of injuries occurring that is assuming these injuries occur independently and take place over time or space [171].

The spreadsheet designed by Hopkins [222] for combining effect statistics was used to make clinically (qualitative) inference for paired-comparisons between incidence rates. In particular, the incidence rate ratio (and its associated confidence limits) was assessed against predetermined thresholds. Thus, an incidence rate ratio of 0.91 represented a substantially lower injury risk, while an incidence rate ratio of 1.10 indicated a substantially higher injury risk [223]. An effect was considered unclear if its CI overlapped the thresholds just mentioned. Otherwise, the effect was clear and deemed to have the magnitude of the largest observed likelihood value. The following scale was used to qualify with a probabilistic term the magnitude of the observed effect: <0.5%, most unlikely; 0.5–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99.5%, very likely; >99.5%, most likely [222].

All of the analyses were performed using the Statistical Package for Social Science (IBM Corp.; IBM SPSS Statistics for Windows, version 20.0, Armonk, NY, USA) and an online spreadsheet (www.sportsci.org).

4.3 Results

During the follow-up period, 16 players dropped out due to transfers to another club or dropout from sport, but their injury data were included for their entire participation at the club. The average duration of the follow-up was 34.9 ± 2.2 weeks with 30.6 ± 2.0 matches per season and 3.1 ± 0.6 trainings sessions per week.

4.3.1 Injury incidences: overall, training and match

A total of 146 injuries were sustained by 101 different youth football players (32.2% of total participants), 72 injuries during training sessions and 74 injuries during matches. This resulted in an overall injury incidence of 3.1 (95%CI = 2.6 to 3.6) injuries per 1000 hours of football exposure, 1.8 (95%CI = 1.4 to 2.2) injuries per 1000 hours of training exposure and 11.2 (95%CI = 8.6 to 13.7) injuries per 1000 hours of match exposure. The match injury incidence was six times higher than training incidence rate (RR = 6.2 [95%CI = 4.5 to 8.6]; 100% likelihood). In general, players sustained 0.46 injuries per season on average, which is equivalent to 9 injuries per season for a squad of 20 players. The probability of players sustaining an injury over the season was 34%. The incidence and characteristics of the injuries for the whole youth football players' sample are shown in Table 4.

4.3.2 Injury location

Table 5 presents the location and type of injury according to Fuller et al. [146] consensus. Lower extremities (2.9, 95%CI = 2.4 to 3.3) were the most commonly injured location (100% likelihood), followed by trunk (0.2, 95%CI = 0.1 to 0.3), and upper limbs (0.1, 95%CI = 0.0 to 0.2). No head and neck injuries were reported. The lower extremity region most frequently injured was the thigh (0.9, 95%CI = 0.6 to 1.1), followed by the knee (0.6, 95%CI = 0.4 to 0.8), and hip/groin (0.5, 95%CI = 0.3 to 0.7). Ankle (0.4, 95%CI = 0.3 to 0.6), lower leg (0.3, 95%CI =

0.1 to 0.4) and foot (0.2, 95%CI = 0.0 to 0.3) were the less injured lower-extremity regions. In terms of paired comparisons, thigh injuries occurred more frequently (100% likelihood) than injuries in ankle, lower leg and foot regions. However, the differences between thigh and knee or hip/groin injuries were not large enough to consider clinically relevant effects. There were no meaningful differences between other paired combinations.

Table 4. Frequency (%), incidence, lay-off and burden of injuries in the whole sample of players.

Injuries	***N* (%)**	**Incidence (95%CI)**	**Lay-off (days)**	**Burden (95%CI)**
Overall	146 (100)	3.1 (2.6–3.6)	2405	51.7 (49.7–53.8)
Training	72 (49.3)	1.8 (1.4–2.2)	960	24.1 (22.6–25.6)
Match	74 (50.7)	11.2 (8.6–13.7)	1445	218.1 (206.9–229.4)
Mechanism				
Traumatic	96 (65.8)	2.1 (1.7–2.5)	1862	40.0 (38.2–41.9)
Overuse	50 (34.2)	1.1 (0.8–1.4)	543	11.7 (10.7–12.7)
Circumstance				
Contact	43 (29.5)	0.9 (0.6–1.2)	710	17.2 (15.9–18.5)
Non-contact	103 (70.5)	2.2 (1.8–2.6)	1605	34.5 (32.8–36.2)
Recurrence				
No	136 (93.2)	2.9 (2.4–3.4)	2114	45.5 (43.5–47.4)
Yes	10 (6.8)	0.2 (0.1–0.3)	291	6.3 (5.5–7.0)
Severity				
Minimal	19 (13)	0.4 (0.2–0.6)	31	0.7 (0.4–0.9)
Mild	40 (27.4)	0.9 (0.6–1.1)	208	4.5 (3.9–5.1)
Moderate	72 (49.3)	1.5 (1.2–1.9)	1107	23.8 (22.4–25.2)
Severe	15 (10.3)	0.3 (0.2–0.5)	1059	22.8 (21.4–24.1)
Position				
Goalkeeper	13 (8.9)	0.3 (0.2–0.4)	181	3.9 (3.3–4.5)
Defender	50 (34.2)	1.1 (0.8–1.4)	1094	23.5 (22.1–24.9)
Mildfielder	59 (40.4)	1.3 (0.8–1.8)	880	18.9 (17.7–20.1)
Forward	24 (16.4)	0.5 (0.1–0.9)	250	5.4 (4.7–6.1)

N: number of injuries; CI: confidence interval.

4.3.3 Injury type

The most common injury type was muscle/tendon (1.9, 95%CI = 1.5 to 2.3), followed by joint (non-bone) and ligament injuries (0.7, 95%CI = 0.4 to 0.9), contusions (0.3, 95%CI = 0.1 to 0.4), fractures and bone stress (0.2, 95%CI = 0.1 to 0.3), and laceration/skin lesions (0.1, 95%CI = 0.0 to 0.1). Only one injury (0.02, 95%CI = 0.0 to 0.1) was recorded for central/peripheral nervous system. Muscle/tendon injury incidence was most likely higher (100% likelihood) than other types of injury rates. Likewise, joint (non-bone) and ligament injury incidence was very likely higher (99% likelihood) than contusions, fractures, laceration/skin lesions and central/peripheral nervous system injuries. No other meaningful differences were found.

Table 5. Frequency (%), incidence, lay-off and burden for type and location of injuries.

	N (%)	Incidence (95% CI)	Lay-off (days)	Burden (95% CI)
TYPE				
Fractures and bone stress	9 (6.0)	0.2 (0.1–0.3)	477	10.3 (9.3–11.2)
Fracture	4 (2.7)	0.1 (0.0–0.2)	343	7.4 (6.6–8.2)
Other bone injuries	5 (3.4)	0.1 (0.0–0.2)	134	2.9 (2.4–3.4)
Joint (non-bone) and ligament	31 (20.8)	0.7 (0.4–0.9)	645	13.9 (12.8–14.9)
Dislocation/subluxation	2 (1.3)	0.04 (0.0–0.1)	9	0.2 (0.1–0.3)
Sprain/ligament injury	25 (16.8)	0.5 (0.3–0.7)	369	7.9 (7.1–8.7)
Lesion of meniscus or cartilage	3 (2.0)	0.1 (0.0–0.1)	256	5.5 (4.8–6.2)
Other joint (non-bone) and ligament injuries	1 (0.7)	0.02 (0.0–0.1)	11	0.2 (0.1–0.4)
Muscle and tendon	89 (59.7)	1.9 (1.5–2.3)	1156	24.9 (23.4–26.3)
Muscle rupture / tear / strain / cramps	77 (51.7)	1.7 (1.3–2.0)	840	18.1 (16.8–19.3)
Tendon injury / rupture / tendinosis / bursitis	9 (6.0)	0.2 (0.1–0.3)	276	5.9 (5.2–6.6)
Other muscle and tendon injuries	3 (0.7)	0.1 (0.0–0.1)	40	0.9 (0.6–1.1)
Contusions / haematoma / bruise	12 (8.1)	0.3 (0.1–0.4)	178	3.8 (3.3–4.4)
Laceration and skin lesion	3 (2.0)	0.1 (0.0–0.1)	13	0.3 (0.1–0.4)
Abrasion	1 (0.7)	0.02 (0.0–0.1)	4	0.1 (0.0–0.2)
Laceration	1 (0.7)	0.02 (0.0–0.1)	4	0.1 (0.0–0.2)
Other skin lesions	1 (0.7)	0.02 (0.0–0.1)	5	0.1 (0.0–0.2)
Central/peripheral nervous system	1 (0.7)	0.02 (0.0–0.1)	18	0.4 (0.2–0.6)
Other injuries	4 (2.7)	0.1 (0.0–0.2)	59	1.3 (0.9–1.6)
LOCATION				
Upper limbs	6 (4.0)	0.1 (0.0–0.2)	153	3.3 (2.8–3.8)
Shoulder / clavicula	1 (0.7)	0.02 (0.0–0.1)	86	1.8 (1.5–2.2)
Upper arm	1 (0.7)	0.02 (0.0–0.1)	13	0.3 (0.1–0.4)
Wrist	1 (0.7)	0.02 (0.0–0.1)	43	0.9 (0.6–1.2)
Hand / finger / thumb	3 (2.0)	0.1 (0.0–0.1)	11	0.2 (0.1–0.4)
Trunk	10 (6.7)	0.2 (0.1–0.3)	78	1.7 (1.3–2.0)
Sternum /ribs / upper back	1 (0.7)	0.02 (0.0–0.1)	2	0.04 (0.0–0.1)
Lower back /pelvis / sacrum	9 (6.0)	0.2 (0.1–0.3)	76	1.6 (1.3 – 2.0)
Lower limbs	133 (89.3)	2.9 (2.4–3.3)	2315	49.8 (47.8–51.8)
Hip / groin	23 (15.4)	0.5 (0.3–0.7)	198	4.3 (3.7–4.8)
Thigh	41 (27.5)	0.9 (0.6–1.1)	557	12.0 (11.0–13.0)
Knee	28 (18.8)	0.6 (0.4–0.8)	739	15.9 (14.7–17.0)
Lower leg / Achilles tendon	12 (8.1)	0.3 (0.1–0.4)	134	2.9 (2.4–3.4)
Ankle	21 (14.1)	0.4 (0.3–0.6)	511	11.0 (10.0–11.9)
Foot / toe	8 (5.4)	0.2 (0.0–0.3)	176	3.8 (3.2–4.3)

N: number of injuries; CI: confidence interval.

4.3.4 Injury severity

Moderate injuries were very likely the most common severity (>98% likelihood) compared to minimal, mild and severe injuries. Mild injuries were also very likely higher (>99% likelihood) than minimal and severe. The total number of days that players were absent from football due to injuries was 2405 (mean lay-off time 16.5 days after injury), which represent an overall injury burden of 51.7 days per 1000h of football exposure (95%CI = 49.7 to 53.8). The burden for match injuries was most likely higher (100% likelihood) than training injuries.

Regarding the type of injuries, muscle and tendon injuries represented most likely the highest (100% likelihood) injury burden, followed by joint (non-bone) and ligament injuries (100% likelihood), and fractures and bone stress (100% likelihood). On the other hand, the burden for knee injuries was most likely higher (100% likelihood) than the rest of the body locations, followed by thigh and ankle (100% likelihood compared to hip/groin, lower leg and foot). Figure 16 displays quantitative risk matrix illustrating the relationship between the severity and incidence of the ten most common reported injury diagnoses (type and location). For each injury diagnosis, severity is shown as the average number of days lost (log scale), while incidence is shown as the number of injuries per 1000h of total football exposure. The shading illustrates relative importance of each of the injury types; the darker the color, the greater the injury burden. Hamstring muscle injury was the most burdensome injury, with an incidence of 0.5 injuries per 1000h of exposure and a mean lay-off time of 17 days.

4.3.5 Injury mechanism

The incidence of traumatic injuries was most likely higher (100% likelihood) than overuse (2.1, 95%CI = 1.7 to 2.5; vs. 1.1, 95%CI = 0.8 to 1.4). Likewise, two out of three injuries were most likely caused by non-contact circumstances, whereas one out of three occurred during contact situations (100% likelihood).

4.3.6 New vs. recurrent injuries

Most injuries were new incidents (93%), with only 7% of the total considered recurrent injuries. Paired comparison showed a most likely higher (100% likelihood) incidence rate for new events than recurrent incidents (RR = 14.5 [95%CI = 8.1 to 25.8]).

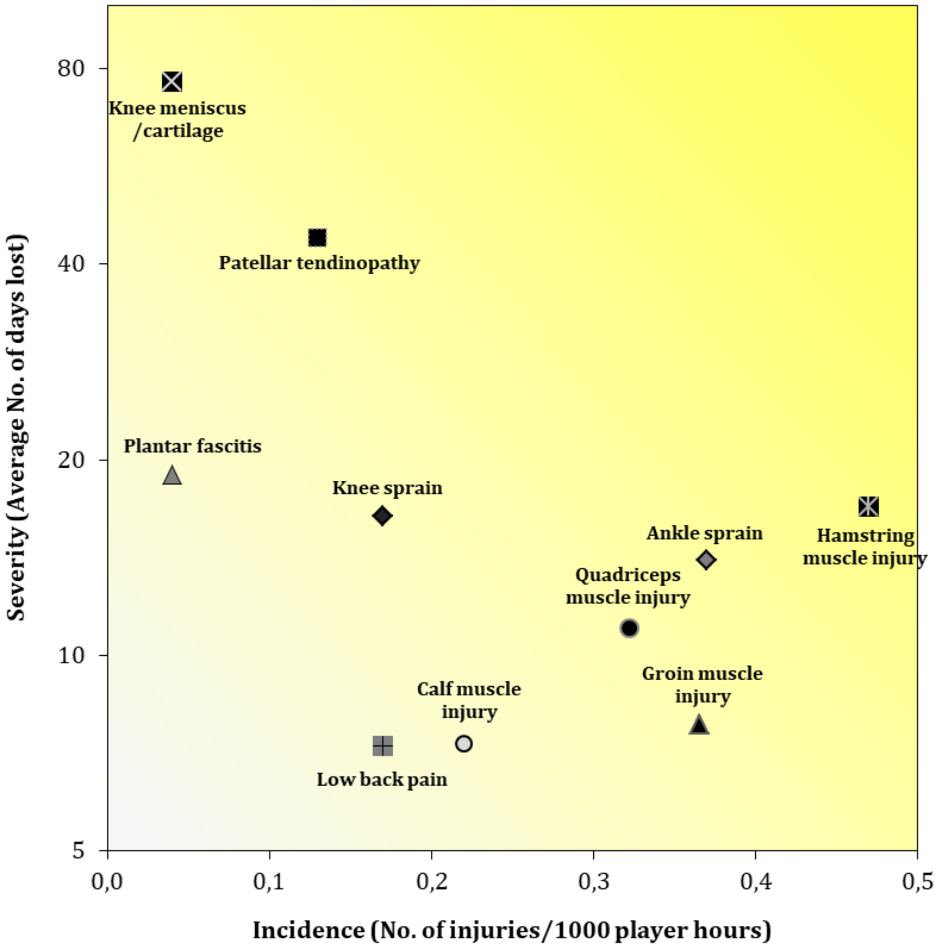


Figure 16. Quantitative risk matrix of injuries, illustrating the relationship between the severity (consequence) and incidence (likelihood) of the 10 most commonly reported injury diagnoses.

4.3.7 Player position

Midfielders (40%) sustained the greatest number of injuries, followed by defenders (34%), forwards (16%) and goalkeepers (9%). However, paired comparisons only reported meaningful differences in injury incidences (100% likelihood) for midfielders (1.3, 95%CI = 0.8 to 1.8) and defenders (1.1, 95%CI = 0.8 to 1.4) compared to goalkeepers (0.3, 95%CI = 0.2 to 0.4).

4.3.8 Seasonal variation

The number of injuries and mean lay-off time during each calendar month is illustrated in Figure 17. A peak was evident in February for the incidence of injuries (4.7, 95%CI = 3.0 to 6.4), which was very likely superior (97% likelihood) compared to the average incidence for the rest of the months (2.9, 95%CI = 2.4 to 3.4). On the contrary, December displayed the highest mean lay-off time per injury (32.7 days/1000h), which led to a greater injury burden (100% likelihood) compared to the average burden for the rest of the months (87.2 [95%CI = 78.9 to 95.5] vs. 45.5 [95%CI = 43.5 to 47.5] days of absence per 1000h of exposure, respectively).

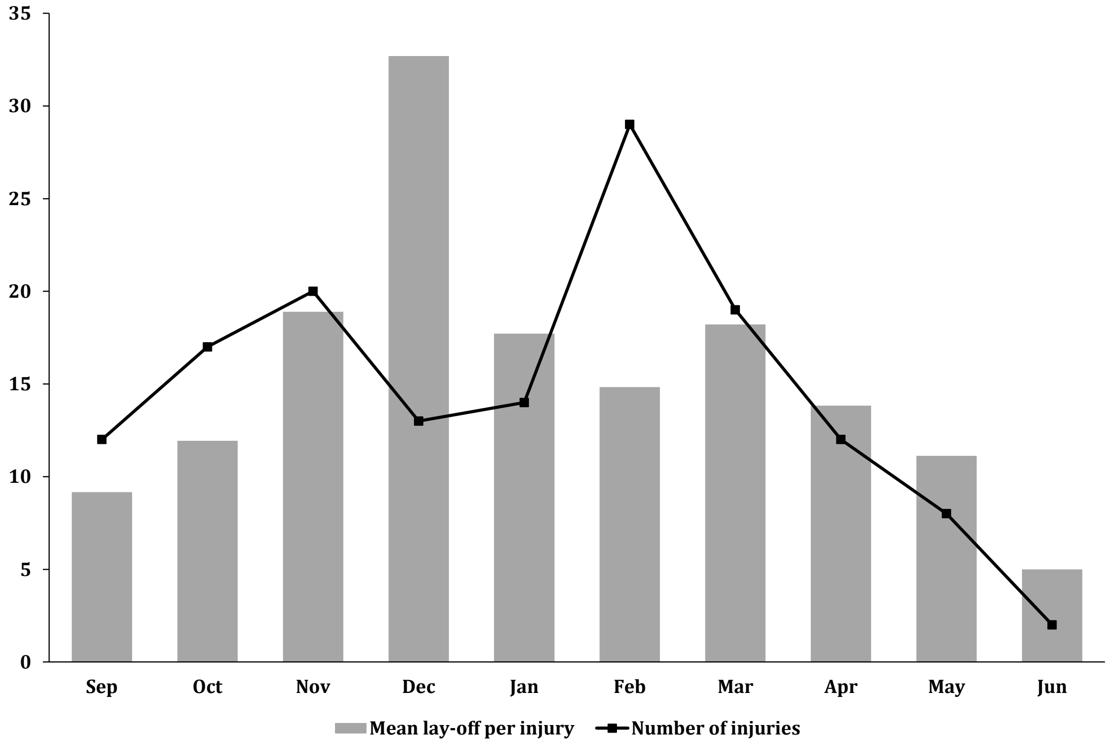


Figure 17. Seasonal variation of number of injuries and mean lay-off per injury.

4.3.9 Chronological age-group comparisons

According to the players' age, the U15-16 and the U17-19 groups showed the highest overall (4.2 [U15-16] and 3.8 [U17-19]), training (2.2 [for both groups]) and match (14.2 [U15-16] and 13.6 [U17-19]) injury incidence rates. However, meaningful differences were only found for overall injury incidences when comparing with U11-12 age group (98-99% likelihood). No clinically relevant differences were found between U13-14, U15-16 and U17-19 comparisons in overall injury rates, neither in training and match injury incidences for any paired age-group combinations. The U15-16 age group also displayed the most likely highest (100% likelihood) overall injury burden (78 days/1000h). Paired comparisons also showed most likely higher (100% likelihood) and possibly higher (59% likelihood) overall injury burden for U13-14 compared to U11-12 and U17-19 age groups, respectively. The probability of players sustaining an injury over the season increased with age (U11-12 = 19%; U13-14 = 29%; U15-16 = 43%; U17-19 = 46%).

A trend towards the increment of traumatic injuries with age was found, showing a very likely higher incidence rate in U17-19 compared to U11-12 (100% likelihood) and U13-14 (99% likelihood) age groups. No meaningful differences in incidence rates were found for the remaining paired combinations by mechanism, circumstances, recurrences and severity of injuries (Table 6). The low number of injuries recorded for some locations and types prevented further comparisons by age groups.

Table 6. Frequency (%), incidence, lay-off and burden of injuries by age groups.

Injuries	**U11-12 (*n* = 92 players)**				**U13-14 (*n* = 82 players)**				**U15-16 (*n* = 69 players)**				**U17-19 (*n* = 71 players)**			
	***N* (%)**	**Incidence (95%CI)**	**Lay-off (days)**	**Burden (95%CI)**	***N* (%)**	**Incidence (95%CI)**	**Lay-off (days)**	**Burden (95%CI)**	***N* (%)**	**Incidence (95%CI)**	**Lay-off (days)**	**Burden (95%CI)**	***N* (%)**	**Incidence (95%CI)**	**Lay-off (days)**	**Burden (95%CI)**
Overall	26 (100)	2.1 (1.3–2.9)	233	19.0 (16.6–21.4)	30 (100)	2.6 (1.7–3.6)	698	61.1 (56.6–65.7)	40 (100)	4.2 (2.9–5.5)	748	78.0 (72.4–83.6)	50 (100)	3.8 (2.7–4.8)	726	54.9 (50.9–58.9)
Training	15 (57.7)	1.4 (0.7–2.1)	115	10.8 (8.8–12.7)	14 (46.7)	1.4 (0.7–2.2)	333	34.1 (30.4–37.7)	18 (45)	2.2 (1.2–3.3)	190	23.6 (20.2–27.0)	25 (50)	2.2 (1.3–3.1)	322	28.3 (25.2–31.4)
Match	11 (42.3)	6.9 (2.8–11.0)	118	73.9 (60.6–87.3)	16 (53.3)	9.7 (5.0–14.5)	365	222.3 (199.5–245.1)	22 (55)	14.2 (8.2–20.1)	558	359.0 (329.2–388.8)	25 (50)	13.6 (8.3–19.0)	404	220.5 (199–242)
Mechanism																
Traumatic	14 (53.8)	1.1 (0.5–1.7)	157	12.8 (10.8–14.8)	17 (56.7)	1.5 (0.8–2.2)	415	36.3 (32.8–39.8)	22 (55)	2.3 (1.3–3.3)	614	64.0 (58.9–69.1)	43 (86)	3.3 (2.3–4.2)	676	51.1 (47.3–55.0)
Overuse	12 (46.2)	1.0 (0.4–1.5)	76	6.2 (4.8–7.6)	13 (43.3)	1.1 (0.5–1.8)	283	24.8 (21.9–27.7)	18 (45)	1.9 (1.0–2.7)	134	14.0 (11.6–16.3)	7 (14)	0.5 (0.1–0.9)	50	3.8 (2.7–4.8)
Circumstance																
Contact	5 (19.2)	0.4 (0.1–0.8)	37	3.0 (2.0–4.0)	10 (33.3)	0.9 (0.3–1.4)	237	28.6 (25.0–32.2)	12 (30)	1.3 (0.5–2.0)	272	28.4 (25.0–31.7)	16 (32)	1.2 (0.6–1.8)	164	12.4 (10.5–14.3)
Non-contact	21 (80.8)	1.7 (1.0–2.4)	196	16.0 (13.7–18.2)	20 (66.7)	1.8 (1.0–2.5)	371	32.5 (29.2–35.8)	28 (70)	2.9 (1.8–4.0)	476	49.6 (45.2–54.1)	34 (68)	2.6 (1.7–3.4)	562	42.5 (39.0–46.0)
Recurrence																
No	26 (100)	2.1 (1.3–2.9)	233	19 (16.6–21.4)	28 (93.3)	2.5 (1.5–3.4)	651	57.0 (52.6–61.4)	37 (92.5)	3.9 (2.6–5.1)	564	58.8 (53.9–63.7)	45 (90)	3.4 (2.4–4.4)	666	50.4 (46.6–54.2)
Yes	0	0	0	0	2 (6.7)	0.2 (0.0–0.7)	47	4.1 (2.9–5.3)	3 (7.5)	0.3 (0.0–0.7)	184	19.2 (16.4–22.0)	5 (10)	0.4 (0.0–0.7)	60	4.5 (3.4–5.6)
Severity																
Minimal	5 (19.2)	0.4 (0.1–0.8)	9	0.7 (0.2–1.2)	3 (10)	0.3 (0.0–0.6)	5	0.4 (0.0–0.82)	4 (10)	0.4 (0.0–0.8)	5	0.5 (0.1–1.0)	7 (14)	0.5 (0.1–0.9)	12	0.9 (0.4–1.4)
Mild	10 (38.5)	0.8 (0.3–1.3)	54	4.4 (3.2–5.6)	8 (26.7)	0.8 (0.3–1.3)	52	4.5 (3.3–5.8)	9 (22.5)	0.9 (0.3–1.6)	41	4.3 (3.0– 5.6)	12 (24)	0.9 (0.4–1.4)	61	4.6 (3.5–5.8)
Moderate	11 (42.3)	0.9 (0.4–1.4)	170	13.9 (11.8–15.9)	15 (50)	1.3 (0.6–2.0)	242	21.2 (18.5–23.9)	20 (50)	2.1 (1.2–3.0)	287	29.9 (26.5–33.4)	26 (52)	2.0 (1.2–2.7)	408	30.9 (27.9–33.9)
Severe	0	0	0	0	3 (10)	0.3 (0.0–0.6)	399	34.9 (31.5–38.4)	7 (17.5)	0.7 (0.2–1.3)	415	43.3 (39.1–47.4)	5 (10)	0.4 (0.0–0.7)	245	18.5 (16.2–20.9)

U: under; *N*: number of injuries; CI: confidence interval.

4.3.10 Maturity status comparisons

Players classified in the circa-PHV group showed the highest overall (4.3, 95%CI = 2.6 to 5.9), training (2.3, 95%CI = 1.0 to 3.7) and match (15.0, 95%CI = 7.1 to 22.9) injury incidences. However, clinically relevant differences were only reached for circa-PHV vs pre-PHV paired comparison in overall injury incidence rates (99% likelihood). Comparison between pre- and post-PHV groups also revealed very likely higher overall injury incidence for post-PHV players (97% likelihood). Similarly, the circa-PHV group presented the highest overall injury burden (92.7 days/1000h), showing meaningful differences in comparison with post- (64.6 days/1000h) and pre-PHV (18.7 days/1000h) maturation groups (100% likelihood). A higher injury burden was also identified in the post-PHV compared to the pre-PHV group (100% likelihood).

Regarding the injury mechanism, an increment in the incidence of traumatic injuries across stages of maturation was also observed, although clinically relevant differences were only reported for pre- and post-PHV group paired-comparison (100% likelihood). Additionally, a very likely increased risk for overuse injuries in players at circa-PHV period was found compared to players at pre- and post-PHV (99-100% likelihood). No other meaningful differences in incidence rates were found for circumstances, recurrences and severity of injuries (Table 7). As before, the low number of injuries within each location and type for some maturation groups prevented further comparisons.

4.4 Discussion

Generally, the overall, training and match injury incidence rates reported in this study are comparable to the previous pooled estimates provided in *Chapter 3* of the current doctoral thesis for players competing at similar levels of play (4.8, 2.8, and 10.6 injuries per 1000h of overall, training and match exposure, respectively), which confirms that Spanish male youth football players are also at high risk of injury. In fact, one in three (34%) of children and adolescents involved in a Spanish football match playing season is likely to sustain a time-loss injury. As previously found [8–10], matches represent the most worrying events, showing the highest data of injury incidence and injury burden. Most of the injuries affect the lower extremity (especially the thigh) and are classified as muscle/tendon injuries, with hamstring muscle injuries representing the most burdensome diagnosis. Finally, although the risk of injury seems to increase with age and maturation, our data also reflect an increased risk of overuse injuries during periods around peak height velocity.

Table 7. Frequency (%), incidence, lay-off and burden of injuries by maturity status.

Injuries	**Pre-PHV (*n* = 120 players)**				**Circa-PHV (*n* = 43 players)**				**Post-PHV (*n* = 103 players)**			
	***N* (%)**	**Incidence (95% CI)**	**Lay–off (days)**	**Burden (95% CI)**	***N* (%)**	**Incidence (95% CI)**	**Lay–off (days)**	**Burden (95% CI)**	***N* (%)**	**Incidence (95% CI)**	**Lay–off (days)**	**Burden (95% CI)**
Overall	32 (100)	2.0 (1.3–2.7)	299	18.7 (16.5–20.8)	26 (100)	4.3 (2.6–5.9)	561	92.7 (85.1–100.4)	61 (100)	3.4 (2.6–4.3)	1151	64.6 (60.8–68.3)
Training	18 (56.2)	1.3 (0.7–1.9)	147	10.6 (8.9–12.3)	12 (46.1)	2.3 (1.0–3.7)	255	49.8 (43.7–56.0)	28 (45.9)	1.8 (1.2–2.5)	390	25.5 (23.0–28.1)
Match	14 (43.7)	6.6 (3.1–10.1)	152	71.9 (60.4–83.3)	14 (53.8)	15.0 (7.1–22.9)	306	328.2 (291.4–365.0)	33 (54.1)	12.9 (8.5–17.2)	761	296.5 (275.5–317.6)
Mechanism												
Traumatic	17 (53.1)	1.1 (0.6–1.6)	175	10.9 (9.3–12.5)	11 (42.3)	1.8 (0.7–2.9)	277	45.8 (40.4–51.2)	52 (85.2)	2.9 (2.1–3.7)	1099	61.6 (58.0–65.3)
Overuse	15 (46.9)	0.9 (0.5–1.4)	124	7.7 (6.4–9.1)	15 (57.7)	2.5 (1.2–3.7)	284	46.9 (41.5–52.4)	9 (14.7)	0.5 (0.2–0.8)	52	2.9 (2.1–3.7)
Circumstance												
Contact	7 (21.9)	0.4 (0.1–0.8)	64	4.0 (3.0–5.0)	7 (26.9)	1.2 (0.3–2.0)	209	34.5 (29.9–39.2)	22 (36.1)	1.2 (0.7–1.7)	385	21.6 (19.4–23.7)
Non–contact	25 (78.1)	1.6 (0.9–2.2)	235	14.7 (12.8–16.5)	19 (73.1)	3.1 (1.7–4.5)	352	58.2 (52.1–64.3)	39 (63.9)	2.2 (1.5–2.9)	766	43.0 (39.9–46.0)
Recurrence												
No	32 (100)	2 (1.3–2.7)	299	18.7 (16.5–20.8)	23 (88.5)	3.8 (2.2–5.4)	507	83.8 (76.5–91.1)	55 (90.2)	3.1 (2.3–3.9)	940	52.7 (49.3–56.1)
Yes	0	0	0	0	3 (11.5)	0.5 (0.0–1.1)	54	8.9 (6.5–11.3)	6 (9.8)	0.3 (0.1–0.6)	211	11.8 (10.2–13.4)
Severity												
Minimal	5 (15.6)	0.3 (0.0–0.6)	9	0.6 (0.2–0.9)	3 (11.5)	0.5 (0.0–1.1)	4	0.7 (0.0–1.3)	9 (14.7)	0.5 (0.2–0.8)	14	0.8 (0.4–1.2)
Mild	13 (40.6)	0.8 (0.4–1.2)	72	4.5 (3.5–5.5)	7 (26.9)	1.2 (0.3–2.0)	35	5.8 (3.9–7.7)	12 (19.7)	0.7 (0.3–1.0)	61	3.4 (2.6–4.3)
Moderate	14 (43.7)	0.9 (0.4–1.3)	218	13.6 (11.8–15.4)	14 (53.8)	2.3 (1.1–3.5)	209	34.5 (29.9–39.2)	30 (49.2)	1.7 (1.1–2.3)	476	26.7 (24.3–29.1)
Severe	0	0	0	0	2 (7.7)	0.3 (0.0–0.8)	313	51.7 (46.0–57.5)	10 (16.4)	0.6 (0.2–0.9)	600	33.6 (31.0–36.3)

PHV: peak height velocity; *N*: number of injuries; CI: confidence interval.

4.4.1 Overall, training and match injury incidences

Even though the injury incidences presented in this study were similar to the previous pooled estimates, some differences were found when comparing with data reported from different players around the world. While similar trends were described for training incidences, the match injury rates found (11.2) were greater than the data provided by youth football players in Brazil (6.4) [30], Portugal (4.7) [26], and Italy (2.8) [31], as well as other regions of Spain (8.8) [28,29]. Although potential differences in methodology should be taken into consideration when interpreting these results, the higher match exposure ratio obtained in the current research (0.143) compared to these previous studies (0.059-0.119) might partially explain these discrepancies in match incidences. A higher match exposure relative to training could indicate low training volumes to provide the required physical readiness for match intensities in our cohort of youth football players [224,225]. Lower training exposures could have also led football coaches to prioritise other components of football training (i.e., technical and tactical skills) to injury prevention and strength and conditioning programmes [226]. Therefore, high-quality training sessions that mimic match demands are essentials to prepare the young player for the competitive football play [138]. The implementation of standardised injury prevention programmes on a regular basis, such as the FIFA 11+ [150] or the FIFA 11+ Kids [193], may also play an important role in reducing the injury risk in youth football settings, where time and staff restrictions sometimes prevent the application of more individualised preventive measures. However, a recent study involving grass-root football coaches from three European countries (including Spain) has revealed a lack of knowledge, attitude and confidence to deliver these injury prevention programmes to young players [227]. Consequently, one of the first steps needed to mitigate the impact of football-related injuries on young players is to improve the education of grass-root coaches in injury risk management [227].

In any case, it should be also noted that football matches entail an inherent risk of injury. During competitions, players are exposed to a greater number of high-intensity and collision situations [186], which may induce neuromuscular fatigue and motor control detriments, increasing the injury risk [228]. Unlike adult players, adolescent players are additionally presented with many opportunities to compete for various youth football teams. In fact, data from our cohort of football players revealed that one in four (28%) players competed with more than one team over the follow-up season. This common practice in youth football clubs may lead young athletes to participate in multiple playing styles and under the supervision of different coaches, as well as more than one match on a typical weekend. Previous studies have shown that coaching change can derive in an increment of injury risk in professional football [229]. Similarly, reducing considerably the time to recover from previous physical efforts may increase the likelihood of sustaining an injury [209]. Thus, it would be advisable to individually monitor match load, wellbeing and recovery status from previous efforts to avoid forcing players to compete under suboptimal physical conditions. New competition rules such as the unlimited number of substitutions and return to competition after replacements may also help to better distribute the total playing time among the different players in the same squad.

4.4.2 Location, type and severity of injuries

Similar to what has been previously described in several studies, lower extremities were the most frequently injured body part (89% of the total injuries recorded). The thigh was the anatomical region of the lower extremities more frequently injured (27%), followed by the knee (19%) and hip/groin (15%) regions. This circumstance strongly correlates with the fact that most of the injuries (60%) were classified as muscle/tendon. The link between both the most injured location and type can be found in the high number of quadriceps and, especially, hamstring muscle injuries reported in this study, both operationally located in the thigh [146]. These muscle groups have been also described as the most frequently diagnosed injuries in previous studies with youth football players [33,42,191]. However, the concern about these injuries is not only due to the high incidence shown. Hamstring muscle injuries have been also presented as the most burdensome incidents in this study, with 8 days of absence per 1000 hours of exposure and a mean lay-off time of 17 days per injury. After hamstring injuries, ankle sprain and patellar tendinopathy had the highest contribution to time-loss from football in our cohort of players. These findings are in agreement with the recent data reported by Wik et al. [34] for Qatari players, where hamstring and ankle injuries were among the most burdensome diagnoses (only exceed by ACL complete tears). Fortunately, most of the hamstring injuries (>95%) and approximately one in two (42-53%) of the ankle sprains were classified as non-contact injuries in this research and in the previous study of Wik et al. [34] and as such they can be regarded as preventable. Therefore, medical and fitness staff should be encouraged to implement measures mainly aimed (but not solely) at reducing the number and severity of hamstring muscle injuries and ankle sprains in order to ensure safer football practice. Although no ACL complete tear was reported in our cohort of players, the important burden shown by other soft tissue injuries of the knee (i.e., patellar tendinopathy, meniscus and cartilage tear, and ligament sprain) reinforce the need to focus prevention strategies on these injuries as well.

4.4.3 Playing position and seasonal variation

Regarding the playing position of young players, meaningful differences were only found when comparing midfielders and defenders injury incidences with goalkeepers. These findings match the results previously reported in English youth football academies [33], and may reflect the differences in the physical demands of the football play between outfield players and goalkeepers. It seems reasonable that the higher number of sprinting, cutting and tackling situations as well as the higher total distance covered by outfield players [230] lead these individuals to a greater risk of sustaining an injury compared to goalkeepers. However, it should be noted that a high incidence has also been previously described for young goalkeepers, especially during training sessions [231]. For this reason, it is essential to plan training sessions based on the individual needs of players according to their positions, which would help them achieve the levels of physical fitness necessary for competitive play while reducing the risk of injury.

On the other hand, seasonal variation of the injury incidence in our study showed a peak in February. This coincides with the return to competition after the winter break (extended until the second week of January in Spain) and could therefore be the result of an inadequate workload after a rest period that might have led to a decline in physical fitness [33,42,232]. On the contrary, the injuries occurred in December reported the highest injury burden. Although the short time until the rest period may favour lower pressure to return to play rapidly and a longer rehabilitation process, the accumulated fatigue from the start of the competition (September) up to this month might also be behind the increased severity of the injuries reported in December. Cumulatively, these results support the recommendations suggested in previous research [42,231] for the inclusion of more regular short breaks throughout the season to allow players to recover from match and training loads, while avoiding the decline in their fitness levels resulting from longer breaks.

4.4.4 Comparisons by age group and maturity status

As previously reported in *Chapter 3*, the incidence of injury increased with advances in chronological age, showing the highest injury rates in the two oldest groups (U15-16 and U17-19). The increased ability to work at high intensities as players' progress to late adolescence stages (completing more accelerations, decelerations and greater total distances during competition [205]) together with greater training loads and contact situations [42] have been suggested as one of the main reasons to explain this trend. Of these age groups, the players classified in the U15-16 group represent a particular concern as they exhibited the highest injury burden as well. Although not being reported consistently across studies [26,35], the U15 and U16 age groups have also notified the highest burden and number of severe incidents in recent investigations elsewhere [12,28,34,42]. These ages coincide with the periods of peak height velocity (estimated around 14 years old in boys [45,46]) and peak weight velocity (expected a few months after PHV [75]), where rapid changes in body size and shape may temporary compromise the structural capacity of body tissues to tolerate the high mechanical loads derived from playing football [80]. In fact, this hypothesis is supported by the data obtained when analysing the influence of maturity status on injury risk. Those players classified in the circa-PHV group presented a two-fold increase in the overall injury incidence compared to the pre-PHV group, and the peak of injury burden for all stages of maturation. These results are broadly in line with previous findings [12,50–52], and may be partially explained by the increased impact that overuse injuries have shown on players around the PHV. Thus, practitioners should be aware of these maturation-dependent differences in injury risk and pattern, reducing the highly demanding mechanical loads during training practices and match congestion in players around the growth spurt to mitigate the impact of injuries during this stage of development [80].

Furthermore, paired comparisons between pre- and post-PHV groups suggested an increased incidence and burden for players at post-PHV. Although the number of recurrences reported was low, it should be noted that the definition of recurrent injury followed in this study (i.e., only recurrences sustained during the same season that the initial injury) might have underestimated the proportion of recurrences recorded for our cohort of football players. Therefore, prior non-recorded recurrences might have led to greater probabilities of sustaining a new and more severe injury in post-PHV group [72]. Indeed, the available data indicated larger days of absence from football due to recurrences compared to new incidents in the post-PHV group (mean lay-off time per injury: 35 days for recurrences vs. 17 days for new events).

4.4.5 Limitations

Finally, the present study has also some limitations. Firstly, while the individual match exposure was easily obtained from official match records, the training exposure was calculated at a team level and corrected by subtracting missed exposure as a result of injuries and/or illnesses. Individual training exposure data would have improved the accuracy of the injury incidence rates; however, the resources available at youth football teams did not allow this. Secondly, the current cohort study followed the time loss injury definition proposed in the consensus statements from Fuller et al. [146] and Hägglund et al. [147] and, thus, such injuries that did not lead to any layoff time were not represented. The inclusion of medical attention injuries might have led to a higher injury incidence, but this could also have intensified the differences between data collection procedures on each youth football team [212]. Likewise, the time available between each training session (3 sessions per week on average) to recover from any physical complaint could have affected the recording of slight/minimal injuries (1-3 days of absence) during the season. Lastly, the procedures detailed in these consensus statements did not explicitly consider the growth-related injuries (e.g., Osgood-Schlatter, Sinding-Larsen-Johansson syndrome, Sever disease, and other physeal fractures), and then it was not possible to report separately the incidence and burden for this injury type. Recent studies [35,121] have found that paediatric injuries might be one of the most burdensome injuries in youth football players. Therefore, the inclusion of additional items in the injury record form (as the latest 2020 consensus statement [220] does with physis injuries) would be needed to accurately report this particular injury type when describing the injury profile of young athletes.

The results of this study are based on youth teams from five football clubs of the southeast of Spain and should not be generalised to other football cohorts. Contextual differences such as the weather conditions for football practice, the number of exposure hours and match congestion, the playing surface, the players' skill level and coaching styles require consideration when interpreting these findings. Within the scope of the study, it was not possible to measure other physical activities aside from organised football (e.g., in free time or at school). These data could have been valuable to analyse the occurrence of overuse injuries.

4.5 Conclusions

The high injury incidences and probability scores found in this study reinforce the need for implementing specific injury risk mitigation strategies in Spanish youth football. Matches showed a six-fold increase in injury incidence compared to training sessions, which recommends a reconsideration of training prescriptions to improve the physical readiness of youth footballers according to match intensities. As previously reported, the most common injury location was the lower extremity (especially the thigh) and muscle/tendon injuries were the predominant injury type. Particularly, hamstring muscle injuries represented the most burdensome diagnosis and thus preventive measures should mainly focus on reducing the number and severity of such injuries. Finally, although the risk of injury increased with age, a higher risk of overuse injuries during periods around the peak height velocity was also identified. Therefore, coaches should routinely monitor young players' growth to adapt training interventions to their stage of maturation. Other relevant information such as the playing position and period of the season should be also considered by practitioners when managing the injury risk.

4.6 Appendices

Appendix 12. Description of the 23 criteria designed to assess quality of the reporting in this epidemiological study (STROBE-SIIS extension).

	Item	Recommendation	# Page
Title and abstract	1	1.1. Include information on the sport, athlete population (sex, age, geographic region), and level of competition	34, 119
		1.2. Include the duration of observation (e.g., 1 season, 1 year, multiple years)	34
Introduction			
Background/rationale	2	2.1. Explain the scientific background and rationale for the investigation being reported	119, 120
Objectives	3	3.1. State whether study was registered. Identify the registration number and database used	NA
		3.2. State the specific purpose of the study (e.g., to describe the injury burden associated with Olympic-level rowing)	120
Methods			
Study design	4	4.1. Clearly specify which health problems are being observed	123
		4.2. State explicitly which approach was used to record the health problem data, including all outcome measures or tools	123, 124
		4.3. State explicitly which coding system was used to classify the health problems (e.g., OSIICS, SMDCS, ICD, etc)	123
		4.4. Where relevant, clearly describe how athletes were categorised. Variables to consider could include the type of athlete and/or sport, environment in which the sport occurs (e.g., type of course or playing area), the typical duration of the sport, the degree of physical contact permitted in the sport, and the equipment permitted	123
Setting	5	5.1. Describe the location, level of play, dates of observation, and data collection methods (ie, who, what, where)	121
		5.2. Specify the dates of the surveillance period and how the data were handled when the study covered more than 1 season/calendar year	121
		5.3. Define whether the health problem data were collected prospectively or retrospectively	121
Participants	6	6.1. Define the population of athletes as well as describe how they were selected and recruited	121
Variables	7	7.1. Justify why you measured your primary and secondary outcomes of interest in the specific way chosen	123, 124
		7.2. Describe the method for identifying the health problem outcome of interest	123, 124
Data sources/ measurement	8	8.1. Specify who collected/ reported the data for the study and their qualifications (e.g., qualified doctor, data analyst, etc)	123, 124
		8.2. Specify who coded the data for the study and their qualifications (e.g., qualified doctor, data analyst, etc; in many instances, this will not be the same as in SIIS 8.1)	123, 124

	Item	Recommendation	# Page
		8.3. Specify the direct methods used to collect the data and the use of physical documents or electronic tools (if extracting information from existing sources, specify the data source)	123, 124
		8.4. Specify the timing of and window for data collection (e.g., day health problem occurred or following day). Specify the frequency of data collection (e.g., daily, weekly, monthly)	123, 124
		8.5. Report the duration of surveillance (e.g., tournament, season, whole year, playing career)	121
Bias	9	9.1. Clearly report any validation or reliability assessment of the data collection tools	NA
		9.2. Formally acknowledge any potential biases associated with the data collection method (e.g., self-report, recall bias, reporting by nonmedically trained staff, etc)	123
Study size	10	Explain how the study size was arrived at	NA
Quantitative variables	11	11.1 Explain in detail how multiple injuries/illness episodes are handled both in individual athletes and across athletes/ surveillance periods	123
		11.2 Specify how injury severity was calculated	123, 124
Statistical methods	12	12.1. Specify how the exposure to risk has been adjusted for and specify units (e.g., per participant, per athlete-exposure, etc)	124
		12.2. Specify how relevant risk measures (incidence, prevalence, etc) were calculated	124
		12.3. When relevant to the study aim, specify how the injury burden was calculated and analyzed	124
		12.4. For studies reporting multiple health problems, state clearly how these were handled (eg, time to the first injury only, ignoring subsequent return to play and reinjuries, or modeling of all injuries)	NA
		12.5. Explain how/if athletes not included at outset (eg, those already injured) were handled in the analyses	121
		12.6. In longitudinal studies, it is particularly important to explain how athlete follow-up has been managed. For example, what happened if a player was trasferred to another team or has been censored (for those no longer part of the study due to removal during the observation period). Censoring can occur when athletes are removed due to transfer out of the team/study, injury/illness, or due to study design])	121
Results			
Participants	13	13.1. Clearly state the number of athletes who were followed up, the number (and percentage) of those with the health problem, and the number of problems reported among them (a median number of problems per affected athlete could be useful)	125
		13.2. For studies over multiple seasons/years, report the total number of health problems for each year and number common to each period	NA

	Item	Recommendation	# Page
		13.3. Report how athletes who were removed (e.g., because of the transfer of teams or timeout due to an injury or illness) impact the data at key data collection/ reporting points, ideally with a flow diagram	NA
Descriptive data	14	14.1. Include details on the level of competition being observed (e.g., by age level, skill level, sex, etc)	122
Outcome data	15	15.1. In observational studies, individuals will sustain more than one health problem over the surveillance period. Take care to ensure that descriptive data represent both the number of health problems and the number of athletes affected. It is important to represent effectively both the analysis and reporting of correct units for frequency data (i.e., the percentage of affected athletes or percentage of injuries, body regions, etc)	125
Main results	16	16.1. Report exposure-adjusted incidence or prevalence measures with appropriate confidence intervals when presenting risk measures	125-132
		16.2. Report details of interest, such as the mode of onset	NA
Other analyses	17	17.1. Report injury diagnosis information, including region and tissue type in tabular form	128, 129
Discussion			
Key results	18	18.1. Summarise key results with reference to study objectives	132
Limitations	19	19.1. Discuss limitations in the data collection and coding procedures adopted, including in relation to any risk measures calculated	137, 138
Interpretation	20	20.1. Give a cautious overall interpretation of results, considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	132, 138
Generalisability	21	21.1. Discuss the generalisability of the athlete study population, and health problem subgroups of interest, to broader athlete groups	138
Other information			
Funding	22	22.1. Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	5
Ethics	23	23.1. Outline how individual athlete data privacy and confidentiality considerations were addressed, in line with the Declaration of Helsinki	121

Note: The STROBE-SIIS checklist with additional sports epidemiology annotations has been used in conjunction with the original STROBE statement (freely available on the websites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE initiative is available at www.strobe-statement.org.

Appendix 13. Operational definitions used in this study.

Term	**Definition**
Time loss injury	Injury that results in a player being unable to take a full part in future football training or match play.
Recurrent injury	An injury of the same type and at the same site as a previously registered injury during the same season, and which occurs after a player's return to full participation from the previous incident.
Injury severity	The number of days that have elapsed from the date of injury to the date of the player's return to full participation in team training and availability for match selection. Injuries are grouped as: *Minimal* Absence (1-3 days) *Minor / Mild* Absence (4-7 days) *Moderate* Absence (8-28 days) *Major / Severe* Absence (>28 days)
Match exposure	Play between teams from different clubs.
Training exposure	Team-based and individual physical activities under the control or guidance of the team's coaching or fitness staff that are aimed at maintaining or improving players' football skills or physical condition.
Overuse injury	An injury caused by repeated microtrauma without a single, identifiable event responsible for the injury.
Traumatic injury	Injury with sudden onset and known cause.
Contact injury	An injury caused by external influence (i.e., any contact with another player or other object).
Non-contact injury	An injury happened without external influence.
Injury location	Head and neck (Head/face; Neck/cervical spine) Upper limbs (Shoulder/clavicula; Upper arm; Elbow; Forearm; Wrist; Hand/finger/thumb) Trunk (Sternum/ribs/upper back; Abdomen; Lower back/pelvis/sacrum) Lower limbs (Hip/groin; Thigh; Knee; Lower leg/Achilles tendon; Ankle; Foot/toe)
Type of injury grouping	Fractures and bone stress Joint (non-bone) and ligament (Dislocation/subluxation; Sprain/ligament injury; Lesion of meniscus or cartilage) Muscle and tendon (Muscle rupture/tear/strain/cramps; Tendon injury/rupture/tendinosis/bursitis) Contusions (Haematoma/contusion/bruise) Laceration and skin lesion (Abrasion; Laceration) Central/peripheral nervous system (Concussion [with or without loss of consciousness]; Nerve injury) Other (Dental injuries; Other injuries)
Injury incidence	Number of injuries per 1000 player hours ((Σ injuries/Σ exposure hours) ×1000).
Injury burden	Number of days of absence from sport participation per 1000 player hours ((Σ days/Σ exposure hours) ×1000).

5

EFFECTS OF AGE AND MATURATION ON LOWER EXTREMITY RANGE OF MOTION IN MALE YOUTH FOOTBALL PLAYERS

[STUDY 3]

5.1 Introduction[1]

Despite the numerous evidence-based health benefits, participation in a physically demanding sport such as football can lead to greater exposure to causal factors of injury (e.g., high mechanical loads repetitively imposed on bones and soft tissues during trainings and matches, fatigue-induced alterations in movement patterns during the execution of high intensity dynamic actions, collisions with other players) [15]. The increased risk of injury (mainly in the lower extremities) produced by playing football is especially relevant in cases in which growth and maturation are not yet completely developed, especially during adolescence [49]. Indeed, injury incidence in adolescent football players has recently been aligned to peak height velocity (PHV) [233], which is defined as the age at which the maximum rate of growth occurs during the adolescent stage [221].

Several mechanisms have been suggested to explain this increase in injury incidence during the years of maximal rate of growth. For example, the rapid increase in the length of arms and legs relative to the trunk that occurs during PHV is not always followed by a similar onset and rate of muscle-tendon flexibility development [234]. Therefore, during this growth spurt, adolescents often experience a situation in which the length of the extremities has already achieved its full development but the muscles still have to reach their full size [46]. This temporary situation (commonly known as "adolescent motor awkwardness") might generate a growth-related decrease in muscle-tendon flexibility (mainly in postural and biarticular muscles) that may

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[1] This study has been published as Robles-Palazón, FJ, Ayala, F, Cejudo, A, De Ste Croix, M, Sainz de Baranda, P, & Santonja, F. (2020). Effects of age and maturation on lower extremity range of motion in male youth soccer players. *Journal of Strength and Conditioning Research*.

result in significant restrictions on joint range of motion (ROM). Furthermore, football players are required to perform a number of repeated high-intensity and multidirectional actions (e.g., sprinting, jumping, kicking, changes of direction) during training and matches that frequently involve high levels of unilateral force production [186]. Consequently, football players develop and selectively use preferred limbs for most game-based actions [235] that generate asymmetric lower extremity loading patterns. As a result, the yet immature musculoskeletal system of the adolescent football players is expose to compressive, torsional, transverse and tensile loads whose magnitude, rate, frequency and unique distribution to each leg may also foster asymmetrical adaptations in muscle-tendon flexibility that are likely to contribute to significant bilateral differences in lower extremities joint ROMs. These potentially restricted and bilaterally asymmetric joint ROMs (especially in the lower extremity [hip, knee and ankle joints]) may lead (alongside with other sensorimotor and structural changes) adolescent football players to adopt altered movements and motor-control strategies during the execution of high intensity dynamic tasks, such as jumping, cutting and landing [46,84]. This decline in essential motor performance that occur during the pubertal years may be one of the main factors behind the increased susceptibility to lower extremity injuries (mainly ligamentous injuries in the knee and ankle joints) demonstrated by youth football players during the stage of PHV [42]. This theory suggests that from an injury prevention perspective that joint ROM assessment should be employed in screening protocols, during all phases of the athlete development framework, but especially around PHV. This in turn may help identify youth football players at high risk of injury and to aid in the design of tailored maturational specific training interventions.

Some studies have investigated the influence of maturation on several parameters of physical performance (running speed and acceleration [85], jumping distance [86]), neuromuscular control (static and dynamic balance [87], landing kinematics [88]) and muscle strength (knee flexion and extension isokinetic strength [89]) in youth football players, reporting some adaptations or deficits that may contribute to the increased injury risk during the adolescent growth spurt. However, no studies have been published (to the authors' knowledge) that have examined the effects of biological maturity on lower extremity joint ROMs in youth football players. Some studies have explored changes in chronological age on some lower extremity ROM measures including the hip [122–124,236], knee [122] and ankle [122] in youth football players reporting a decreasing trend in hip rotation (mainly internal rotation) and knee flexion ROMs with advancing age. In addition, two of these studies [123,124] have also shown that young football players had significantly lower (>8°) hip internal rotation ROM than their age-matched controls. Likewise, one study did not find statistically significant bilateral asymmetries between the average hip, knee and ankle joints ROM of both legs in a large cohort of youth football players [122]. This restricted hip rotation ROM profile generated over time, as a consequence of football training and match play, might play a meaningful role in the increased risk of non-contact anterior cruciate ligament (ACL) injuries shown in adolescent (16-18 years) players [237]. Previous studies have clearly demonstrated that individuals of the same chronological age can differ markedly with respect to biological maturity [48]. Thus, significant interindividual differences regarding level (magnitude of change), tempo (rate of change) and timing (onset of change) of biological maturation have been observed between children and adolescents of the same chronological age (up to 15 cm and 21 kg in the stature and body mass, respectively) [48]. Depending on these three variables, children and adolescents will be viewed as either biologically ahead of their chronological age (early-maturing individual), "on-time" with their chronological age (average maturer) or behind their chronological age (late-maturing individual) [47]. Therefore, this relative mismatch and wide variation in biological maturation between children and adolescents of the same chronological age emphasises the limitations in using chronological age as the sole determinant to explore decreases in lower extremity joint ROMs and highlights the importance of also considering biological maturation to aid the identification and understanding of the possible changes in joint ROMs and injury risk in youth football players. This knowledge may help coaches and sports science specialists to design tailored age and/or maturational stage-based training programs to both optimise motor performance and reduce potential injury risk in young football players.

In an attempt to minimise the effects of inter-player variability and achieve a more realistic diagnosis regarding the presence (or absence) of changes in ROM measures attributed to a certain phenomenon (e.g. growth-related effects), recently López-Valenciano et al. [228] suggested using a new comprehensive profile of joint ROMs. In this profile not only average ROM scores are reported but also the number of players showing bilateral asymmetries (between limb differences >6-10°) [238,239] and normal (compared to their age-matched controls) and non-pathologic (based on the previously published cut-off scores to classify athletes at high risk of injury) ROM values.

Therefore, the main purpose of the present study was to analyze and compare the influence of chronological age and PHV (as an indicator of biological maturity) on lower extremity joints (hip, knee and ankle) ROM as well as to describe the lower extremity ROM profile using a comprehensive approach in youth football players. Based on both the documented negative and temporary influence of maturation on essential motor performance [85–88], and the reported decrease in hip (mainly internal rotation) and knee (flexion) ROMs with advancing age in young athletes [122–124], the hypothesis of the present study was that the football players belonging to the younger age groups (under 12 and under 14 y) and whose predicted maturation status was categorised as "before-PHV" would show higher hip and knee ROM values than their counterparts of the older age groups and that were immersed in the maturation years of "around" and "after-PHV".

5.2 Methods

5.2.1 Design

A cross-sectional design was used to analyze and compare the potential influence of chronological age and stage of maturation on lower extremity ROM measures in young football players. The study was conducted during the preseason phase (September) of the years 2017-18.

The testing sessions conducted in each football academy were divided into two different parts within a single testing session. The first part of each testing session was used to record the anthropometric measures needed to calculate the stage of maturation of the participants. The second part was designed to assess the lower extremity ROMs.

5.2.2 Participants

A total of 286 male youth football players from the academies of five Spanish football clubs completed this study. Descriptive statistics for each chronological age and maturation group are displayed in Table 8 and Table 9, respectively. Participants met the following inclusion/exclusion criteria: 1) engaged regularly in football training and competitions (at least 2-3 training sessions and 1 match per week), 2) no history of orthopedic problems to the ankle, knee, thigh, hip or lower back in the 3 months before the data collection phase, and 3) were free of delayed onset muscle soreness (DOMS) at the time of testing (self-reported). In addition, none of the participants were involved in systematic and specific strength training programs and stretching regimes within the last six months, apart from the 1-2 sets of 15-30 seconds of static stretches designated for the major muscles of the lower extremities that were performed daily during their pre-exercise warm-up and/or post-exercise cool down phases.

Table 8. Participants' descriptive anthropometric scores (mean ± standard deviation) for each chronological age group. The maturity offset per chronological age group is also presented.

Age group	***N***	**Age (years)**	**Body mass (kg)**	**Stature (cm)**	**Leg length (cm)**	**Maturity offset**
U12	76	11.1 ± 0.5	39.6 ± 6.8	148.0 ± 6.8	72.6 ± 4.1	-2.4 ± 0.6
U14	79	13.2 ± 0.5	51.8 ± 8.7	162.0 ± 7.9	80.7 ± 5.2	-0.7 ± 0.6
U16	68	14.9 ± 0.5	61.7 ± 8.0	172.3 ± 6.2	84.5 ± 3.8	0.9 ± 0.6
U19	63	17.3 ± 0.8	68.6 ± 8.2	176.9 ± 6.7	86.8 ± 5.4	2.5 ± 0.7

U: under.

Before any participation, experimental procedures and potential risks were fully explained to both parents and children in verbal and written forms, and written informed consent was obtained from parents and children. The experimental procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the Ethics and Scientific Committee of the University of Murcia (Spain) (ID: 1551/2017).

Table 9. Descriptive anthropometric values (mean ± standard deviation) for participants per maturation sub-group.

Maturation sub-group	***N***	**Age (years)**	**Body mass (kg)**	**Stature (cm)**	**Leg length (cm)**	**Maturity offset**
Pre-PHV	101	11.6 ± 0.9	40.9 ± 7.1	149.6 ± 7.1	73.8 ± 4.8	-2.2 ± 0.7
Circa-PHV	43	13.9 ± 0.7	57.2 ± 7.0	167.3 ± 4.8	82.8 ± 4.5	-0.0 ± 0.3
Post-PHV	93	16.6 ± 1.3	67.8 ± 7.9	176.9 ± 5.9	86.5 ± 4.8	2.2 ± 0.8

PHV: peak height velocity.

5.2.3 Procedures

5.2.3.1 Anthropometry

Body mass in kilograms was measured on a calibrated physician scale (SECA 799, Hamburg, Germany). Standing and sitting heights in centimeters were recorded on a measurement platform (SECA 799, Hamburg, Germany). A measuring tape was used to assess the leg length to all the football players. Leg length was defined as the length measured in centimeters from the anterior superior iliac spine to the most distal portion of the medial tibial malleolus [240].

5.2.3.2 Maturity status

Stage of maturation was calculated in a noninvasive manner using a regression equation comprising measures of age, body mass, standing height and sitting height taken during the first part of the testing sessions [221]. Using this method, maturity offset (calculation of years from PHV) was completed (Equation 1). The equation has been used to predict maturation status with a standard error of approximately 6 months in pediatric population [221]. Therefore, the following equation to calculate maturity offset was used:

> *- 9.236 + [0.0002708*leg length and sitting-height interaction] – [0.001663*age and leg-length interaction] + [0.007216*age and sitting-height interaction] + [0.02292*weight by height ratio*100]* [equation 1]

5.2.3.3 Range of motion

The passive hip extension [PHE], hip adduction with hip flexed 90° [$\mathrm{PHAD}_{\mathrm{HF90^{\circ}}}$], hip flexion with knee flexed [$\mathrm{PHF}_{\mathrm{KF}}$] and extended [$\mathrm{PHF}_{\mathrm{KE}}$], hip abduction with hip neutral [PHABD] and hip flexed 90° [$\mathrm{PHABD}_{\mathrm{HF90^{\circ}}}$], hip external [PHER] and internal [PHIR] rotation, knee flexion [PKF], ankle dorsiflexion with knee flexed [$\mathrm{ADF}_{\mathrm{KF}}$] and extended [$\mathrm{ADF}_{\mathrm{KE}}$] ROM measures of the dominant (defined as the participant's preferred kicking leg) and non-dominant legs were assessed following the methodology described by Cejudo et al. [122,241].

These ROM tests were selected because they have been considered operationally valid by some American Medical Organizations [242] and included in prominent manuals of Sports Medicine [243] based on anatomical knowledge and extensive clinical and sport experience. In addition, previous studies from our laboratory [122,241] have reported moderate to high intra-tester reliability scores for all the ROM procedures employed by the testers who were in charge of carrying out all the testing sessions, with coefficients of variation (CV) ranging from 0.2 to 9.1% (CVs = 0.4, 1.7, 9.1, 3.5, 3.7, 3.5, 3.4, 1, 0.2 and 1.2% for $\mathrm{PHF}_{\mathrm{KF}}$, $\mathrm{PHF}_{\mathrm{KE}}$, PHE, $\mathrm{PHABD}_{\mathrm{HF90^{\circ}}}$, PHABD, $\mathrm{PHAD}_{\mathrm{HF90^{\circ}}}$, PHIR, PHER, PKF, $\mathrm{ADF}_{\mathrm{KF}}$ and $\mathrm{ADF}_{\mathrm{KE}}$, respectively).

For the ROM measurement, an ISOMED Unilevel inclinometer (Portland, Oregon) was used with an extendable telescopic arm as the key measure for the PHE, $\mathrm{PHAD}_{\mathrm{HF90^{\circ}}}$, $\mathrm{PHF}_{\mathrm{KF}}$, $\mathrm{PHF}_{\mathrm{KE}}$, $\mathrm{PHABD}_{\mathrm{HF90^{\circ}}}$, PHER, PHIR, PKF, $\mathrm{ADF}_{\mathrm{KF}}$ and $\mathrm{ADF}_{\mathrm{KE}}$ tests, while a metallic long arm goniometer (Baseline® Stainless) was employed for the PHABD test. A low-back protection support (Lumbosant, Murcia, Spain) was used to maintain the normal lordotic curve during most of the assessment tests [241].

Prior to the ROM assessment (second part of the testing sessions), players performed the standardised dynamic warm-up designed by Taylor et al. [244]. The overall duration of the entire warm-up was approximately 20 min. A 3-5 min rest interval between the end of the warm-up and beginning of the ROM assessment was given to the football players for rehydrating and drying their sweat prior to the ROM assessment. It has been shown that the effects elicited by the dynamic warm-up on muscle properties might last more than 5 min [245] and hence, decreases in ROM values within the 3-5 min rest interval were not expected. Standardisation procedures, (including the warm-up, test setup and participant instructions) were replicated at each test session conducted in the different academies. After the warm-up, football players were instructed to perform, in a randomised order, two maximal trials of each ROM test for each leg, and the mean score for each test was used in the statistical analyses. One of the following criteria determined the endpoint for each test: a) palpable onset of pelvic rotation, and/or b) the football player feeling a strong but tolerable stretch, slightly before the occurrence of pain [241]. When a variation >5% was found in the ROM values between the two trials of any test, an extra trial was performed, and the two most closely related trials were used for the subsequent statistical analyses [241].

Football players were examined wearing sports clothes and without shoes. A 30 s rest was given between trials, legs and tests. All tests were carried out by the same two experimented sport scientists under stable environmental conditions.

5.2.3.4 Data analyses

To account for the reported error (approximately 6 months) in the equation [221], players were grouped into discrete bands based on their maturational offset (pre-PHV [<-1], circa-PHV [-0.5 to 0.5], post-PHV [>1]). Players who recorded a maturational offset from -1 to -0.5 and 0.5 to 1 were subsequently removed from the dataset when players were analyzed by stage of maturation.

Likewise, in each participant the hip, knee and ankle ROM scores were categorised as normal or restricted according to the reference values previously reported to consider an athlete as being more prone to suffer an injury [233,246–248]. When no cut-off scores for detecting athletes at high risk of injury were found for a ROM score, it was compared with data derived from the age-matched controls. Otherwise, when several cut-off scores were found for the same ROM, the most conservative criteria were selected. Thus, ROM values were reported as restricted according to the following cut-off scores: < 114° PHF_{KF} [246], < 70° PHF_{KE} [249], < 0° PHE [250], < 50° $\text{PHABD}_{\text{HF90°}}$ [242], < 28° PHABD [251], < 25° $\text{PHAD}_{\text{HF90°}}$ [247], < 30° PHIR [233], < 30° PHER [233], < 120° PKF [252], < 34° ADF_{KF} [248], < 17° ADF_{KE} [251]. Using the mean value of the cut-off scores suggested by Fousekis et al. [239] and Ellenbecker et al. [238], the number of players with side-to-side differences (>8°) in each ROM measure were also calculated.

5.2.4 Statistical analyses

Prior to the statistical analysis, the distribution of raw data sets was checked using the Kolmogorov-Smirnov test and demonstrated that all data had a normal distribution ($p > 0.05$). Descriptive statistics including means and standard deviations were calculated for each ROM measure and group separately.

A one-way analysis of variance (ANOVA) was performed to determine the existence of between-groups differences for all normal data distribution. Homogeneity of variance was tested by Levene's statistic, and where violated Brown-Forsythe adjustment was used to calculate the F-ratio. Post-hoc comparisons were made using the Bonferroni or Dunnett's T3 test to determine significant between-group differences when equal variance was or was not assumed, respectively. In particular, separate analyses were performed to examine between-group differences for a range of chronological age groups that represented those in a football academy (U12, U14, U16 and U19). A secondary analysis was also employed, grouping players by their stages of maturation (pre-PHV, circa-PHV or post-PHV). The significance level was set to $p < 0.05$ for all tests.

Batterham & Hopkins [253] suggested that for intra and inter-groups comparisons, the traditional null hypothesis tests (i.e. analysis of variance) whose qualitative decisions or interpretations are based on the basic of a specific p value (when a p value is lower than 0.05 the magnitude of the difference is considered statistically significant) should be complemented (as this approach may be misleading, depending on the magnitude of the statistic, error of measurement, and sample size) with a more intuitive and practical approach based directly on uncertainty in the true value of the statistic. Consequently, magnitude-based decisions on differences between chronological age groups (U12 vs. U14 vs. U16 vs. U19), maturity offset groups (pre-PHV vs. circa-PHV vs. post-PHV) and legs (dominant vs non-dominant) were also determined by expressing the probabilities that the true effect was trivial or substantial in relation to predetermined threshold values (i.e. smallest worthwhile clinical changes). Probabilities were then used to make a qualitative probabilistic inference about the effects [222]. Based on the cut off scores proposed by Fousekis et al. [239] and Ellenbecker et al. [238] (>6° and >10°, respectively), the cut off value of >8° (mean from both previous studies) was used to determine the smallest substantial/worthwhile change for all paired-comparisons and for each of the ROM variables. The qualitative descriptors proposed by Hopkins [254] were used to interpret the probabilities that the true affects are harmful, trivial or beneficial: <1%, almost certainly not; 1–4%, very unlikely; 5– 24%, unlikely or probably not; 25–74%, possibly or may be; 75–94%, likely or probably; 95–99%, very likely; >99%, almost certainly.

Effect sizes were also calculated to determine the magnitude of differences between groups and legs for each of the ROM measures using the method and descriptors previously described by Cohen [255] assigning descriptors to the effect sizes (d) such that an effect size < 0.2 was considered as being trivial, between 0.2 and 0.5 represented a small magnitude of change, while 0.5–0.8 and greater than 0.8 represented moderate and large magnitudes of change, respectively.

The current study considered a “clinically relevant” main effect when a change was noted between paired-comparisons in ROM measures that reported a p values < 0.05, a probability of the worthwhile differences of “possible” or higher (> 50% positive or negative) and at least a moderate effect size ($d > 0.5$).

Pearson’s chi-squared (χ^2) test was used to examine the existence of a relationship between the ROM classification (normal and restricted) and the chronological age and maturational stage groups.

Finally, Pearson (*r*) correlation analysis was performed to examine the correlation between players' leg length and each ROM score. Magnitudes of correlations were assessed using the following scale of thresholds: < 0.80 low, 0.80–0.90 moderate and > 0.90 high [256].

All the analysis was completed using SPSS version 20 (SPSS Inc, Chicago, IL, USA) and an online spreadsheet (www.sportsci.org).

5.3 Results

Tables 10 and 11 show the descriptive ROM values for hip (PHF_{KF}, PHF_{KE}, PHE, $PHABD_{HF90^{\circ}}$, PHABD, $PHAD_{HF90^{\circ}}$, PHIR and PHER), knee (PKF) and ankle (ADF_{KF} and ADF_{KE}) joints and for all chronological age and maturational groups, respectively.

With all players combined, ANOVA and magnitude-based decisions analyses reported no clinically relevant differences between dominant and non-dominant legs for each ROM measure (most likely trivial effect with a probability of 100% [Appendix 14 and Appendix 15]) and hence, the mean ROM score for both limbs was used for between-group comparisons.

Although the one-way ANOVA analysis showed statistically significant differences ($p < 0.05$; d = 0.5-1.25) between chronological age groups in almost all (PHF_{KF}, PHF_{KE}, PHE, $PHABD_{HF90^{\circ}}$, PHABD, $PHAD_{HF90^{\circ}}$, PHIR, PKF, ADF_{KE}) ROM measures (Figure 18), the magnitude-based decisions analysis reported non-substantial differences (<8°) for all the ROM values (likely trivial effect with a probability of 81-100%) and between pairwise chronological age groups comparisons, except for the PKF ROM measure where a possibly negative effect (with a probability of 54%; $d = 0.92$; $p < 0.05$) was found between U12 and U19 players' groups.

Likewise, the ANOVA analysis also showed statistically significant differences ($p < 0.05$; d = 0.5-1.17) between paired maturational groups comparisons in all the ROM measures with the exception of PHER, ADF_{KF} and ADF_{KE} (Figure 19). However, magnitude-based decisions did not find any substantial difference in ROM measures between maturation groups (likely trivial effect with a probability of 94-100%), with the exception of PKF where a possibly negative effect (with a probability of 65%; $d = 0.98$; $p < 0.05$) was shown between the pre-PHV and post-PHV groups.

Table 10. Mean range of motion scores and percentage of players with bilateral differences per age group.

	U12 (n = 76)		**U14 (n = 79)**		**U16 (n = 68)**		**U19 (n = 63)**	
Ranges of motion (°)	**Mean ± SD (Qualitative outcome[a])**	**Percentage of players with bilateral difference >8°**	**Mean ± SD (Qualitative outcome[a])**	**Percentage of players with bilateral difference >8°**	**Mean ± SD (Qualitative outcome[a])**	**Percentage of players with bilateral difference >8°**	**Mean ± SD (Qualitative outcome[a])**	**Percentage of players with bilateral difference >8°**
PHF$_{KF}$	136.3 ± 4.8 (Normal [0])	4	132.7 ± 5.2 (Normal [0])	9	132.7 ± 6.4 (Normal [0])	6	135.4 ± 6.7 (Normal [0])	8
PHF$_{KE}$	71.5 ± 7.2 (Normal [38])	8	69.3 ± 6.6 (Restricted [57])	0	70.2 ± 9.0 (Normal [49])	1	74.8 ± 9.3 (Normal [32])	2
PHE	15.7 ± 4.4 (Normal [0])	3	12.8 ± 5.8 (Normal [1])	1	10.4 ± 4.5 (Normal [0])	0	10.5 ± 5.3 (Normal [6])	0
PHABD$_{HF90°}$	73.0 ± 4.9 (Normal [0])	5	71.0 ± 5.4 (Normal [0])	6	69.4 ± 7.0 (Normal [0])	3	70.5 ± 6.5 (Normal [0])	0
PHABD	38.6 ± 3.1 (Normal [0])	0	37.2 ± 2.2 (Normal [0])	0	36.9 ± 3.4 (Normal [0])	0	37.3 ± 2.3 (Normal [0])	0
PHAD$_{HF90°}$	28.8 ± 3.5 (Normal [8])	3	27.7 ± 3.0 (Normal [10])	3	28.1 ± 3.1 (Normal [10])	1	31.5 ± 3.8 (Normal [3])	2
PHIR	47.0 ± 6.1 (Normal [0])	4	43.9 ± 6.2 (Normal [1])	3	42.8 ± 6.6 (Normal [1])	1	42.6 ± 7.0 (Normal [1])	0
PHER	58.6 ± 6.8 (Normal [0])	5	56.8 ± 7.2 (Normal [0])	5	58.9 ± 9.4 (Normal [0])	4	57.2 ± 5.4 (Normal [0])	5
PKF	129.6 ± 8.8 (Normal [14])	9	126.7 ± 9.0 (Normal [19])	4	123.1 ± 11.3 (Normal [41])	4	121.4 ± 11.4 (Normal [49])	6
ADF$_{KF}$	36.7 ± 4.6 (Normal [20])	1	37.2 ± 4.1 (Normal [16])	0	36.6 ± 5.3 (Normal [18])	1	36.6 ± 5.2 (Normal [25])	0
ADF$_{KE}$	30.0 ± 4.6 (Normal [0])	1	29.4 ± 3.9 (Normal [0])	1	30.2 ± 4.7 (Normal [0])	1	32.0 ± 4.9 (Normal [0])	0

°: degrees.

[a]: Qualitative score of the mean range of motion, in brackets the percentage of players with a restricted range of motion scores according to previously published cut-off scores (see Statistical analysis section). PHF$_{KF}$: passive hip flexion with the knee flexed; PHF$_{KE}$: passive hip flexion with the knee extended; PHE: passive hip extension; PHABD$_{HF90°}$: passive hip abduction at 90° of hip flexion; PHABD: passive hip abduction; PHAD$_{HF90°}$: passive hip adduction at 90° of hip flexion; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF$_{KF}$: ankle dorsi-flexion with the knee flexed; ADF$_{KE}$: ankle dorsi-flexion with the knee extended.

Table 11. Mean range of motion scores and percentage of players with bilateral differences per maturation group.

Ranges of motion (°)	**Pre-PHV (*n* = 101)**		**Circa-PHV (*n* = 43)**		**Post-PHV (*n* = 93)**	
	Mean ± SD (Qualitative outcome[a])	**Percentage of players with bilateral difference >8°**	**Mean ± SD (Qualitative outcome[a])**	**Percentage of players with bilateral difference >8°**	**Mean ± SD (Qualitative outcome[a])**	**Percentage of players with bilateral difference >8°**
PHF$_{KF}$	136.1 ± 4.4 (Normal [0])	5	130.9 ± 5.8 (Normal [0])	5	134.4 ± 6.5 (Normal [0])	8
PHF$_{KE}$	71.9 ± 7.0 (Normal [37])	6	69.5 ± 6.1 (Restricted [51])	0	73.6 ± 9.8 (Normal [38])	2
PHE	15.2 ± 5.0 (Normal [1])	2	11.6 ± 5.7 (Normal [0])	0	10.5 ± 5.0 (Normal [4])	0
PHABD$_{HF90°}$	72.6 ± 5.4 (Normal [0])	7	69.3 ± 6.8 (Normal [0])	7	70.4 ± 6.4 (Normal [0])	1
PHABD	38.4 ± 2.7 (Normal [0])	0	37.0 ± 2.2 (Normal [0])	0	37.1 ± 2.7 (Normal [0])	0
PHAD$_{HF90°}$	28.5 ± 3.3 (Normal [6])	4	28.0 ± 3.4 (Normal [14])	1	30.2 ± 3.9 (Normal [8])	1
PHIR	46.7 ± 5.8 (Normal [0])	3	42.9 ± 6.5 (Normal [1])	5	42.5 ± 6.9 (Normal [2])	1
PHER	58.3 ± 7.0 (Normal [0])	4	56.4 ± 8.0 (Normal [0])	9	57.4 ± 7.2 (Normal [0])	4
PKF	129.5 ± 8.7 (Normal [14])	8	124.4 ± 10.5 (Normal [30])	0	121.0 ± 11.2 (Normal [51])	4
ADF$_{KF}$	37.2 ± 4.4 (Normal [16])	1	36.4 ± 5.3 (Normal [28])	0	36.3 ± 5.1 (Normal [24])	0
ADF$_{KE}$	30.0 ± 4.4 (Normal [0])	2	30.3 ± 5.0 (Normal [0])	0	31.3 ± 4.5 (Normal [0])	1

°: degrees.

[a]: Qualitative score of the mean range of motion, in brackets the percentage of players with a restricted range of motion score according to previously published cut-off scores (see Statistical analysis section). PHF$_{KF}$: passive hip flexion with the knee flexed; PHF$_{KE}$: passive hip flexion with the knee extended; PHE: passive hip extension; PHABD$_{HF90°}$: passive hip abduction at 90° of hip flexion; PHABD: passive hip abduction; PHAD$_{HF90°}$: passive hip adduction at 90° of hip flexion; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF$_{KF}$: ankle dorsi-flexion with the knee flexed; ADF$_{KE}$: ankle dorsi-flexion with the knee extended.

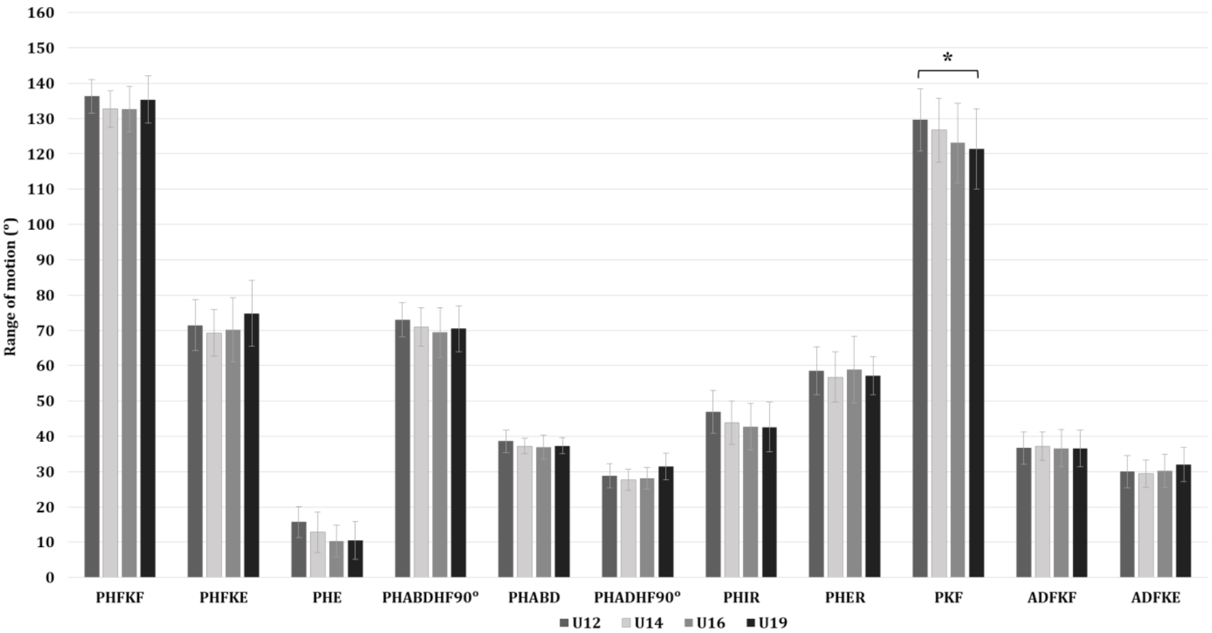


Figure 18. Age-related inter-group differences for lower extremity joint ranges of motion values. *: Clinically relevant (probability of the worthwhile differences > 50%; *d* > 0.5; $p < 0.05$). PHF_{KF}: passive hip flexion with the knee flexed; PHF_{KE}: passive hip flexion with the knee extended; PHE: passive hip extension; $PHABD_{HF90^\circ}$: passive hip abduction at 90° of hip flexion; PHABD: passive hip abduction; $PHAD_{HF90^\circ}$: passive hip adduction at 90° of hip flexion; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF_{KF}: ankle dorsi-flexion with the knee flexed; ADF_{KE}: ankle dorsi-flexion with the knee extended. U12: under-12; U14: under-14; U16: under-16; U19: under-19.

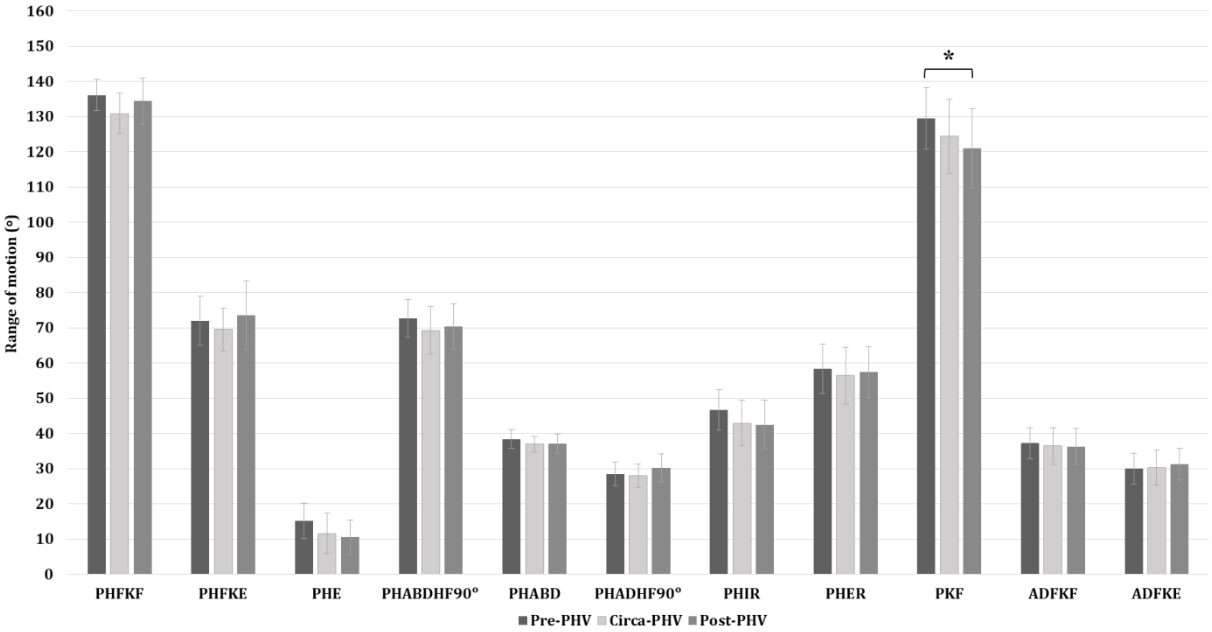


Figure 19. Maturation-related inter-group differences for lower extremity joint ranges of motion values. *: Clinically relevant (probability of the worthwhile differences > 50%; *d* > 0.5; $p < 0.05$). PHF_{KF}: passive hip flexion with the knee flexed; PHF_{KE}: passive hip flexion with the knee extended; PHE: passive hip extension; $PHABD_{HF90^\circ}$: passive hip abduction at 90° of hip flexion; PHABD: passive hip abduction; $PHAD_{HF90^\circ}$: passive hip adduction at 90° of hip flexion; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF_{KF}: ankle dorsi-flexion with the knee flexed; ADF_{KE}: ankle dorsi-flexion with the knee extended. PHV: peak height velocity.

The comprehensive analysis conducted in this study found that approximately 40%, 35% and 20% of the total players displayed restrictions in their PHF_{KE}, PKF, and ADF_{KF} ROM values, respectively. This analysis also displayed an incremental number of football players with restricted PKF ROM values throughout chronological age and maturational stage (from 14% in the U12 and pre-PHV groups to 50% in the U19 and post-PHV groups; $\chi^2 = 28.541–30.352$; $p < 0.05$), whereas the proportion of players with restricted PHF_{KE} reached its peak in the U14 and U16 age groups ($PHF_{KE} \approx 50\%$; $\chi^2 = 10.805$; $p < 0.05$) and also in the circa-PHV group ($PHF_{KE} = 51\%$; $\chi^2 = 2.923$; $p > 0.05$).

Pearson correlation analysis did not report any significant correlation between leg length and ROM measures (all r values < 0.37) for both chronological age and maturational groups.

5.4 Discussion

The main findings of the present study indicated that only PKF ROM was clearly and equally influenced by the course of chronological age and maturational stage in this cohort of male young football players. A gradual and continuous decrease in the PKF ROM score was found across the chronological ages (Figure 18) and maturational stages (Figure 19). However, only the magnitude of the observed changes in the PKF ROM between the groups situated in the opposite extremes of both grouping categories may be considered as clinically relevant. Football players in the U12 (129.6°) and pre-PHV (129.5°) groups reported clinically relevant ($p < 0.05$ [statistically significant], $d > 0.8$ [large effect size] and very likely substantial [>8°]) higher PKF ROM values than their peers in the U19 (121.4°) and post-PHV (121°) groups, respectively. These findings are in agreement with the previous results reported by Cejudo et al. [122], who also found that U12 football players showed substantially higher PKF ROM values than U19 football players (133.8° [U12] vs. 120.4° [U19]).

This progressive decrease in the PKF ROM values of players with advancing age and stage of maturation may be partially explained by the impact that the systematic practice of football might have on the development of body posture. For example, rapid changes in spinal curvature and the sudden increase in the length of extremities experienced by adolescents during the growth spurt are not always followed by a similar onset and rate of strength development of the muscles involved in postural control adjustment (e.g., abdominal external and internal obliques, erector spinae, quadratus lumborum, rectus abdominis). This temporary circumstance may place adolescents in a vulnerable situation to develop body posture disorders caused, among other, by misalignments of the spinal curvatures in the sagittal plane [257]. In order to generate maximal power during the repeated high intensity movements required in football, players often adopt postures (mainly in flexion) that require strong and coordinated contractions of the trunk extensor and flexor muscles to keep balance and energy transfer to the distal segments [258]. Therefore, as a measure to improve football-related motor skills (among others), in their daily football trainings, players often perform exercises designed to improve the strength and endurance of the major trunk muscles (e.g., planks, prone "Supermans", traditional abdominal crunches). However, these strength and endurance training programs are not usually well-balanced (from the authors' extensive applied experience in youth football settings), whereby the number and repetitions of the exercises included to improve the strength and resistance of the trunk flexor muscles are higher than their antagonist trunk extensors. It is plausible that these training programs may generate muscle imbalances between trunk flexors and extensors that might altered the postures adopted by the players during the execution of the movements inherent to football play and this repeated over time may lead to the development of football-specific adaptations in players spinal morphotypes. In support of this assumption, Wodecky et al. [259] found significant increases in the anterior pelvic tilt angle of young adult football players, in contrast with their age-matched sedentary counterparts. Therefore, it is possible that the young football players of the present study had also started to develop an increased angle of anterior pelvic tilt. This circumstance may generate a hyperlordotic morphotype that places the quadriceps musculature in a relative shortened position that may result in gradual and continuous restrictions on PKF ROM, which may become clinically relevant in older and more mature players [257].

It should be highlighted that, although less evident, there seems to be a slow and gradual decrease in PHE and PHIR ROMs as the chronological age (Figure 18) and maturational stage (Figure 19) increase. However, and unlike that found for PKF ROM, the magnitude of the observed changes between the groups that demonstrated the highest and lowest PHE and PHIR average ROM values were not large enough (approximately 5º) to be considered clinically relevant (but they were close to the previously established cut-off scores of 8º). A similar decrease (but higher in magnitude and slope) over the adolescent years in PHIR ROM was also found in previous studies conducted in young football players and in contrast with their age-matched non-athlete counterparts [123,124,236].

The qualitative interpretation (normal vs. restricted) of the average PHE, PHIR and PKF ROM values demonstrated in this cohort of young football players reports that these three ROM measures may be classified as normal or non-restricted (independently of the chronological age and maturational stage) according to the cut-off scores previously established by the scientific literature (PHE > 0º, PHIR > 30º, and PKF > 120º) [233,250,252]. Similar results were found by Cejudo et al. [122] and López-Valenciano et al. [228], who after having carried out the same ROM maneuvers and testing procedures (ROM-Sport protocol) found average PHE, PHIR and PKF

ROM values that may be categorised as normal in a cohort of young (independent of the chronological age of the participants assessed) and professional male football players, respectively. However, these findings were different to those reported by Scaramussa et al. [124] in also young football players and for the average PHIR ROM. Scaramussa et al. [124] found average PHIR ROM values that may be categorised as restricted (<30°) in all chronological ages they assessed (from 9 to 18 years). Perhaps, this discrepancy may be attributed to the different testing position chosen by Scaramussa et al. [124] to assess the PHIR ROM (lying supine with hip and knee actively flexed to 90°) which could require a more restrictive cut-off score to identify football players with limited PHIR ROM than the <30° cut-off score used in the current study and that was previously defined for a testing position in which participants were laying prone with hip neutral and knee flexed to 90° [233]. Thus, the previously reported decrease between maturational stage in the PHE, PHIR and PKF ROMs of our youth football players might be considered as musculoskeletal adaptations generated as a consequence of the increase in single sport specialised football training play experience and the enhance of the football-specific physical and technical skills (e.g., kicking the ball and cutting) without any apparent negative repercussion on the likelihood of sustaining an injury. Similarly, the rest of the ROM measures also reported average scores that could be classified as normal or non-restricted according to their respective cut-off scores previously defined. Therefore, this traditional profiling approach could lead to the conclusion that there is no need to deliver measures aimed at improving lower extremity joints ROMs in young football players.

However, when a novel and more comprehensive analysis is carried out (in which the inter-players variability in the lower extremity ROM profile is considered), the current data indicate that an incremental number of the football players demonstrated restricted PKF ROM values (cut-off score <120°) throughout chronological age and maturational stage. Our data indicate that in the early adolescent years (12 years) and before the period of maximal rate of growth (pre-PHV), the percentage of football players with restricted PKF ROM values was approximately 14%. However, there is a marked increase with both chronological age and maturational status with 50% in the players in the U19 and post-PHV groups demonstrating restricted PKF ROM. As it has been stated before, the possible effects of football play on players' posture may partially justify this increased in the number of players that displayed restricted PKF ROM values with advancing age and maturational stage. Contrarily, the proportion rates of players showing restricted PHE (cut-off score < 0°) and PHIR (cut-off score < 30°) ROM values were minimal (not exceeding the 6% and 2%, respectively) for each chronological age and maturational stage group.

This comprehensive approach used for describing lower extremity ROM profile also reported a reasonably large proportion of young football players with restricted PHF_{KE} (cut-off score < 70°) [249] and ADF_{KF} (cut-off score < 34°) [248] ROM values in all chronological age and maturational stage groups. The proportion of players with restricted PHF_{KE} and ADF_{KF} ROMs reached its peak in the circa-PHV group (PHF_{KE} = 51%; ADF_{KF} = 28%). This latter circumstance might be explained by the demands of football training and match play, which are abruptly increased in the 14-16U categories, which corresponds with PHV in most football academies (sport specialisation). The majority of the movements inherent to football play impose strong concentric but mainly eccentric loads on the hip and ankle dorsi-flexion muscles at shortened contracted positions [260]. When these actions are repeated several times during training sessions and games, they have the potential to generate muscle damage and micro-trauma. The increase in the weekly training frequency (from 2-3 days to 3-4 days per week) and match congestion that often are experienced by the U14 and U16 players along with the absence of proper recovery and protective measures might induce impairments in the mechanical and neural properties of the posterior kinetic chain muscle-tendon units, including a reduction in the normal PHF_{KE}, and ADF_{KF} ROMs [261].

It would appear that the growth spurt that is experienced by adolescents around PHV manifests itself in restricted ROM in the hip, knee and ankle flexion in the sagittal plane, and this restriction may be exaggerated by the course of chronological age and/or single sport specialisation of football [46]. This restrictive profile of lower extremity flexion movements in the sagittal plane may be an age- and maturity-related injury risk factor and may partly explain the high incidence of low back pain, and knee and ankle ligament injuries observed during the stage of PHV [42]. Owing to the adverse consequences that the back, knee (mainly), and ankle ligament injuries usually have in the physical and emotional well-being of the adolescent athletes, those football players around or just after PHV should be targeted for screening and prevention strategies. Thus, the trauma associated with an ACL injury contributes to significant pain, depression, decreased athletic identity and lower academic performance [262], in addition to the potential ending of an athletic career, greatly amplified risk of a subsequent ACL injury, likelihood for long term disability and risk of early osteoarthritis and chronic pain [263]. Consequently, the findings reported by this more realistic profiling approach suggest that the application of specific preventive measures aimed at improving hip, knee and ankle flexion ROMs (i.e., stretching programs, well-balanced muscle strength and endurance training programs) in the year before, but mainly during PHV, seems to be essential in young football players.

Despite having been considered as an asymmetrical sport [235], the results of the current study also found non-clinically relevant bilateral differences (>8°) between the dominant and non-dominant lower extremity joints ROM average values in this cohort of football players (independent of chronological age and maturational stage). In addition, by calculating the number of players with bilateral differences greater than 8° in any hip, knee and ankle ROM measure, a very low percentage (≤ 9%) of players were identified as having bilateral asymmetries. These results are in conflict with the findings reported by López-Valenciano et al. [228] in professional male football players, who found that approximately 30% of the players could be identified as having bilateral asymmetries (>6°) for $\mathrm{PHABD}_{\mathrm{HF90}}$, PHIR and PHER. An explanation for this discrepancy may be associated with the differences that exist between both cohorts of football players (young vs. professional players) regarding, among others, weekly training load (3 sessions [young players] vs. 6-8 sessions [professional players]), number of matches per week and year (28-32 matches per year at the weekends [young players] vs. 40-60 matches per year with periods of two matches per week [professional players]), training age and the physical demands associated with football. Potentially congested training and competitive calendars, alongside the very high physical demands inherent in current professional football, may result in a suboptimal recovery and an overexposure of the players to perform a substantive number of asymmetrical and repeated technical movements inherent to football that may lead them to develop bilateral ROM asymmetries in favor of the dominant leg. Other hypotheses for this discrepancy may be based on fact that player's roles vary more greatly in youth football which may in part help to preserve symmetrical between-joints ROM distribution. Finally, the slightly less restrictive cut-off score (>6°) used by López-Valenciano et al. [228] to identify professional football players with bilateral asymmetries in comparison with our cut-off score (>8°) may also play a role (but probably to a less extent than other hypotheses) in explaining this discrepancy.

Finally, some limitations to this study should be acknowledged. The age at PHV has been calculated using an equation based on the participants' leg length, sitting height, age, height, and weight, which may not be as accurate as using skeletal imaging; however, to minimise the group allocation error derived from the equation, players with a maturational offset between -1 to -0.5 and 0.5 to 1 were removed from the data set. This decision subsequently led to a smaller sample size in the circa-PHV group in comparison with the other groups. Nonetheless, the large total sample size attempted to mitigate differences in group sample size distribution.

5.5 Conclusions

Given the large percentage of total number of players with restricted PHF_{KE} (≈40%), PKF (≈35%), and ADF_{KF} (≈20%) ROM scores, the findings of the present study emphasise the necessity of prescribing compensatory measures (e.g., stretching exercises, well-balanced muscle strength and resistance training programs) with the aim of improving ROM values in the daily football training practices of youth players. As we found no age- and maturation-related differences (> 8°) in almost all ROM assessed, we would recommend that stretching is included across all periods of growth and maturation, as early single sport specialisation appears to contribute to restricted ROM. Likewise, as no bilateral differences between dominant and non-dominant legs were found, it is recommended that these routines should be equally applied to both limbs.

5.6 Appendices

Appendix 14. Descriptive values and decision about side-to-side difference for the lower extremity joint ranges of motion by players' age-group (*N* = 286).

Ranges of motion (°)	Dominant leg		Non-dominant leg		Standardised difference^{T}	Qualitative outcome^{a}
	Mean ± SD	Qualitative outcome^{a}	Mean ± SD	Qualitative outcome^{a}		
U12 (*n* = 76)						
PHF$_{\text{KF}}$	136.3 ± 5.7	Normal (0)	136.3 ± 5.0	Normal (0)	-0.01 ± 0.25	Trivial (0/100/0)
PHF$_{\text{KE}}$	71.8 ± 7.9	Normal (32)	71.2 ± 7.3	Normal (36)	-0.09 ± 0.23	Trivial (0/100/0)
PHE	15.5 ± 5.1	Normal (0)	15.8 ± 4.5	Normal (0)	0.06 ± 0.23	Trivial (0/100/0)
PHABD$_{\text{HF90°}}$	72.9 ± 5.6	Normal (0)	73.1 ± 5.3	Normal (0)	0.03 ± 0.23	Trivial (0/100/0)
PHABD	38.7 ± 3.1	Normal (0)	38.5 ± 3.8	Normal (0)	-0.08 ± 0.25	Trivial (0/100/0)
PHAD$_{\text{HF90°}}$	28.6 ± 4.1	Normal (17)	29.0 ± 4.0	Normal (14)	0.11 ± 0.25	Trivial (0/100/0)
PHIR	46.8 ± 6.6	Normal (0)	47.2 ± 6.5	Normal (0)	0.06 ± 0.25	Trivial (0/100/0)
PHER	59.1 ± 7.4	Normal (0)	58.2 ± 6.9	Normal (0)	-0.12 ± 0.25	Trivial (0/100/0)
PKF	129.4 ± 9.2	Normal (13)	129.8 ± 9.1	Normal (13)	0.03 ± 0.23	Trivial (0/100/0)
ADF$_{\text{KF}}$	37.0 ± 5.4	Normal (17)	36.4 ± 4.6	Normal (20)	-0.12 ± 0.25	Trivial (0/100/0)
ADF$_{\text{KE}}$	29.9 ± 5.0	Normal (0)	30.0 ± 4.7	Normal (0)	0.01 ± 0.23	Trivial (0/100/0)
U14 (*n* = 79)						
PHF$_{\text{KF}}$	133.2 ± 5.6	Normal (0)	132.2 ± 6.0	Normal (0)	-0.18 ± 0.23	Trivial (0/100/0)
PHF$_{\text{KE}}$	69.5 ± 6.9	Restricted (57)	69.1 ± 6.6	Restricted (54)	-0.05 ± 0.22	Trivial (0/100/0)
PHE	12.5 ± 6.1	Normal (1)	13.2 ± 6.0	Normal (3)	0.12 ± 0.22	Trivial (0/100/0)
PHABD$_{\text{HF90°}}$	71.3 ± 6.1	Normal (0)	70.8 ± 5.8	Normal (0)	-0.09 ± 0.22	Trivial (0/100/0)
PHABD	37.5 ± 3.0	Normal (0)	37.0 ± 2.3	Normal (0)	-0.19 ± 0.23	Trivial (0/100/0)
PHAD$_{\text{HF90°}}$	27.5 ± 3.6	Normal (27)	27.9 ± 3.6	Normal (14)	0.11 ± 0.23	Trivial (0/100/0)
PHIR	44.1 ± 6.4	Normal (0)	43.8 ± 6.5	Normal (1)	-0.05 ± 0.23	Trivial (0/100/0)
PHER	56.6 ± 7.1	Normal (0)	57.0 ± 8.0	Normal (0)	0.06 ± 0.23	Trivial (0/100/0)
PKF	126.9 ± 9.4	Normal (16)	126.5 ± 9.1	Normal (22)	-0.04 ± 0.22	Trivial (0/100/0)
ADF$_{\text{KF}}$	37.2 ± 4.1	Normal (10)	37.2 ± 4.7	Normal (20)	0.01 ± 0.23	Trivial (0/100/0)
ADF$_{\text{KE}}$	29.5 ± 4.1	Normal (0)	29.4 ± 4.2	Normal (0)	-0.01 ± 0.22	Trivial (0/100/0)
U16 (*n* = 68)						
PHF$_{\text{KF}}$	133.6 ± 6.7	Normal (0)	131.8 ± 6.9	Normal (0)	-0.26 ± 0.29	Trivial (0/100/0)
PHF$_{\text{KE}}$	70.2 ± 9.0	Normal (47)	70.3 ± 9.2	Normal (44)	0.01 ± 0.24	Trivial (0/100/0)
PHE	10.0 ± 5.0	Normal (1)	10.7 ± 4.6	Normal (0)	0.13 ± 0.24	Trivial (0/100/0)
PHABD$_{\text{HF90°}}$	70.0 ± 7.7	Normal (0)	68.9 ± 6.8	Normal (0)	-0.14 ± 0.24	Trivial (0/100/0)
PHABD	37.0 ± 4.0	Normal (0)	36.9 ± 3.5	Normal (0)	-0.03 ± 0.29	Trivial (0/100/0)
PHAD$_{\text{HF90°}}$	28.0 ± 3.8	Normal (18)	28.3 ± 3.1	Normal (13)	0.10 ± 0.29	Trivial (0/100/0)
PHIR	43.4 ± 6.6	Normal (3)	42.2 ± 7.1	Normal (1)	-0.17 ± 0.29	Trivial (0/100/0)
PHER	58.6 ± 9.7	Normal (0)	59.1 ± 9.5	Normal (0)	0.05 ± 0.29	Trivial (0/100/0)
PKF	123.1 ± 12.0	Normal (40)	123.0 ± 11.0	Normal (38)	-0.01 ± 0.24	Trivial (0/100/0)
ADF$_{\text{KF}}$	36.4 ± 5.4	Normal (19)	36.8 ± 5.6	Normal (18)	0.07 ± 0.29	Trivial (0/100/0)
ADF$_{\text{KE}}$	30.4 ± 5.1	Normal (0)	30.1 ± 4.7	Normal (0)	-0.06 ± 0.24	Trivial (0/100/0)

Ranges of motion (°)	Dominant leg		Non-dominant leg		Standardised difference[T]	Qualitative outcome[a]
	Mean ± SD	Qualitative outcome[a]	Mean ± SD	Qualitative outcome[a]		
			U19 (*n* = 63)			
PHF_{KF}	135.9 ± 7.2	Normal (0)	134.9 ± 7.0	Normal (0)	-0.13 ± 0.28	Trivial (0/100/0)
PHF_{KE}	74.9 ± 9.5	Normal (30)	74.8 ± 9.7	Normal (30)	-0.01 ± 0.25	Trivial (0/100/0)
PHE	10.3 ± 5.3	Normal (2)	11.1 ± 5.7	Normal (5)	0.14 ± 0.25	Trivial (0/100/0)
$PHABD_{HF90°}$	71.0 ± 6.7	Normal (0)	69.9 ± 6.9	Normal (2)	-0.16 ± 0.25	Trivial (0/100/0)
PHABD	37.6 ± 2.9	Normal (0)	37.0 ± 2.6	Normal (0)	-0.20 ± 0.28	Trivial (0/100/0)
$PHAD_{HF90°}$	31.1 ± 4.2	Normal (11)	32.0 ± 4.2	Normal (5)	0.22 ± 0.28	Trivial (0/100/0)
PHIR	42.3 ± 7.2	Normal (2)	42.9 ± 7.2	Normal (0)	0.08 ± 0.28	Trivial (0/100/0)
PHER	57.8 ± 6.5	Normal (0)	56.5 ± 5.5	Normal (0)	-0.18 ± 0.28	Trivial (0/100/0)
PKF	121.3 ± 11.4	Normal (51)	121.6 ± 11.9	Normal (49)	0.03 ± 0.25	Trivial (0/100/0)
ADF_{KF}	36.7 ± 5.2	Normal (22)	36.4 ± 5.5	Normal (27)	-0.05 ± 0.28	Trivial (0/100/0)
ADF_{KE}	32.6 ± 5.0	Normal (0)	31.5 ± 5.3	Normal (0)	-0.22 ± 0.25	Trivial (0/100/0)

°: degrees; [a]: qualitative score of the mean range of motion, in parentheses the percentage of players with a restricted range of motion score according to previously published cut-off scores (see Statistical analysis section). [T]: mean ± 90% confidence limits; + or - indicates an increase or decrease from dominant limb to non-dominant limb. PHF_{KF}: passive hip flexion with the knee flexed; PHF_{KE}: passive hip flexion with the knee extended; PHE: passive hip extension; $PHABD_{HF90°}$: passive hip abduction at 90° of hip flexion; PHABD: passive hip abduction; $PHAD_{HF90°}$: passive hip adduction at 90° of hip flexion; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF_{KF}: ankle dorsiflexion with the knee flexed; ADF_{KE}: ankle dorsiflexion with the knee extended.

Appendix 15. Descriptive values and decision about side-to-side difference for the lower extremity joint ranges of motion by players' maturation-group (*N* = 237).

Ranges of motion (°)	**Dominant leg**		**Non-dominant leg**		**Standardised difference**[T]	**Qualitative outcome**[a]
	Mean ± SD	**Qualitative outcome**[a]	**Mean ± SD**	**Qualitative outcome**[a]		
Pre-PHV (*n* = 101)						
PHF_{KF}	136.1 ± 5.4	Normal (0)	136.0 ± 4.8	Normal (0)	-0.02 ± 0.21	Trivial (0/100/0)
PHF_{KE}	72.2 ± 7.7	Normal (33)	71.6 ± 7.1	Normal (34)	-0.07 ± 0.20	Trivial (0/100/0)
PHE	15.1 ± 5.6	Normal (1)	15.3 ± 5.1	Normal (2)	0.04 ± 0.20	Trivial (0/100/0)
$\text{PHABD}_{\text{HF90°}}$	72.7 ± 6.0	Normal (0)	72.6 ± 5.9	Normal (0)	-0.01 ± 0.20	Trivial (0/100/0)
PHABD	38.6 ± 3.0	Normal (0)	38.3 ± 3.5	Normal (0)	-0.10 ± 0.21	Trivial (0/100/0)
$\text{PHAD}_{\text{HF90°}}$	28.3 ± 4.0	Normal (21)	28.8 ± 3.8	Normal (12)	0.11 ± 0.21	Trivial (0/100/0)
PHIR	46.4 ± 6.1	Normal (0)	46.9 ± 6.2	Normal (0)	0.09 ± 0.21	Trivial (0/100/0)
PHER	58.7 ± 7.5	Normal (0)	57.9 ± 7.2	Normal (0)	-0.10 ± 0.21	Trivial (0/100/0)
PKF	129.5 ± 8.9	Normal (12)	129.5 ± 9.0	Normal (14)	0.00 ± 0.20	Trivial (0/100/0)
ADF_{KF}	37.4 ± 5.0	Normal (14)	36.9 ± 4.4	Normal (16)	-0.10 ± 0.21	Trivial (0/100/0)
ADF_{KE}	30.1 ± 4.9	Normal (0)	30.0 ± 4.6	Normal (0)	0.00 ± 0.20	Trivial (0/100/0)
Circa-PHV (*n* = 43)						
PHF_{KF}	131.5 ± 5.9	Normal (0)	130.2 ± 6.6	Normal (0)	-0.22 ± 0.35	Trivial (0/100/0)
PHF_{KE}	69.8 ± 6.2	Restricted (49)	69.1 ± 6.4	Restricted (51)	-0.11 ± 0.31	Trivial (0/100/0)
PHE	11.2 ± 6.0	Normal (2)	12.0 ± 6.0	Normal (0)	0.12 ± 0.31	Trivial (0/100/0)
$\text{PHABD}_{\text{HF90°}}$	69.6 ± 7.8	Normal (0)	68.9 ± 6.5	Normal (0)	-0.09 ± 0.31	Trivial (0/100/0)
PHABD	37.5 ± 2.9	Normal (0)	36.6 ± 2.1	Normal (0)	-0.30 ± 0.35	Trivial (0/100/0)
$\text{PHAD}_{\text{HF90°}}$	27.9 ± 3.9	Normal (19)	28.1 ± 4.0	Normal (19)	0.04 ± 0.35	Trivial (0/100/0)
PHIR	43.2 ± 6.4	Normal (0)	42.5 ± 7.3	Normal (2)	-0.10 ± 0.35	Trivial (0/100/0)
PHER	56.6 ± 8.5	Normal (0)	56.2 ± 8.5	Normal (0)	-0.05 ± 0.35	Trivial (0/100/0)
PKF	124.4 ± 11.1	Normal (28)	124.4 ± 10.2	Normal (28)	0.00 ± 0.31	Trivial (0/100/0)
ADF_{KF}	36.5 ± 5.3	Normal (19)	36.2 ± 5.8	Normal (30)	-0.05 ± 0.35	Trivial (0/100/0)
ADF_{KE}	30.7 ± 5.2	Normal (0)	30.0 ± 5.0	Normal (0)	-0.12 ± 0.31	Trivial (0/100/0)
Post-PHV (*n* = 93)						
PHF_{KF}	134.7 ± 7.0	Normal (0)	134.0 ± 6.7	Normal (0)	-0.10 ± 0.22	Trivial (0/100/0)
PHF_{KE}	73.6 ± 9.8	Normal (37)	73.6 ± 10.2	Normal (35)	0.00 ± 0.21	Trivial (0/100/0)
PHE	10.2 ± 5.1	Normal (1)	11.1 ± 5.4	Normal (3)	0.16 ± 0.21	Trivial (0/100/0)
$\text{PHABD}_{\text{HF90°}}$	71.0 ± 6.9	Normal (0)	69.8 ± 6.5	Normal (1)	-0.18 ± 0.21	Trivial (0/100/0)
PHABD	37.4 ± 3.4	Normal (0)	36.8 ± 2.8	Normal (0)	-0.15 ± 0.22	Trivial (0/100/0)
$\text{PHAD}_{\text{HF90°}}$	29.8 ± 4.3	Normal (15)	30.7 ± 4.0	Normal (9)	0.21 ± 0.22	Trivial (0/100/0)
PHIR	42.5 ± 7.0	Normal (2)	42.4 ± 7.3	Normal (1)	-0.01 ± 0.22	Trivial (0/100/0)
PHER	57.6 ± 7.8	Normal (0)	57.3 ± 7.3	Normal (0)	-0.04 ± 0.22	Trivial (0/100/0)
PKF	120.9 ± 11.5	Normal (52)	121.1 ± 11.3	Normal (49)	0.02 ± 0.21	Trivial (0/100/0)
ADF_{KF}	36.4 ± 5.1	Normal (23)	36.3 ± 5.5	Normal (26)	-0.04 ± 0.22	Trivial (0/100/0)
ADF_{KE}	31.6 ± 4.8	Normal (0)	30.9 ± 4.8	Normal (0)	-0.14 ± 0.21	Trivial (0/100/0)

°: degrees; [a]: qualitative score of the mean range of motion, in parentheses the percentage of players with a restricted ROM. [T]: mean ± 90% confidence limits; + or - indicates an increase or decrease from dominant to non-dominant limb. PHF_{KF}: passive hip flexion with the knee flexed; PHF_{KE}: passive hip flexion with the knee extended; PHE: passive hip extension; $\text{PHABD}_{\text{HF90°}}$: passive hip abduction at 90° of hip flexion; PHABD: passive hip abduction; $\text{PHAD}_{\text{HF90°}}$: passive hip adduction at 90° of hip flexion; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF_{KF}: ankle dorsiflexion with the knee flexed; ADF_{KE}: ankle dorsiflexion with the knee extended.

6

RELIABILITY, VALIDITY, AND MATURATION-RELATED DIFFERENCES OF FRONTAL AND SAGITTAL PLANE LANDING KINEMATIC MEASURES IN DROP JUMP AND TUCK JUMP SCREENING TESTS

[STUDY 4]

6.1 Introduction

Young team sport players are at risk of knee and ankle injuries [8,264]. Neuromuscular control has been associated with this increased risk [57,84], and screening may be useful to identify players with altered movement patterns [265]. Most studies analysing landing technique have mainly focused on frontal plane kinematic measures [101]. Knee medial displacement (dynamic valgus) has shown to increase the magnitude of loads experienced by medial collateral (MCL) and anterior cruciate ligaments (ACL), and hence predispose knee injuries [91,92]. Higher valgus angles have been displayed by younger male football players in periods prior to and around the PHV compared to older youths [88,126], demonstrating an interaction effect between landing mechanics and maturation. Furthermore, it has been suggested that the appearance of dynamic knee valgus might be influenced by deficits in sagittal plane motions [101,102]. Reduced hip, knee and ankle flexion patterns may contribute to knee valgus as a compensatory strategy that modulates the greater ground reaction forces derived from a stiffer landing posture [101,102,266].

To investigate the kinematics of landing tasks, a broad range of tests have been used in previous literature and the drop vertical jump (DVJ) has been a popular test choice [96]. The assessment of landing kinematic measures from a cost-effectiveness approach (through 2-dimensional video cameras) in DVJ tasks has shown to be reliable (intra- and inter-rater intra-class correlation coefficients [ICC] > 0.89)[125,267], providing a suitable field-based test for kinematic screening into clinical practice. However, while a number of studies have found some relationships between DVJ biomechanics and the risk of sustaining knee injuries (e.g., ACL)[90,97], other investigations have failed in making these associations [268,269]. These inconsistent results together with the questionable external validity of a test which entails a drop from a standard height [126,270] have led to the emergence of new protocols with performances closer to the competitive practice.

Myer et al. [98] proposed the tuck jump assessment (TJA). This test consists of repeated tuck jumps during a 10-second period while a rater visually grades jumping and landing mechanics. The TJA may offer clinical advantages over the DVJ test: for instance, in this protocol the participant starts and stops from ground level instead of dropping from a box, better representing techniques encountered in sport [270]. In the original protocol movement mechanics were qualitatively rated using a 10-item scoring sheet [98]. More recently, quantitative assessment of important kinematic markers during the TJA, such as dynamic valgus (through frontal plane projection angles [FPPA]), has increased [88,126,271]. While some reliability data has been reported for kinematic assessment of FPPA [88,126], more research is needed to determine the reliability of kinematic assessments beyond just the knee from both a frontal and sagittal plane.

Previous research comparing unilateral and bilateral tasks have demonstrated a task-dependent nature of landing from a jump [101,127–129] and, then, a variety of assessments have been suggested when analysing kinematic measures in youth athletes [43]. However, the restricted testing time and human resources in applied settings may require coaches to prioritise between screening tools. The knowledge of potential relationships between DVJ and TJA tests, as well as their interaction with maturity status, may assist coaches' decision making to select the most informative jumping and landing assessment in youth football. To date, only a recent study [126] has compared frontal kinematic measures in both tests and across different stages of maturation, showing greater knee medial displacement values for TJA and superior sensitivity to detect differences based on maturation. No previous research (from the authors' knowledge) has provided this information for sagittal plane measures.

Therefore, the purposes of this study were: (1) to determine the inter-rater and intra-rater reliability of frontal (frontal plane projection angle) and sagittal (hip, knee and ankle flexion angles at initial contact and peak flexion) plane landing kinematic measures during DVJ and TJA tasks in male youth football players; (2) to assess the concurrent validity between DVJ and TJA tests for all landing kinematic measures; and (3) to evaluate the ability of both jumping tasks to detect differences between players' stage of maturation (pre-PHV, circa-PHV, and post-PHV).

6.2 Methods

6.2.1 Design

A cross-sectional observational design was used to analyse the reliability, validity, and maturation-related differences of several frontal and sagittal plane landing kinematic measures during DVJ and TJA among young male football players (Figure 20). This study was conducted during the preseason period (September) of the years 2017 and 2018.

The testing sessions conducted in each football team were divided into 2 different parts within a single testing session. The first part of each testing session was used to record the anthropometric measures needed to calculate the stage of maturation of the subjects. The second part was designed to collect data for the DVJ and TJA tests. A 20-minute standardised dynamic warm-up [244] was performed before the DVJ and TJA data collection. All the kinematic variables were retrospectively extracted through 2-D video-analysis.

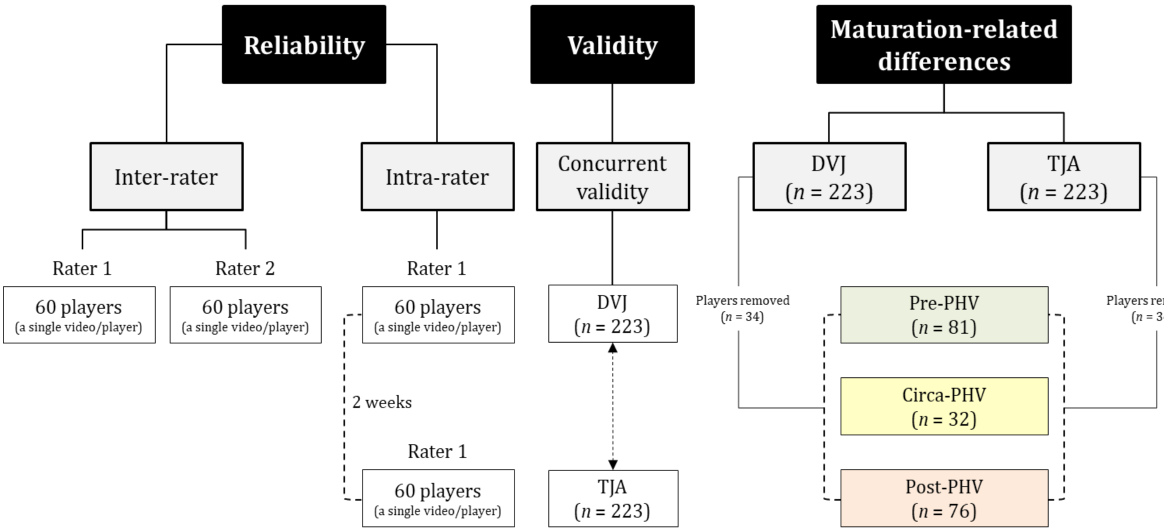


Figure 20. Study design.

6.2.2 Participants

A convenience sample of 223 male youth football players from five Spanish football clubs completed this study (descriptive statistics are displayed in Table 12). Participants met the following inclusion/exclusion criteria: 1) engaged regularly in football training and competitions (at least 2-3 training sessions and 1 match per week), and 2) were free of injuries and delayed onset muscle soreness (DOMS) at the time of testing (self-reported). Participants were asked to refrain from vigorous exercise at least 48 hours prior to the testing session. The experimental procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the Ethics and Scientific Committee of the University of Murcia (Spain) (ID:

1551/2017), and written informed consent and assent was obtained from parents and participants.

Table 12. Descriptive anthropometric values (mean ± standard deviation) for all the participants and per maturation sub-group.

Group	***N***	**Age (years)**	**Body mass (kg)**	**Stature (cm)**	**Leg length (cm)**	**Maturity offset**
Pre-PHV	81	11.5 ± 1.0	40.7 ± 7.3	149.8 ± 7.3	74.3 ± 4.9	-2.2 ± 0.7
Circa-PHV	32	13.8 ± 0.6	57.1 ± 6.9	167.6 ± 5.2	83.1 ± 5.0	-0.1 ± 0.3
Post-PHV	76	16.7 ± 1.1	67.9 ± 8.6	177.4 ± 6.7	86.6 ± 5.4	2.3 ± 0.8
Whole group	223	14.0 ± 2.4	54.2 ± 13.9	163.9 ± 13.5	80.8 ± 7.3	-0.1 ± 2.0

PHV: peak height velocity.

6.2.3 Procedures

6.2.3.1 Anthropometry and maturity status

Body mass in kilograms was measured on a calibrated physician scale (SECA 799, Hamburg, Germany). Standing and sitting heights in centimeters were recorded on a measurement platform (SECA 799, Hamburg, Germany). Stage of maturation was calculated in a noninvasive manner using the regression equation proposed by Mirwald et al. [221] (Equation 1). This equation has been used to predict maturation status with a standard error of approximately 6 months in pediatric population [221]. To account for the reported error, players were grouped into discrete bands based on their maturational offset (pre-PHV [<-1], circa-PHV [-0.5 to 0.5], post-PHV [>1]), and players with a maturity offset from -1 to -0.5 and 0.5 to 1 were removed from the dataset when players were analysed by stage of maturation.

> *- 9.236 + [0.0002708*leg length and sitting-height interaction] – [0.001663*age and leg-length interaction] + [0.007216*age and sitting-height interaction] + [0.02292*weight by height ratio*100]* [equation 1]

6.2.3.2 Drop vertical jump (DVJ)

A drop vertical jump without arm swing was performed following the procedures previously described by Onate et al. [272]. Participants stood with feet shoulder-width apart on a 40 cm high box. They were instructed to lean forward and drop from the box. Players were required to land with both feet simultaneously on a contact mat (Ergo Jump Bosco System, Italia) that was located 20 cm in front of the box, then immediately perform a maximal vertical jump minimising ground contact time, and finally land back on the contact mat. After three familiarisation repetitions, each player performed two maximal jumps with at least 1 min of recovery between jumps.

6.2.3.3 Tuck jump assessment (TJA)

Tuck jumps were performed in place for a period of 10 consecutive seconds. Players were instructed to start with a countermovement and follow with repeated vertical jumps as high as possible while simultaneously pulling their knees up towards their chest [98]. Players were asked for landing in the same footprint, minimising ground contact time. After three consecutive repetitions to become familiar with the test, a single trial of the TJA was performed by each player.

6.2.3.4 Landing kinematic analysis

Two-dimensional video cameras (Panasonic Lumix DMC-FZ200, Japan) were positioned in both frontal and sagittal planes at a height of 0.70 m and a distance of 5 m from the landing area to capture the tests and, retrospectively, players' landing technique was assessed through a free available software (Kinovea 0.8.15, USA). For each video, knee displacement (valgus vs. varus alignment) in the frontal plane, and hip, knee and ankle flexion angles at initial contact and peak flexion in the sagittal plane were calculated. All kinematic data were recorded at 100 fps using a high-definition resolution.

Knee displacement was assessed for both the dominant (i.e., players' preferred kicking leg) and non-dominant legs by measuring the frontal plane projection angle (FPPA). FPPA was measured as the angle created by lines drawn between the hip (anterior superior iliac spine [ASIS]), knee (mid-patella), and ankle (midpoint between both medial and lateral malleoli) joint centers at the point of peak maximum knee flexion [88,267]. Peak knee flexion was defined as the one frame before the subject started to increase knee extension in order to perform the maximum vertical jump [88,267]. FPPA was calculated for each DVJ and each ground contact during the TJA. The mean FPPA values for the DVJ trials, and the mean of the two maximum valgus scores for the TJA were used for the analysis. Values <180° were indicative of knee valgus, whereas values ≥180° denoted knee varus alignment.

Hip, knee and ankle flexion angles at initial contact and peak flexion were assessed for the dominant leg, based on the methodology described in previous studies [101,273]. Initial contact (IC) was determined as the first video frame in which ground contact was observed, and peak flexion (PF) was defined as the deepest landing position (i.e., where no movement occurred at the hip, knee and ankle) [101]. Hip flexion (HF) angle was measured as the angle formed by a straight line joining the medial part of the thigh originating in the lateral femoral epicondyle and the straight line joining the estimated hip rotation axis with the projection of the spine in neutral position. Knee flexion (KF) angle was considered the angle formed by the straight lines of the thigh, as described above, and leg segments, joining the lateral femoral epicondyle and the lateral malleolus. Ankle (dorsi)flexion (ADF) angle was described as the angle formed by this straight line of the shank and the tip of the foot. All the sagittal variables were measured for each DVJ and each ground contact during the TJA. The mean values for the DVJ trials, and the mean values of the two worst (maximum valgus) repetitions for the TJA were used for the subsequent analysis. Greater angles were indicative of decreased flexion during landing (stiffer landing pattern), whereas lower angle values represented increased flexion landing pattern.

6.2.4 Statistical analysis

The distribution of raw data sets was checked using the Kolmogorov–Smirnov test and demonstrated that all data had a normal distribution ($p > 0.05$). Descriptive statistics including means and standard deviations (SDs) were calculated for all measures.

6.2.4.1 Reliability

The inter- and intra-rater reliability for frontal and sagittal measures were assessed on a randomly selected sub-section ($n = 60$) of the sample included in the current study. Two sport scientists (FJR-P and IR-P) with more than 5 years of experience in landing kinematic analysis evaluated 60 videos in a randomised order to determine the inter-rater reliability. For intra-rater reliability, a single rater (FJR-P) assessed the same 60 videos on two occasions separated by a two-week interval to determine the repeatability of the measure.

A two-way random intra-class correlation coefficient ($ICC_{2,1}$) with absolute agreement was used to analyse both inter- and intra-rater reliability. Magnitudes of ICC were classified according to the following thresholds: <0.5, poor reliability; 0.5 to 0.74, moderate reliability; 0.75 to 0.9, good reliability; and >0.9, excellent reliability [274]. The precision of measurement was also determined using the standardised typical error of measurement, the typical percentage error and the minimal detectable change at a 95% confidence interval (CI) using the Hopkins' spreadsheet [275]. The standardised typical error of measurement (TEM_{ST}) was calculated dividing the typical error of measurement (TEM [$SD_{diff}/\sqrt{2}$]) by the mean SD for the measurements included in the analysis. The typical percentage error (coefficient of variation [CV_{TE}]) was calculated using the log-transformed data via the following formula: 100 ($e^{S} - 1$), where s is the typical error of measurement. Finally, the minimal detectable change at a 95% CI (MDC_{95}) was calculated as follow: TEM × 1.96 × $\sqrt{2}$. As previously suggested [276], half of the thresholds of the modified Cohen scale and the arbitrary value (10%) proposed by Weir & Vincent [277] were used to interpret the TEM_{ST} and the CV_{TE}, respectively. Thus, the TEM_{ST} was interpreted using the following scale: <0.1, trivial; 0.1-0.3, small; 0.3-0.6, moderate; 0.6-1.0, large; 1.0-2.0, very large; >2.0, extremely large [275]. A value of 5% or below was used to interpret the CV_{TE}.

6.2.4.2 Validity

To compare values obtained from the TJA with those from the DVJ, the Pearson's product-moment correlation coefficient with a 95% CI and the standardised typical error of estimate (TEE_{ST}), together with an estimation equation generated by plotting and after fitting a straight line to DVJ data against TJA data (y = slope · X + intercept), were calculated. The TEE_{ST} was calculated as the mean typical error of the difference between the DVJ and TJA data reported by the players divided by the SD of the criterion (DVJ) test. Magnitudes of Pearson (r) correlation coefficients were assessed using the following scale: <0.80 low, 0.80 to 0.90 moderate, and >0.90 high [256], while the TEE_{ST} was interpreted using the same scale as the TEM_{ST}.

To examine possible differences between DVJ and TJA mean values for each kinematic measure, a Bayesian paired samples t-test was also used. In these comparisons, the quantification of the relative degree of evidence for supporting the null hypothesis (H_0 = no significant differences between tests) or alternative hypothesis (H_1 = significant differences between tests) was performed through the Bayesian factor (BF_{10}) [278]. The BF_{10} was interpreted using the evidence categories suggested by Lee & Wagenmakers [279]: < 1/100 = extreme evidence for H_0, from 1/100 to 1/30 = very strong evidence for H_0, from 1/30 to 1/10 = strong evidence for H_0, from 1/10 to 1/3 = moderate evidence for H_0, from 1/3 to 1 anecdotal evidence for H_0, from 1 to 3 = anecdotal evidence for H_1, from 3 to 10 = moderate evidence for H_1, from 10 to 30 = strong evidence for H_1, from 30 to 100 = very strong evidence for H_1, > 100 extreme evidence for H_1. The median and the 95% central credible interval of the posterior distribution of the standardised effect size (δ) (i.e., the population version of Cohen's d) were also calculated for each of the paired-comparisons carried out. Magnitudes of the posterior distribution of the standardised effect size were classified as: trivial (< 0.2), small (0.2 – 0.6), moderate (0.6 – 1.2), large (1.2 – 2.0) and very large (2.0 – 4.0) [253]. Only those comparisons that showed at least a strong evidence for supporting the alternative hypothesis (BF_{10} > 10), an error percentage < 10 (which indicates great stability of the numerical algorithm that was used to obtain the result) and δ > 0.6 (at least moderate) were considered robust to describe significant differences.

6.2.4.3 Maturation-related differences

A Bayesian analysis of variance (ANOVA) was conducted to examine whether there were significant differences among stages of maturation (pre-PHV vs. circa-PHV vs. post-PHV) for each frontal and sagittal plane measure in DVJ and TJA tests. In the post hoc analysis, posterior odds were corrected for multiple testing by fixing to 0.5 the prior probability that the null hypothesis holds across all comparisons [280]. In these comparisons, the quantification of the relative degree of evidence for supporting the null hypothesis (H_0 = no significant differences between maturation groups) or alternative hypothesis (H_1 = significant differences between maturation groups) was performed through the Bayesian factor (BF_{10}) [278]. The BF_{10} was interpreted using the evidence categories suggested by Lee & Wagenmakers [279] as before. Likewise, only those comparisons that reported strong evidence ($BF_{10} > 10$; error < 10; $\delta > 0.6$) for supporting alternative hypothesis were considered robust to describe significant differences between maturation groups.

All statistical analyses were performed using the JASP computer software (version 0.13.1), the Statistical Package for Social Science (IBM Corp.; IBM SPSS Statistics for Windows, version 20.0, Armonk, NY, USA), and an online spreadsheet (www.sportsci.org).

6.3 Results

6.3.1 Reliability of the landing kinematic measures

Table 13 shows inter-rater reliability data for all frontal and sagittal plane variables in DVJ and TJA tests. Most of the measures selected to assess the landing kinematic pattern within this study evidenced good-to-excellent reliability when analysed by two different testers (ICC = 0.87-0.97; TEM_{ST} = 0.2-0.3; CV_{TE} = 1.0-2.5), except for the ADF which showed weaker reliability values with moderate (ADF-IC in both DVJ and TJA, and ADF-PF in TJA) to poor (ADF-PF in DVJ) ICCs and moderate standardised typical errors of measurement.

All the frontal and sagittal plane measures demonstrated good-to-excellent intra-rater reliability (ICC = 0.79-0.99; CV_{TE} = 0.6-2.7) (Table 14). Regarding the MDC_{95}, scores ranged from 3.8 to 5.7° and from 2.9 to 8.7° for all DVJ and TJA kinematic variables, respectively. Although adequate ICC and CV_{TE} values were found for the ADF-IC and ADF-PF measures, these angles presented again slightly greater standardised typical errors of measurement (ADF-IC = 0.4 for TJA; ADF-PF ~ 0.4 for DVJ and TJA) compared to the rest of variables.

Table 13. Inter-rater reliability for frontal and sagittal plane measures.

Measurement (°)	**Rater 1**	**Rater 2**	**ChM**	**TEM_{ST}**	**CV_{TE}**	**$\text{ICC}_{2,1}$ (95% CI)**
DVJ						
FPPA-D	179.2 ± 9.9	181.6 ± 10.7	2.3 ± 3.6	0.25	1.41	0.92 (0.77 – 0.96)
FPPA-ND	183.7 ± 12.5	184.4 ± 13.2	0.7 ± 3.4	0.19	1.34	0.96 (0.94 – 0.98)
HF-IC	139.8 ± 9.5	140.9 ± 10.0	1.2 ± 3.7	0.27	1.95	0.92 (0.87 – 0.95)
KF-IC	147.7 ± 6.4	147.2 ± 6.0	-0.5 ± 3,2	0.36	1.55	0.87 (0.79 – 0.92)
ADF-IC	116.7 ± 11.0	124.7 ± 13.8	6.0 ± 7.9	0.34	3.74	0.74 (0.00 – 0.91)
HF-PF	110.9 ± 17.0	111.6 ± 17.3	0.7 ± 3.9	0.16	2.50	0.97 (0.96 – 0.98)
KF-PF	98.8 ± 9.3	100.7 ± 8.0	1.9 ± 3.0	0.24	2.25	0.92 (0.78 – 0.96)
ADF-PF	77.6 ± 4.8	85.0 ± 4.9	7.3 ± 3.9	0.57	3.54	0.32 (-0.09 – 0.67)
TJA						
FPPA-D	179.1 ± 10.4	178.9 ± 11.5	-0.2 ± 2.9	0.19	1.18	0.97 (0.94 – 0.98)
FPPA-ND	181.1 ± 10.3	179.8 ± 10.9	-1.4 ± 2.6	0.17	1.02	0.96 (0.91 – 0.98)
HF-IC	147.4 ± 11.8	146.8 ± 12.3	-0.7 ± 4.8	0.28	2.38	0.92 (0.87 – 0.95)
KF-IC	144.9 ± 8.1	144.0 ± 7.7	-0.9 ± 3.1	0.28	1.56	0.92 (0.86 – 0.95)
ADF-IC	120.4 ± 7.6	123.5 ± 7.5	3.1 ± 6.1	0.57	3.62	0.62 (0.38 – 0.78)
HF-PF	142.5 ± 12.9	141.0 ± 12.8	-1.5 ± 3.7	0.21	1.87	0.95 (0.91 – 0.97)
KF-PF	120.2 ± 11.0	119.8 ± 10.8	-0.5 ± 3.0	0.20	1.79	0.96 (0.94 – 0.98)
ADF-PF	79.3 ± 5.1	80.2 ± 5.4	0.9 ± 3.9	0.53	3.56	0.71 (0.56 – 0.82)

°: degrees; ChM: change in the mean; TEM_{ST}; standardised typical error of measurement; CV_{TE}: coefficient of variation expressed as percentage values; ICC: intraclass correlation coefficients; CI: confidence interval; DVJ: drop vertical jump; TJA: tuck jump assessment; FPPA: frontal plane projection angle; HF: hip flexion; KF: knee flexion; ADF: ankle dorsiflexion; D: dominant; ND: non-dominant; IC: initial contact; PF: peak flexion.

Table 14. Intra-rater reliability for frontal and sagittal plane measures.

Measurement (°)	**Assessment 1**	**Assessment 2**	**ChM**	**TEM_{ST}**	**CV_{TE}**	**MDC_{95}**	**$\text{ICC}_{2,1}$ (95% CI)**
			DVJ				
FPPA-D	179.2 ± 9.9	180.5 ± 10.1	1.3 ± 1.9	0.14	0.76	3.77	0.97 (0.92 – 0.99)
FPPA-ND	183.7 ± 12.5	185.1 ± 12.8	1.4 ± 2.1	0.12	0.80	4.16	0.98 (0.94 – 0.99)
HF-IC	139.8 ± 9.5	141.2 ± 10.0	1.5 ± 2.6	0.19	1.35	5.18	0.95 (0.89 – 0.98)
KF-IC	147.7 ± 6.4	149.1 ± 6.5	1.4 ± 2.6	0.28	1.25	5.07	0.90 (0.77 – 0.95)
ADF-IC	116.7 ± 11.0	117.5 ± 11.0	0.8 ± 3.4	0.22	2.18	6.74	0.95 (0.92 – 0.97)
HF-PF	110.9 ± 17.0	111.7 ± 17.4	0.8 ± 2.6	0.11	1.67	5.16	0.99 (0.98 – 0.99)
KF-PF	98.8 ± 9.3	100.5 ± 8.9	1.7 ± 2.2	0.17	1.64	4.38	0.95 (0.83 – 0.98)
ADF-PF	77.6 ± 4.8	78.1 ± 4.0	0.4 ± 2.9	0.46	2.70	5.68	0.79 (0.67 – 0.87)
			TJA				
FPPA-D	179.1 ± 10.4	179.2 ± 10.7	0.1 ± 1.6	0.11	0.66	3.24	0.99 (0.98 – 0.99)
FPPA-ND	181.1 ± 10.3	181.3 ± 10.3	0.1 ± 1.5	0.10	0.58	2.91	0.99 (0.98 – 0.99)
HF-IC	147.4 ± 11.8	148.6 ± 11.8	1.2 ± 2.1	0.12	0.99	4.05	0.98 (0.95 – 0.99)
KF-IC	144.9 ± 8.1	145.0 ± 7.7	0.1 ± 1.8	0.16	0.89	3.52	0.97 (0.96 – 0.99)
ADF-IC	120.4 ± 7.6	119.8 ± 7.9	-0.6 ± 4.4	0.41	2.74	8.70	0.83 (0.74 – 0.90)
HF-PF	142.5 ± 12.9	143.9 ± 13.4	1.4 ± 2.2	0.12	1.11	4.27	0.98 (0.94 – 0.99)
KF-PF	120.2 ± 11.0	120.6 ± 11.4	0.4 ± 1.7	0.11	1.07	3.38	0.99 (0.98 – 0.99)
ADF-PF	79.3 ± 5.1	78.9 ± 5.6	-0.4 ± 2.8	0.37	2.52	5.49	0.87 (0.78 – 0.92)

°: degrees; ChM: change in the mean; TEM_{ST}; standardised typical error of measurement; CV_{TE}: coefficient of variation expressed as percentage values; MDC_{95}: minimal detectable change 95%; ICC: intraclass correlation coefficients; CI: confidence interval; DVJ: drop vertical jump; TJA: tuck jump assessment; FPPA: frontal plane projection angle; HF: hip flexion; KF: knee flexion; ADF: ankle dorsiflexion; D: dominant; ND: non-dominant; IC: initial contact; PF: peak flexion.

6.3.2 Concurrent validity between the DVJ and TJA kinematic measures

Table 15 displays concurrent validity between the DVJ and TJA tests. Results revealed poor validity scores, showing low correlation (all r values < 0.56) and very-to-extremely large standardised typical errors of estimate (all TEE_{ST} values > 1.49) between both jumping tasks for all frontal and sagittal variables measured and maturation groups. The estimation equations obtained from plotting DVJ against TJA data are available at Appendix 16.

The Bayesian t-test reported strong evidence ($BF_{10} > 10$; error % < 10; $\delta > 0.6$) for supporting the alternative hypothesis (H_1 = the presence of differences between DVJ and TJA test) for FPPA (dominant and non-dominant) and KF-IC, KF-PF and HF-PF values in the whole group. When categorising by stage of maturation, these significant differences were maintained for FPPA, HF-PF and KF-PF across all groups.

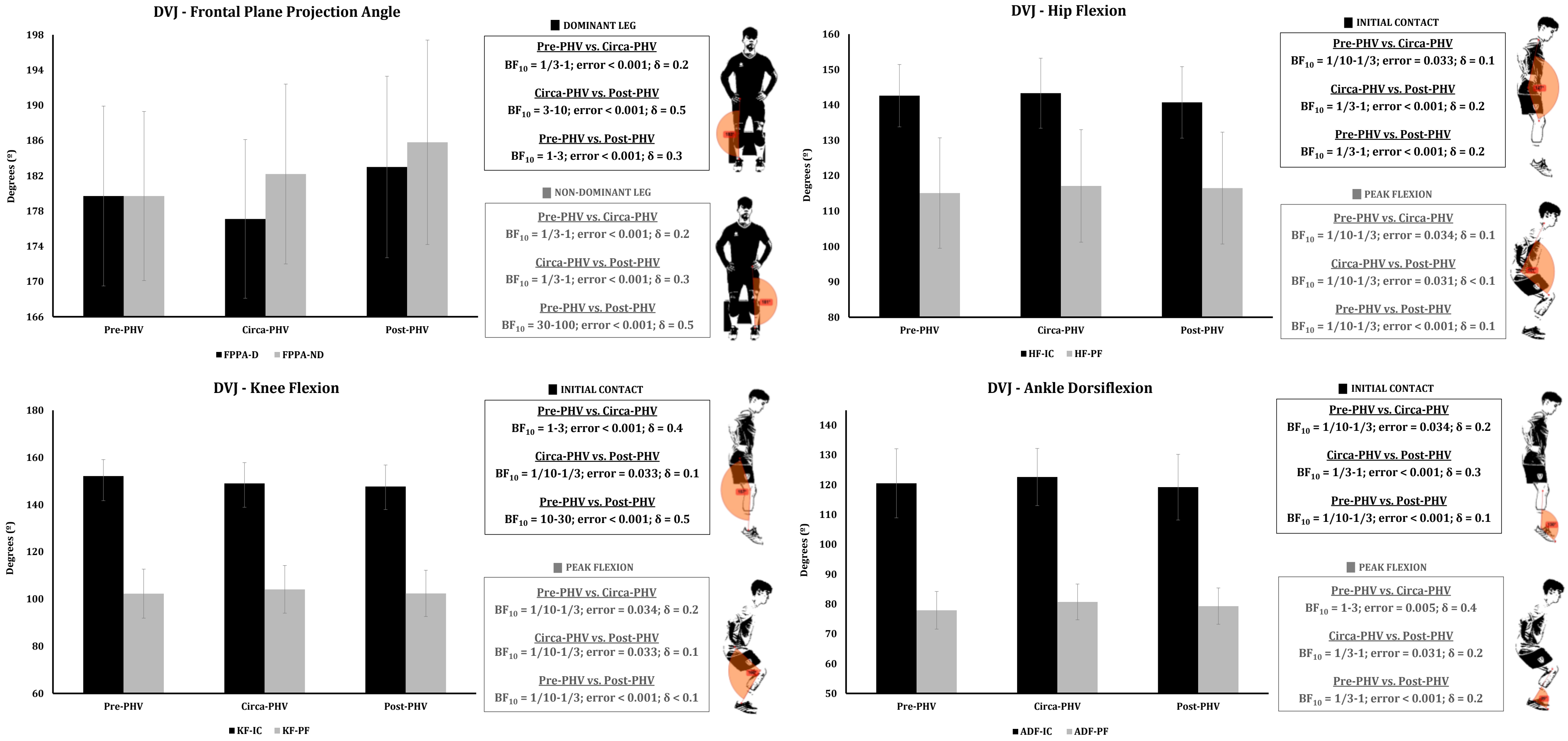
6.3.3 Maturation-related differences on landing kinematic measures by jumping task

The Bayesian ANOVA did not show strong evidence ($BF_{10} > 10$; error % < 10; $\delta > 0.6$) for supporting the alternative hypothesis (H_1 = the presence of differences between stages of maturation) for any frontal and sagittal measure of the DVJ (Figure 21). By contrast, strong evidence for supporting H_1 in the TJA was found. Pairwise comparisons showed significant higher knee valgus (lower FPPA values) in dominant and non-dominant legs ($BF_{10} > 100$ [extreme evidence in favour of H_1]; error < 0.001; $\delta = 0.6$-0.8), and greater hip (at initial contact and peak flexion), knee (at initial contact), and ankle (at initial contact) flexion (lower angle values) in the sagittal plane for pre-PHV compared to post-PHV maturation group ($BF_{10} > 30$ [very strong evidence in favour of H_1]; error < 0.001; $\delta = 0.6$-1.2). Pre-PHV group also displayed greater hip and knee flexion at the time of initial contact than circa-PHV group ($BF_{10} > 30$ [very strong evidence in favour of H_1]; error < 0.001; $\delta = 0.6$-0.9) (Figure 22).

Table 15. Validity for the DVJ vs. TJA frontal and sagittal plane measures.

Measurement (°)	**DVJ**	**TJA**	**TEE_{ST}**	**Pearson *r* (95% CI)**
Whole group				
FPPA-D	180.9 ± 10.1	170.3 ± 8.7*	1.99	0.45 (0.36 – 0.53)
FPPA-ND	182.8 ± 10.5	170.9 ± 8.1*	1.82	0.48 (0.39 – 0.56)
HF-IC	141.8 ± 9.6	145.6 ± 13.7	13.27	-0.08 (-0.19 – 0.04)
KF-IC	149.9 ± 8.4	141.1 ± 7.5*	9.37	-0.11 (-0.22 – 0.01)
ADF-IC	120.3 ± 10.9	118.0 ± 8.3	41.59	0.02 (-0.09 – 0.14)
HF-PF	115.6 ± 16.1	145.6 ± 11.7*	4.66	0.21 (0.10 – 0.31)
KF-PF	102.5 ± 10.2	123.9 ± 9.7*	4.47	0.22 (0.11 – 0.32)
ADF-PF	79.1 ± 6.2	79.5 ± 5.7	4.96	0.20 (0.09 – 0.30)
Pre-PHV				
FPPA-D	179.7 ± 10.2	167.8 ± 8.3*	2.38	0.39 (0.22 – 0.53)
FPPA-ND	179.7 ± 9.6	167.3 ± 7.5*	2.41	0.38 (0.21 – 0.53)
HF-IC	142.6 ± 8.8	137.4 ± 13.2	31.00	0.03 (-0.15 – 0.22)
KF-IC	152.1 ± 7.0	137.8 ± 7.3*	17.61	0.06 (-0.13 – 0.24)
ADF-IC	120.5 ± 11.6	115.9 ± 8.6	18.96	-0.05 (-0.24 – 0.13)
HF-PF	115.1 ± 15.6	141.1 ± 12.9*	4.67	0.21 (0.03 – 0.38)
KF-PF	102.3 ± 10.4	122.5 ± 10.3*	3.18	0.30 (0.12 – 0.46)
ADF-PF	77.9 ± 6.3	78.9 ± 6.1	2.95	0.32 (0.14 – 0.48)
Circa-PHV				
FPPA-D	177.1 ± 9.0	168.7 ± 5.9*	1.73	0.50 (0.24 – 0.69)
FPPA-ND	182.2 ± 10.2	170.8 ± 7.2*	2.11	0.43 (0.15 – 0.64)
HF-IC	143.3 ± 9.9	150.1 ± 12.4	10.76	0.09 (-0.21 – 0.38)
KF-IC	149.0 ± 8.8	143.4 ± 8.2	22.67	0.04 (-0.26 – 0.34)
ADF-IC	122.6 ± 9.6	116.3 ± 7.5	3.59	0.27 (-0.04 – 0.53)
HF-PF	117.1 ± 15.9	146.6 ± 9.3*	8.06	0.12 (-0.18 – 0.41)
KF-PF	104.1 ± 10.1	123.0 ± 8.5*	8.96	0.11 (-0.20 – 0.40)
ADF-PF	80.7 ± 6.0	78.9 ± 5.9	4.60	0.21 (-0.09 – 0.48)
Post-PHV				
FPPA-D	183.0 ± 10.3	173.1 ± 8.9*	1.66	0.52 (0.36 – 0.64)
FPPA-ND	185.8 ± 11.6	174.0 ± 8.0*	1.49	0.56 (0.41 – 0.68)
HF-IC	140.7 ± 10.1	152.9± 10.4*	6.92	-0.14 (-0.33 – 0.05)
KF-IC	147.7 ± 9.1	143.4 ± 6.3	6.72	-0.15 (-0.33 – 0.05)
ADF-IC	119.2 ± 11.0	120.6 ± 8.1	17.38	0.06 (-0.14 – 0.25)
HF-PF	116.5 ± 15.8	150.6 ± 8.9*	4.16	0.23 (0.04 – 0.41)
KF-PF	102.4 ± 9.8	126.0 ± 9.3*	4.43	0.22 (0.03 – 0.39)
ADF-PF	79.3 ± 6.1	80.1 ± 5.1	5.74	0.17 (-0.02 – 0.35)

°: degrees; *: Significant differences compared to the DVJ values ($BF_{10} > 10$; error % < 10; $\delta > 0.6$); TEE_{ST}; typical error of estimate; CI: confidence interval.



■ DOMINANT LEG

Pre-PHV vs. Circa-PHV
BF_{10} = 1/3-1; error < 0.001; δ = 0.2

Circa-PHV vs. Post-PHV
BF_{10} = 3-10; error < 0.001; δ = 0.5

Pre-PHV vs. Post-PHV
BF_{10} = 1-3; error < 0.001; δ = 0.3

■ NON-DOMINANT LEG

Pre-PHV vs. Circa-PHV
BF_{10} = 1/3-1; error < 0.001; δ = 0.2

Circa-PHV vs. Post-PHV
BF_{10} = 1/3-1; error < 0.001; δ = 0.3

Pre-PHV vs. Post-PHV
BF_{10} = 30-100; error < 0.001; δ = 0.5

■ INITIAL CONTACT

Pre-PHV vs. Circa-PHV
BF_{10} = 1/10-1/3; error = 0.033; δ = 0.1

Circa-PHV vs. Post-PHV
BF_{10} = 1/3-1; error < 0.001; δ = 0.2

Pre-PHV vs. Post-PHV
BF_{10} = 1/3-1; error < 0.001; δ = 0.2

■ PEAK FLEXION

Pre-PHV vs. Circa-PHV
BF_{10} = 1/10-1/3; error = 0.034; δ = 0.1

Circa-PHV vs. Post-PHV
BF_{10} = 1/10-1/3; error = 0.031; δ < 0.1

Pre-PHV vs. Post-PHV
BF_{10} = 1/10-1/3; error < 0.001; δ = 0.1

■ INITIAL CONTACT

Pre-PHV vs. Circa-PHV
BF_{10} = 1-3; error < 0.001; δ = 0.4

Circa-PHV vs. Post-PHV
BF_{10} = 1/10-1/3; error = 0.033; δ = 0.1

Pre-PHV vs. Post-PHV
BF_{10} = 10-30; error < 0.001; δ = 0.5

■ PEAK FLEXION

Pre-PHV vs. Circa-PHV
BF_{10} = 1/10-1/3; error = 0.034; δ = 0.2

Circa-PHV vs. Post-PHV
BF_{10} = 1/10-1/3; error = 0.033; δ = 0.1

Pre-PHV vs. Post-PHV
BF_{10} = 1/10-1/3; error < 0.001; δ < 0.1

■ INITIAL CONTACT

Pre-PHV vs. Circa-PHV
BF_{10} = 1/10-1/3; error = 0.034; δ = 0.2

Circa-PHV vs. Post-PHV
BF_{10} = 1/3-1; error < 0.001; δ = 0.3

Pre-PHV vs. Post-PHV
BF_{10} = 1/10-1/3; error < 0.001; δ = 0.1

■ PEAK FLEXION

Pre-PHV vs. Circa-PHV
BF_{10} = 1-3; error = 0.005; δ = 0.4

Circa-PHV vs. Post-PHV
BF_{10} = 1/3-1; error = 0.031; δ = 0.2

Pre-PHV vs. Post-PHV
BF_{10} = 1/3-1; error < 0.001; δ = 0.2

Figure 21. Maturation-related differences for all frontal and sagittal plane measures in the DVJ test. *: $BF_{10} > 10$; error % < 10; $\delta > 0.6$.

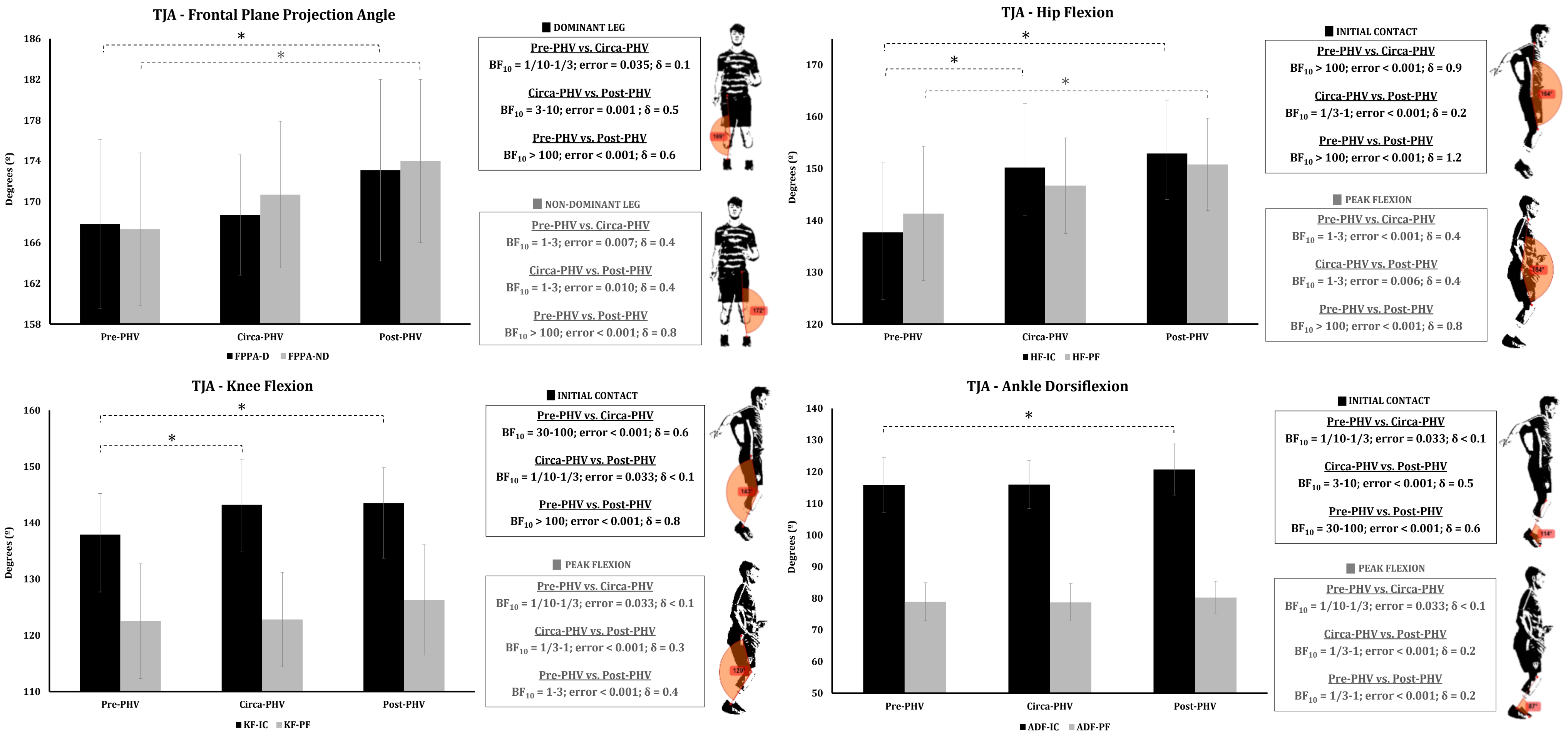


Figure 22. Maturation-related differences for all frontal and sagittal plane measures in the TJA test. *: $BF_{10} > 10$; error % < 10; δ > 0.6.

6.4 Discussion

The main findings of this study revealed that the 2D landing video analysis was a reliable tool for assessing the knee FPPA as well as the hip and knee flexion angles during DVJ and TJA tasks by experienced single or different testers. Although both tests have been used to examine landing technique previously, the results of this research showed a low relationship between DVJ and TJA kinematic measures, demonstrating significant higher FPPA values and lower hip and knee flexion values at peak flexion during the TJA test. Furthermore, while the DVJ was not able to report strong evidence for supporting between group differences regarding the maturity status, the TJA displayed a higher ability to discriminate between developmental stages for all frontal and sagittal measures.

Previous studies examining intra- and inter-rater reliability for frontal [125] and sagittal [101] kinematic measures during DVJs in adult athletes have shown excellent values for FPPA, HF-PF, KF-PF and ADF-PF (ICCs ≥ 0.9). Recently, very large intra-rater ICCs (≥0.9) have also been reported for FPPA during TJA tasks in youth football players [88,126]. In agreement with these findings, good-to-excellent reliability values were found for almost all the variables analysed during DVJ and TJA in our study, with the only exception of the inter-rater ADF measures. It is worth mentioning that the observers in this research had previous experience of 2D video analysis and reliability may differ for non-experienced raters. The reduced reliability reported for the ADF-IC and ADF-PF variables may be partly explained by the smaller between-player variation presented for these values, together with the increased complexity of drawing accurate angles overlapping the players' footwear. In fact, intra-rater assessments also showed slightly poorer ICCs, CV_{TE}, and TEM_{ST} scores as well as greater MDC_{95} values (ranged from 5.5° to 8.7°) for both ADF angles. In other variables, changes larger than 3 degrees for FPPA and 3-5 degrees for sagittal measures would be needed to ensure that changes in kinematics are not simply caused by measurement errors. Nevertheless, to accept a meaningful change when implementing an intervention, further errors should also be taken into consideration such as inter-trial and inter-session players' variability [281]. To the authors' knowledge, there is no previous research examining inter-trial and inter-session reliability for 2D video analysis during DVJ and TJA landings in youth football players.

Landing technique seems to be task-dependent. Several studies have found different landing kinematic patterns for unilateral and bilateral dynamic actions [101,127,129], and also when landing from a different jumping task [282]. In this sense, the results of the present study also support this notion: the DVJ and TJA tests showed highly different landing techniques. Pairwise comparisons between landing tasks displayed greater valgus alignments (FPPA) in the frontal plane and reduced flexion patterns (HF-PF and KF-PF) in the sagittal plane for the TJA in the whole group and across all stages of maturation when compared to the DVJ. Furthermore, these findings are in line with the recent data reported by Lloyd et al. [126] in the only previous study that has compared both DVJ and TJA tasks. In that research [126], the TJA was also more likely to expose male youth football players to greater FPPA values in both legs. To a certain extent, these results may be explicated by the different nature of both landing performances. When landing from a standardised height like in the DVJ, impact forces are controlled by muscles that go from rest to eccentric contraction [270]. This situation may artificially promote an anticipated muscle response (feedforward control mechanisms) [126,270,283] to help lower extremity stabilisation during landing. However, in a more functional landing task such as the TJA, individuals must control the landing with musculature just activated to move the body during the propulsion phase [270,283]. Thus, coordination deficits in musculature contractions may compromise the ability of the neuromuscular system to prepare the landing phase in this scenario [139,283]. Additionally, and despite the fact both are rebounding tests, the TJA requires repetitively performance of what may be more demanding jumps (knee to chest) during 10 seconds [98]. Accumulated fatigue in later repetitions may result in greater variability between jumps and the appearance of kinematic flaws compared to a single DVJ.

Studies on knee biomechanics have indicated that valgus collapse is often coupled with decreased knee and hip flexion [284]. Dynamic knee valgus overloads the MCL and ACL knee ligaments, increasing the injury risk [91,92]. At low knee-flexion angles, quadriceps contractions pull the tibia forward and also increase the stress on the ACL [139]. Therefore, aberrant movements (i.e., higher FPPA values and reduced hip and knee flexion angles at peak flexion) that contribute to sports injury might be better detected by the TJA rather than the DVJ when screening young athletes. The development of neuromuscular control training programs in players showing greater valgus scores and/or stiffer landing techniques may help to prevent an excessive loading on knee ligaments that place the athlete at risk of sustaining an injury [285,286]. To optimise their effects on joint kinematics, neuromuscular programs should incorporate a combination of trunk and lower extremity strength, dynamic balance and plyometric exercises [287], with coaches providing appropriate visual and verbal cues to ensure the correct joint alignment during exercise executions [287,288].

The analysis of the maturation-related differences reported some different patterns by test as well. A trend towards the reduction of FPPA values with advancing maturity was observed for both DVJ and TJA tasks, although the magnitude of evidence for supporting these findings was only meaningful for paired comparisons between pre- and post-PHV groups in the TJA. These results are consistent with those obtained in previous research [88,126], which indicate that reductions in valgus could be due to the benefits of growth and maturation in terms of increased muscular strength and motor control [283,289,290]. Older athletes have shown higher pre-landing co-contractions (hamstring pre-activation) than children, suggesting feedforward mechanisms develop with maturation and subsequent joint stabilisation [283,290]. Similarly, the higher jump heights presented by more mature players may reveal a better jumping ability that assists landing skills providing more time to prepare for landing [283]. In this regard, a relationship between knee valgus displacements during the TJA and heightened injury risk has been identified for U12 male football players [59]. Consequently, the assessment of dynamic knee valgus during TJA has been suggested as a worthwhile screen especially for prepubescent athletes [59].

The data obtained in this study also reflects different strategies to control the impact force of TJA landings in the sagittal plane across maturation group. Players classified in the pre-PHV group exhibited increased hip and knee flexion angles (especially at initial contact) in comparison with players at circa- and post-PHV groups. These results suggest that prepubescent football players rely on hip and knee flexion movements as strategy for modulating the external ground reaction forces produced by landing actions more than their pubescent and postpubescent peers. To some degree, the potential differences in timing of strength and neuromuscular control development between the proximal and distal body segments might contribute to the application of a more proximal control strategy (focused on large muscles in the trunk and hip) at earlier maturational stages, as hypothesised in previous research [283,291]. These significant reductions on hip and knee flexion angles in conjunction with the exponential increment in body weight throughout stages of maturation could also be behind the linear increment shown in ACL injury rates after 12 years of age [292–294]. Thus, the detection of stiffer landing patterns might be even more relevant than knee frontal plane mechanics for reducing the injury risk in circa- and post-PHV groups. Similarly, although the increased ankle plantar flexion at initial contact shown by players in the post-PHV group could also support this progression towards distal control strategies (based on ankle motions first) as growth and maturation advance, the low reliability values reported for ankle measures in the current study recommend caution with these findings.

Finally, some limitations should be considered when interpreting the findings of the current study. Kinematic data was measured through 2D video recordings instead of 3D motion analysis systems, which have been considered the gold standard measurement [101,295]. This limited the examination of landing technique to the frontal and sagittal planes, preventing the analysis of movements in the transverse plane. However, 2D video analysis has previously shown to be a valid, less expensive and time demanding alternative to 3D motion caption systems [296] and thus, a more accessible tool to screen athletes in the real framework of youth sports. Additionally, while both dominant and non-dominant legs were analysed for frontal plane knee angles, sagittal kinematic measures were only calculated in players' dominant leg for operational reasons. Nevertheless, minimal (non-clinically relevant) differences in sagittal plane landing pattern between both legs have been found for bilateral DVJs [297], so the trends shown in this study for hip, knee and ankle flexion measures can be expected to be similar for the non-dominant leg.

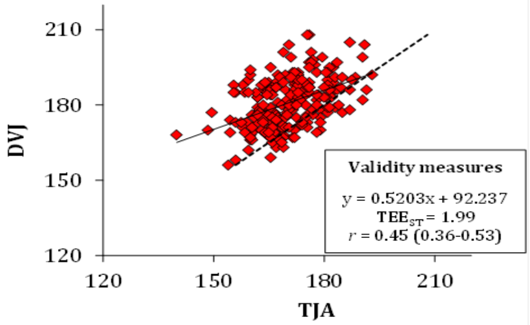
6.5 Conclusions

Both the DVJ and TJA tests are reliable tools to assess frontal and sagittal plane lower-extremity landing kinematics in youth football players. However, outcomes from the two tests are not well related. The TJA may be viewed as a more informative tool for landing technique assessments given it causes greater levels of FPPA and can also detect differences between players of different maturity. Due to the deficits demonstrated in the frontal plane by players' at pre-PHV group and in the sagittal plane by players' at circa- and post-PHV groups, the implementation of neuromuscular strategies aimed to improve muscular strength, dynamic balance and plyometric skills is recommended from pre-puberty and across all periods of growth and maturation to mitigate the risk of injury in youth football.

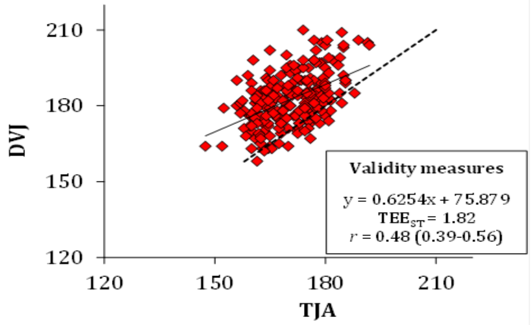
6.6 Appendices

Appendix 16. Validity measures of the frontal and sagittal view variables

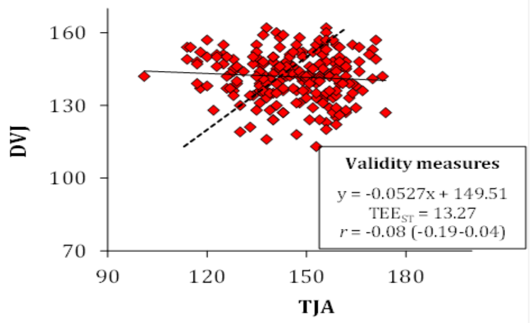
Frontal Plane Projection Angle - Dominant Leg



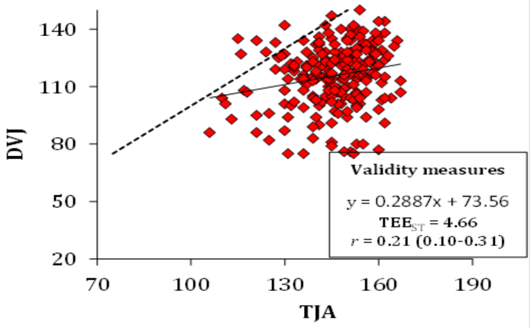
Frontal Plane Projection Angle - Non-Dominant Leg



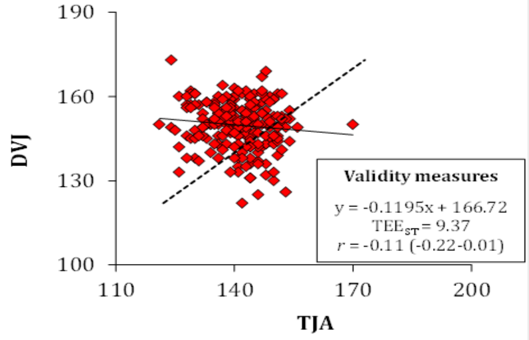
Hip Flexion at Initial Contact



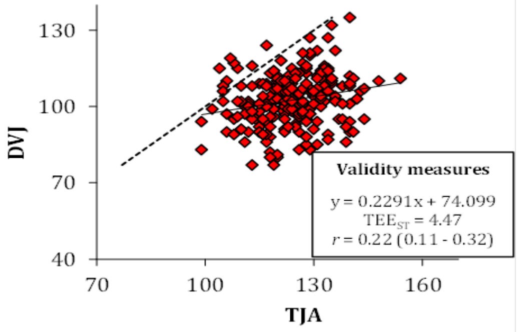
Hip Flexion at Peak Flexion



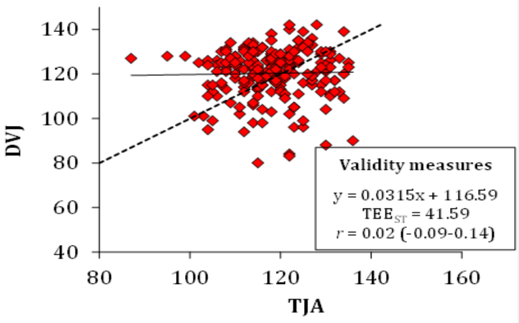
Knee Flexion at Initial Contact



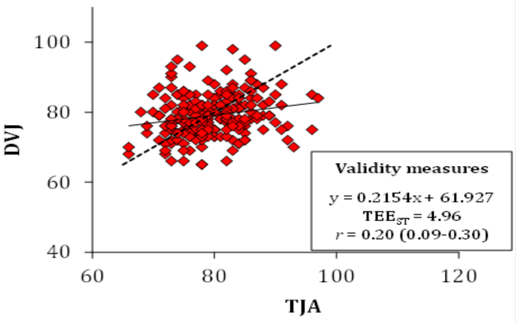
Knee Flexion at Peak Flexion



Ankle Dorsiflexion at Initial Contact



Ankle Dorsiflexion at Peak Flexion



7

A NOVEL MACHINE LEARNING APPROACH TO DETERMINE THE RISK OF LOWER EXTREMITY SOFT TISSUE INJURY IN MALE YOUTH FOOTBALL PLAYERS

[STUDY 5]

7.1 Introduction

Despite the numerous health-related benefits [4,6,7,298], the participation in a very physically demanding team sport such as football results in a notable increase in injury risk. Epidemiological studies have reported that the frequency and severity of injuries among young football players accelerate and peak during the adolescence [12,27,44,50–52], when periods of rapid and non-uniform growth in skeletal structures are experienced, resulting in alterations in both physical performance and motor control/function [46,82–84]. Thigh muscle/tendon strains (hamstring and quadriceps) and knee and ankle ligament sprains and tears (anterior cruciate ligament [ACL] of the knee, anterior inferior tibiofibular ligament of the ankle) are the most frequently diagnosed and severe type of injury in young football players [34,121,299]. These lower extremity soft tissue (LE-ST) injuries frequently foster players to refrain from sport participation for an extensive period of time. In addition, young players who sustain LE-ST injuries during football participation may experience important residual symptoms that can have major negative consequences in their long-term athlete developments and limit their ability to engage in exercise and athlete activities later in life [219]. Consequently, football-related LE-ST injuries can counter the beneficial effects on health of sport participation at a young age if a child or adolescent is unable to continue participating because of the effects of injury [15].

Most of the LE-ST injuries documented in youth football have shown a non-contact mechanism (*Chapters 3* and *4* of this thesis) and hence, they might be considered as preventable [150,193].

Thus, the implementation of multicomponent strategies aimed at mitigating the risk of injury in such cohort is a big challenge that coaches and physical trainers have to address every season worldwide. It has been suggested that for an injury prevention measure being highly effective, its design must be targeted on each player's individual needs [56]. Therefore, the use of a valid screening model that allows coaches and physical trainers to profile injury risk and identify those factors that impact most on the likelihood of sustaining a LE-ST injury in each of their young football players may be a valuable tool to design tailored preventive measures.

In the last five years, a growing number of studies have used contemporary Machine Learning algorithms (e.g., Random Forest, ADTree, Naïve Bayes, Neural Networks) and resampling methods (e.g., K-fold cross validation, leave-one-out, bootstrapping), as alternatives to the traditional logistic regression techniques, to build screening models to predict injuries in team sport athletes showing, in most of the cases, promising validity results [111–116,118,119]. Only two recent studies [67,68] (to the best of the authors' knowledge) have developed screening models to predict injuries through the use of decision tree classifiers (XGBoost [68] and bagging ensemble method with a J48con decision tree as base classifier [67]) in youth football players. In particular, these two studies have built models to predict football-related injuries based on anthropometric (e.g., age, standing and sitting height, body mass), physical fitness (e.g., sprint and jump [vertical and horizontal] performance, agility, lower back and posterior chain flexibility) and neuromuscular (e.g., tuck jump knee valgus angle, unilateral landing peak vertical ground reaction force and asymmetry) measures in elite young male players from the youth academies of six England [67] and seven Belgium [68] premier league football clubs, reporting moderate to high levels of sensitivity and specificity, respectively. Furthermore, these studies [67,68] have also identified interactions of asymmetry, knee valgus angle and body size as contributing factors to an injurious profile in elite young football players.

However, it should be acknowledged that a limitation of any prediction model developed through the use of learning algorithms is that its generalisation to individuals with different characteristics (e.g., sport background, exposure to casual factors of injury, physical performance) to those who were employed in its building and validation process may be sub-optima. In this sense, the well-documented differences in several physical performance measurements [300] between elite and non-elite (i.e., sub-elite or amateur) young football players may lead to a dramatic reduction in the ability of these two currently available screening models to predict LE-ST injuries in the latter cohort. Given that a large proportion of the young footballers play for non-professional clubs engaged in local and regional leagues and that the injury incidence and severity still being high in this cohort (*Chapters 3* and *4*), studies aimed at building injury risk factor models to identify non-elite young football players at high risk of LE-ST injury are urgently warranted.

Therefore, the purpose of this study was to develop a robust screening model based on pre-season measures to prospectively predict LE-ST injuries after having applied supervised learning algorithms and resampling methods in non-elite young football players.

7.2 Methods

To conduct this study, guidelines for reporting prediction model and validation studies in Health Research (Transparent Reporting of a multivariable prediction model for Individual Prognosis or Diagnosis [the TRIPOD statement]) were followed [301]. The TRIPOD checklist is presented in Appendix 17.

7.2.1 Participants

A convenience sample of 301 young male football players from the youth academies of five different Spanish non-professional football clubs were recruited for this study. All young players were engaged in regional (non-national) youth football leagues of the south-east of Spain. Participants were included in this study if they met the following criteria: 1) they were free from pain, illness and/or injury at the time of testing and 2) they were regularly involved in football training and competition. Players who reported the presence of orthopedic problems that prevented the proper execution of one or more of the field-based tests, or who were transferred to another club and were not available for follow-up testing at the end of 9-months were excluded. Before any participation, experimental procedures and potential risks were fully explained to coaches, parents and children in verbal and written forms, and written informed consent was obtained from parents and children. The experimental procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the Ethics and Scientific Committee of the University of Murcia, Spain (ID: 1551/2017).

Finally, a sample of 260 young male football players of four different age categories (age-based categories [*n*]: U12 [78], U14 [69], U16 [50], U19 [63]) completed this study (Table 16). Forty-one players were removed from the initial sample of 301 young based on the exclusion criteria (11 players reported a presence of pain and orthopaedic problems, 14 players did not provide the required signed informed consent before the start of the study, and 16 players were transferred to another club or left their club before the end of the follow up period).

7.2.2 Study design

A prospective cohort study design was used to address the purpose of this study. In particular, all LE-ST injuries accounted for within the 9 months following the initial testing session (in-season phase) were prospectively collected for all players. Players were required to attend their respective club's training facilities during the pre-season phase (September) of the years 2017 (*n* = 175 players) and 2018 (*n* = 85 players) to undergo an evaluation of a number of personal characteristics, psychological constructs, and physical fitness/neuromuscular measures, most of them considered potential sport-related injury risk factors.

7.2.3 Procedure

The testing session was divided into three different parts. The first part of the testing session was used to obtain information related to the participants' personal or individual characteristics. The second part was designed to assess psychological constructs related to anxiety and mood state. Finally, the third part of the session was used to assess several physical performance, neuromuscular capability and biomechanical measures through 10 field-based tests. All measures were taken by six trained and experienced testers, coordinated by the principal investigator (FJR-P) to guarantee standardisation of protocols.

7.2.3.1 Personal or individual characteristics

The ad hoc questionnaire designed by Olmedilla, Laguna, & Redondo [302] was used to record personal or individual measures that have been defined as potential non-modifiable risk factors for sport injuries: player position (goalkeeper, defender, midfielder or forward), years of playing football, training frequency, dominant leg (defined as the player's kicking leg) and chronological age.

Anthropometric measures (body mass, stature [i.e., standing height], sitting height, body mass index [BMI], and leg and tibia length) and maturity status were also measured. Body mass (kg) was measured on a calibrated physician scale (SECA 799, Hamburg, Germany). Standing and sitting height (cm) were recorded to the nearest 0.1 cm on a measurement platform (SECA 799, Hamburg, Germany) with seated height measured using a box. Leg length was calculated as the length measured in centimeters from the anterior superior iliac spine to the most distal portion of the medial tibial malleolus [240]. Tibia length was defined as the distance between the lateral knee joint line and the lateral malleolus [303]. Stage of maturation was calculated in a noninvasive manner using a regression equation comprising measures of age, body mass, standing height and sitting height [221]. Using this method, maturity offset (calculation of years from peak height velocity [PHV]) was determined.

Appendix 18 displays a description of the personal risk factor recorded.

7.2.3.2 Psychological constructs

The Spanish version of the State-Trait Anxiety Inventory (STAI) questionnaire [304] was used to measure the current state and trait anxiety of the players. This questionnaire consists of 40 items (20 for state and 20 for trait). The state items describe how the athletes feel just at the specific moment when the questionnaire is completed, whereas the trait items describe the athletes' general anxiety level. For the purposes of this research, only the trait anxiety was analysed.

Mood states were evaluated using the Spanish adapted version for adolescent athletes of the Profile of Mood States (POMS) scale [305]. This version comprises 7 different psychological factors (tension, depression, anger, vigour, fatigue, confusion, friendliness) in a 33-item scale.

The Spanish version of the Psychological Characteristics Related to Sport Performance questionnaire (CPRD) [306] was used to measure the following psychological characteristics: stress control, influence of performance evaluation, motivation, team cohesion and mental skills. The questionnaire consists of 55 items graded in a 5-option Likert scale (from totally disagree to totally agree).

Appendix 19 displays a description of the psychological risk factor recorded.

Table 16. Descriptive anthropometric values (mean ± standard deviation) by age group.

Group	***N***	**Age (years)**	**Body mass (kg)**	**Stature (cm)**	**Leg length (cm)**	**Maturity offset**
U12	78	11.1 ± 0.5	39.8 ± 7.4	148.1 ± 6.6	72.8 ± 4.2	-2.4 ± 0.6
U14	69	13.3 ± 0.4	51.9 ± 8.6	162.3 ± 7.8	80.8 ± 5.4	-0.7 ± 0.6
U16	50	15.0 ± 0.5	62.6 ± 8.5	173.2 ± 6.3	84.9 ± 3.9	1.1 ± 0.6
U19	63	17.3 ± 0.8	68.7 ± 8.4	176.6 ± 7.3	86.2 ± 5.5	2.6 ± 0.7

U: under.

7.2.3.3 Physical fitness, neuromuscular capability and biomechanical measures

Players completed the standardised dynamic warm-up designed by Taylor et al. [244] before the physical performance, neuromuscular capability and biomechanical measures were taken. In particular, these measures were concurrently recorded using a randomised circuit style approach (due to time constraints) (Figure 23) from six jump tests, a linear 30 m sprint test, the ROM-Sport battery, Y-Balance test and Illinois agility test. A 5-min rest interval was given between consecutive testing maneuvers.

Appendices 20-23 display a description of the physical fitness, neuromuscular capability and biomechanical measures recorded.

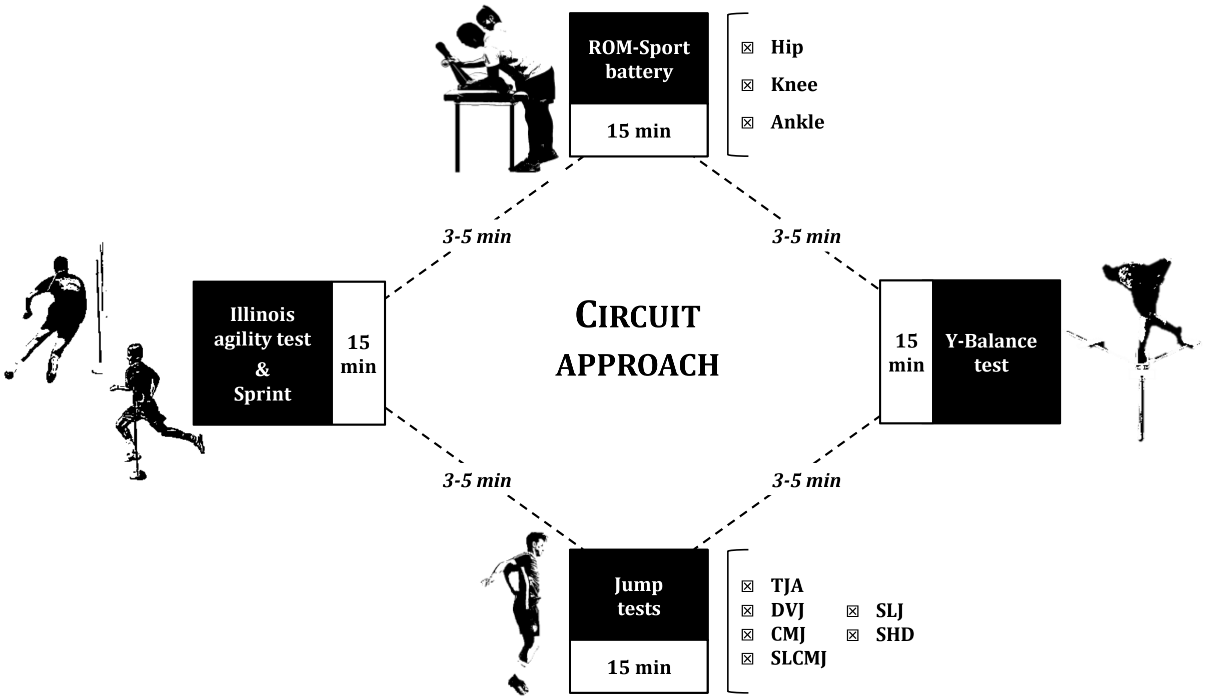


Figure 23. Circuit style approach.

Jump tests

Four vertical and two horizontal jump tests were performed and several measures of performance, kinematic and kinetic variables and neuromuscular parameters were extracted from them. Three to five attempts of each jump test were performed. For each variable, the highest absolute score (regardless of whether it was either positive or negative in terms of physical performance and injury risk) recorded in the attempts carried out was selected for the subsequent analysis.

Vertical jump tests:

Tuck jump assessment (TJA). Tuck jumps were performed in place for 10 consecutive seconds following the methodology previously described by Myer et al. [98]. Each participant's technique was visually assessed at frontal and sagittal planes. A 2-dimensional video cameras (model: Lumix DMC-FZ200; Panasonic, Japan) were positioned in both planes at a height of 0.70 m and a distance of 5 m from the landing area to capture the test and grade each player's technique retrospectively. Afterwards, frontal plane projection angles (FPPA) at the point of maximum knee flexion were analysed, and the presence of knee valgus was subjectively classified as minor (<10°), moderate (10°–20°) or severe (>20°) following the methodology described by Read et al. [88]. Additionally, hip flexion (HF), knee flexion (KF), and ankle dorsiflexion (ADF) was assessed at initial contact and peak maximum flexion in the sagittal plane. All scores were marked by two experienced testers in 2-D landing kinematic assessments.

Drop vertical jump (DVJ). A double leg drop vertical jump from a box height of 40 cm and without arm swing was performed on a contact platform connected to the Ergo tester (Ergo Jump Bosco System, Italia) unit [307]. Both jump height and reactive strength index (RSI = jump height/contact time) [308] were considered to assess stretch-shortening cycle (SSC) function and hence, recorded. A 2-dimensional landing kinematic analysis following the methodology described for the TJA was also carried out. In addition to the FPPA, the knee medial displacement (KMD) (expressed as the displacement measure [d2–d1] between the initial contact [d1] and the maximal peak knee flexion [d2]) [303] the knee-to-ankle separation ratio (KASR) (defined as the ratio of distance between knees and ankles during peak knee flexion [KASR = knee/ankle]) [267] and the knee separation distance (KSD) (expressed as the difference [d2-d1] between knee separation distance at the initial contact [d1] and the peak knee flexion [d2]) [267] were also used to assess knee valgus during DVJ tests. All trials were retrospectively analysed by the same two experienced tester in 2-D landing kinematics assessments.

Countermovement jump (CMJ). A double leg countermovement jump without arm swing was performed on a contact platform connected to the Ergo tester (Ergo Jump Bosco System, Italia) unit. Jump height, calculated from the flight time ($h=ft^{2}\cdot g\cdot 8-1$) [309], was recorded for subsequent analyses.

Single leg countermovement jump (SLCMJ). A single leg (dominant and non-dominant) countermovement jump was also performed on a force platform (9286AA, Kistler, Switzerland). Height, peak vertical ground reaction force (pVGRF) during take-off and landing, and peak landing force timing (pLFT) were captured at a sampling rate of 1000 Hz. A threshold of >10 N to determine contact and <10 N to determine flight moments was used, and no filter was applied to the data obtained for subsequent analyses [310]. The pVGRF at take-off and landing were normalised to body weight (BW), and side-to-side differences for each of these variables were calculated. Asymmetries in all SLCMJ variables were determined when bilateral differences were ≥ 10%.

Horizontal jump tests:

Standing long jump (SLJ). Jump distance in a SLJ was measured to the nearest centimetre from the starting line to the player's heel with a standard tape measure. Free movement of the arms was allowed during the test.

Single hop for distance (SHD). Jump performance in a SHD was also measured for dominant and non-dominant legs [311]. The jump distance in cm was then normalised and presented as percentage of leg length (SHD/leg length*100 = %leg length). Bilateral differences were calculated and asymmetry was considered when differences ≥ 10%.

Sprint

Time during a 10-20 and 30 m sprint in a straight line was measured by means of three pairs of Microgate Witty photocells (Microgate, Italy) placed 1.0 m above the ground level. Each sprint was initiated from an individually chosen standing position, 50 cm behind the photocell gate, which started a digital timer. The theoretical maximal force (F0), velocity (V0), maximal power output (Pmax) and mechanical effectiveness of ground force application (ratio of force [RF] and decrease in the RF over acceleration [DRF]) during a 30m-sprint were also analysed. For this purpose, all sprint trials were recorded through an iPad Air (Apple Inc., USA) and retrospectively analysed by a single tester using *MySprint* app [312]. Subsequently, the *MySprint* app automatically calculated each split time in milliseconds and sprint mechanical outputs by implementing the equations developed by Samozino et al. [313].

ROM-Sport battery

The passive hip extension (PHE), hip adduction with hip flexed 90° ($\text{PHAD}_{\text{HF90°}}$), hip flexion with knee flexed (PHF_{KF}) and extended (PHF_{KE}), hip abduction with hip neutral (PHABD) and hip flexed 90° ($\text{PHABD}_{\text{HF90°}}$), hip external (PHER) and internal (PHIR) rotation, knee flexion (PKF), ankle dorsiflexion with knee flexed (ADF_{KF}) and extended (ADF_{KE}) ROM measures of the dominant and non-dominant legs were assessed following the methodology described by Cejudo et al. [314]. For each joint ROM measure, side-to-side differences were also calculated. When a side-to-side difference ≥ 8° was found, players were categorised as showing bilateral asymmetries [315].

Y-Balance test

Dynamic postural control was evaluated using the Y-Balance test [316]. The distance reached in each direction (anterior, posteromedial, and posterolateral) was normalised by dividing by the previously measured leg length to standardise the reach distance ([excursion distance/leg length] x 100 = % leg length) [316]. Bilateral differences between dominant and non-dominant legs were also calculated for each distance ((higher score – lower score)/higher score x 100) [317], and differences equal or greater than 10% for anterior, posteromedial, and posterolateral directions were considered as asymmetries. Finally, to obtain a global measure of the balance test for each leg, data from each direction were averaged to calculate a composite score.

Illinois agility test

Players' agility was assessed using the Illinois agility test, which has been commonly used in measuring agility in football [318]. The length of the zone was 10 m, while the width (distance between the start and finish points) was 5 m. Four cones were placed in the center of the testing area at a distance of 3.3 m from one another. Four cones were used to mark the start, finish, and two turning points. The participants started the test lying face down, with their hands at shoulder level. The trial started on the "go" command, and the participants began to run as fast as possible. The trial was completed when the players crossed the finish line without having knocked any cones over. Time was measured using a photocell system (Microgate Witty photocells; Microgate, Italy).

7.2.3.4 Injury surveillance

The procedures for data collection and reporting injury occurrences described in the International Consensus Statements were followed in the current research [146,147]. For the purpose of this study, an injury was defined as any non-contact, soft tissue (muscle, tendon and ligament) injury sustained by a player during a training session or competition which resulted in a player being unable to take a full part in future football training or match play (time loss injuries). Injuries were classified as non-contact where no clear contact or collision with another player, object or ball occurred. Only lower extremity injuries were considered for the analysis as these injuries are the most common at youth football practice (as reported in *Chapter 3* and *4* of this thesis) and more likely to be influenced by the investigated variables. All injuries were confirmed by team doctors, and players were considered injured until the club medical staff (medical doctor or physiotherapist) allowed them to fully participate in training and were available for match selection.

The team medical staff of each club recorded LE-ST injuries on an injury form that was sent to the study group monthly. On this form, team medical staff provided the following details for each LE-ST injury that satisfied the inclusion criteria: date of injury, moment (training or competition), leg injured (dominant or non-dominant), injury location (hip/groin, thigh, knee, lower leg, ankle or foot/toe), injury severity based on lay-off time from football (slight/minimal [1-3 days], minor/mild [4-7 days], moderate [8-28 days], severe [>28 days]), whether it was a recurrence (defined as a soft tissue injury that occurred in the same extremity and during the same season as the initial injury), and total time taken to return to full training and competition. At the conclusion of the 9-month follow-up period, all data from the individual clubs were entered into a central database, and discrepancies were identified and followed up at the different clubs to be resolved. Some discrepancies among medical staff teams were found to diagnose minimal LE-ST injuries and to record their total time lost. To resolve these inconsistencies in the injury surveillance process (risk of misclassification of the players), only ST-LE injuries showing a time loss of > 4 days (mild to severe) were selected for the subsequent statistical analysis. Due to the confounding effects of previous injuries, only the first occurring injury for each player during the season was considered in the analyses [67,68].

7.2.4 Statistical analysis

After having completed an exhaustive data cleaning process (detected anomalies or errors were removed [32 cases] and missing data (12.6%) were replaced by the mean value of the corresponding variable according to the age category of the players) we had an imbalanced (showing an imbalance ratio of 0.21) and a high-dimensional data set comprising of 260 young male football players (instances) and 135 potential risk factors (features). In this study, an anomaly or error was defined as a score or value that could not be classified as real or true because of the consequence of a human error or a machine failure. An example of an error was a jumping height value of 256 cm since it is impossible for an adolescent to jump as such height.

To evaluate the performance of the algorithms selected, the fivefold stratified cross-validation technique was used [319]. That is, we split the data set into five stratified folds maintaining the class distribution, each one containing 20% of the patterns of the data set. For each fold, each algorithm was run in order to build a model with the examples contained in the remaining four folds (training instances) and then its predictive ability was tested with the current fold (test instances). This value is set up with the aim of having enough positive class instances in the different folds, hence avoiding additional problems in the data distribution. A wide range of classification performance measures can be obtained from the stratified cross-validation technique. A well-known approach to produce an evaluation criterion is to use the receiver operating characteristic (ROC) curve. Thus, the AUC was used as a measure of a classifier's performance for evaluating which models showed high (0.90–1.00), moderate (0.70-0.90), low (0.50-0.70) and fail (<50) scores (Altman & Bland, 1994). Only those algorithms whose performance scores (AUC) were higher than 0.70 were considered as acceptable for the purposes of this study. Furthermore, two extra measures from the confusion matrix were also used as evaluation criteria: (a) true positive (TP rate) = TP / (TP + FN) also called sensitivity or recall, is the proportion of actual positives that are predicted to be positive, and (b) true negative (TN) rate = TN / (TN + FP) or specificity, that is, the proportion of actual negatives that are predicted to be negative. In imbalanced domains, when the AUC has reached a high score (> 0.70), the classification performance may not be as perfect as the AUC value reflects because plenty of "trash" negative samples exist in the dataset. These trash negative samples may raise the AUC value, but a few other negative samples remain mixed with the positive samples, which are difficult to distinguish. These few remaining negative samples may diminish performance, including precision and recall, while very slightly influencing the AUC score. Consequently, Zou et al. [320] suggest to employ the F-score together with the AUC as a classification measurement for imbalanced problems. The F-score is a trade-off between precision (P = TP / (TP + FP) and recall (R) and is described as follows:

$$F_{ß} = \frac{(ß^2 + 1)P \: x \: R}{ß^2 \: P + R}$$

where β is a parameter used to adjust the weight between P and R.

In order to select the best performing model among those showing AUC scores > 0.70, the F score was selected as single criterion measure.

Similar to previously published studies aimed at building prediction models to identify elite football [112,119] and futsal [111] players at high risk of injury, the taxonomy for external (resampling techniques), internal (ensemble techniques) and cost-sensitive methods for learning with imbalanced data sets proposed by Lopez et al. [109] and Elkarami et al. [321] was applied.

Due to the high dimensionality of the data set, before running the algorithms included in the taxonomy described below, a feature selection process was carried out in order to help base classifiers to reduce the feature space and eliminate irrelevant, weakly relevant and/or redundant features. In particular, we used the metaclassifier "attribute selected classifier" available in Weka's repository to address this issue. In this sense, we selected as attribute evaluator the classify subset evaluator filter [322] because it extracts features from the data without any learning involved, which avoids any risk of overfitting the models and the GreedyStepwise as search technique (It performs a conservative greedy forward search through the space of attribute subsets). To interpret and visualise the behavior and relevance of the variables selected, the Shapley Additive exPlanations (SHAP) approach (SHAP summary plot) was used [323]. This approach visualises every single player or injury case and gives an overview of the variables in the model by order of importance (vertically listed features), with the top ones having a higher global impact on the model than bottom ones. The SHAP-values represent the impact of a variable in the decision-making process. Dots representing the SHAP-values for each feature value of a player in the dataset are plotted horizontally next to the feature. Negative SHAP-values represent a higher probability of a positive prediction (i.e., being injured). Each dot is coloured by the value (i.e., measured value) of the feature for an individual.

Four classifiers based on different paradigms, namely decision trees with C4.5 [324] and ADTree [325], Support Vector Machines with SMO [326] and the well-known k-Nearest Neighbor (KNN) [327] as an Instance-Based Learning approach were selected to be used in the resampling, ensemble and cost-sensitive learning methodologies as base classifiers. The configuration of each base classifier was optimised through the use of the metaclassifier MultiSearch (it performs a search of an arbitrary number of parameters of a classifier and chooses the best pair found for the actual filtering and training) with the F-score as evaluation criterion for evaluate classifier performance (C4.5: confidence factor [from 0.05 to 0.75], ADTree: number of interactions [from 5 to 50], SMO: complexity [from 1 to 10] and ridge [from -10 to 5], KNN: number of neighbors [from 1 to 5]).

Thus, and with regard to the resampling techniques, four (two oversampling and two undersampling algorithms) of the most popular methodologies were selected, which are the synthetic minority oversampling technique (SMOTE) [328], random oversampling (ROS), random undersampling (RUS) and Wilson's edited nearest neighbor rule (ENN) (Wilson, 1972). In the four resampling techniques selected, a level of balance in the training data near the 40/60 was attempted. In addition, the interpolations that are computed to generate new synthetic data are made considering the k-3-nearest neighbors of minority class instances using the Euclidean distance.

Regarding ensemble learning algorithms, classic ensembles such as Bagging [329], AdaBoost [330] and AdaBoot.M1 [331] were included in this study. Furthermore, the algorithm families designed to deal with skewed class distributions in data sets were also included: Boosting-based and Bagging-based. The Boosting based ensembles that were considered in the current study were SMOTEBoost [332] and RUSBoost [333]. Concerning Bagging based ensembles, it was included from the OverBagging group, OverBagging (which uses ROS) [334], UnderBagging (which uses RUS) [334] and SMOTEBagging [334]. The number of internal classifiers used within each ensemble learning algorithm was set 100 (always the same) base classifiers (C4.5, ADTree, SVM and KNN) by default.

Concerning the cost-sensitive learning algorithms, two different algorithms were used, namely MetaCost [335] and cost-sensitive classifier. Cost-sensitive learning solutions incorporating both the data (external) and algorithmic level (internal) approaches assume higher misclassification costs for samples in the minority class and seek to minimise the high cost errors. For the both cost-sensitive algorithms selected, the cox matrix set-up was to:

$c = \begin{Bmatrix} 0 & 2 \\ 1 & 0 \end{Bmatrix}$ where a false negative has a cost of 2 and a false positive had a cost of 1.

The behavior of some specific combinations of class-balanced ensembles with cost-sensitive base classifiers was also studied. The algorithm Random Forest [336] in isolation and in combination with the resampling techniques was also explored due to its good results showed in previous studies [337]. Finally, to allow comparison of the constructed models to a baseline model a ZeroR classifier was also used

For the sake of brevity and the lack of space, the code of the algorithms used in this study has not been written here. Instead, we have only specified the names and refer the reader to their original sources. Furthermore, all the classification algorithms used are available in Weka Data Mining software.

7.3 Results

7.3.1 Soft-tissue lower extremity injuries epidemiology

There were 61 soft tissue injuries over the follow-up period, 36 (59%) of which corresponded to thigh muscles (18 hamstrings, 8 quadriceps and 10 adductors) injuries, 9 (14.8%) to knee (5 ligament sprains) and 7 (11.5%) to ankle (all ligament sprains) joints. Injury distribution between the legs was 70.5% dominant leg and 29.5% non-dominant leg. A total of 26 injures occurred during training and 35 during competition. In terms of severity, most injures were categorised as moderate (*n* = 40), whereas only 6 cases were considered severe injuries and 15 as minor/mild injuries. Thirteen players sustained multiple LE-ST injuries during the observation period (10 players were injured twice and three players three times), so their first injury was used as the index injury in the analyses. Consequently, 45 soft-tissue injuries were finally used to develop the prediction models.

7.3.2 Prediction models for soft tissue lower extremity injuries

As all the algorithms employed in this study can be found in the Weka experimenter, only the scheme (and not the full code) of the algorithm finally selected is displayed in Appendix 24 in order to allow practitioners to replicate our analysis and to use the model generated with their young male football players.

The feature selection process carried out in the data set identified a subset of six measures as the most relevant (considering the individual predictive ability of each feature along with the degree of redundancy among them) (Table 17) on which was subsequently applied the taxonomy of learning algorithms described in the “Materials and Methods” section.

The baseline ZeroR classifier achieved an AUC of 0.500 ± 0.000, specificity of 100% and sensitivity of 0%. Table 18 shows the average AUC results for all resampling, ensemble and cost-sensitive learning methods separately for each decision base classifiers, nearly all of which have greater accuracy and sensitivity than the baseline model. Thus, a total of 16 algorithms built (using this subset of features) prediction models with AUC scores ≥0.7 (Table 19). Among these 16 algorithms, the SBAG with ADTree as base classifier technique was the one that showed the highest F-score (0.440 ± 0.149) and hence, it was considered as the "winning model". Therefore, the final model to predict LE-ST injuries in young male football players comprised 100 different decision-tree shape (ADTree) classifiers (Figure 24 shows an example of one of these ADTree decision trees, the rest can be got upon request to the authors). In term of practical applications, each classifier has a vote or decision [yes (high risk of LE-ST injury) or no (lower risk of LE-ST injury)], and the final decision regarding whether or not a player might suffer an injury is based on the combination of the votes of each individual classifier to each class (yes or no).

For the model finally selected, i.e. SBAG with ADTree as base classifier, an analysis of the average influence that each of its six variables has in the decision-making process regarding whether or not a player might suffer an injury was carried out by the SHAP approach and can be visualised in Figure 25. In particular, the variable that showed the biggest impact was knee medial displacement (dominant leg) in the DVJ, followed by BMI, ROM-ADF$_{KE}$ (dominant leg), landing BIL-pVGRF [SLCMJ], ROM-BIL-PHIR and BIL-FPPA [TJA]. In Figure 26, the SHAP values for each feature value of an individual in the dataset are displayed.

Table 17. Features selected after having applied the classify subset evaluator filter to the data set.

Name	**Labels**
KMD (dominant leg) [DVJ]	0 (varus), 1 (slight valgus), 2 (moderate valgus) or 3 (severe valgus)
BMI	Numeric
ROM-ADF$_{KE}$ (dominant leg)	Numeric
Landing BIL-pVGRF [SLCMJ]	0 (Asymmetry) or 1 (No Asymmetry)
ROM-BIL-PHIR	0 (Asymmetry) or 1 (No Asymmetry)
BIL-FPPA [TJA]	0 (Asymmetry) or 1 (No Asymmetry)

DVJ: drop vertical jump; KMD: knee medial displacement; BMI: body mass index; ROM: range of motion; ADF$_{KE}$: ankle dorsiflexion with the knee extended; pVGRF: peak vertical ground reaction force; SLCMJ: single-leg countermovement jump; PHIR: passive hip internal rotation; FPPA: frontal plane projection angle; TJA: tuck jump assessment; BIL: bilateral ratio.

Table 18. AUC results (mean and standard deviation) for the five base classifiers in isolation and after applying in them the resampling, ensemble (Classic, Boosting-based, Bagging-based and Class-balanced ensembles) and cost-sensitive learning techniques selected.

Technique	**Base classifiers**									
	C4.5		**ADTree**		**SMO**		**KNN**		**RF**	
	AUC		**AUC**		**AUC**		**AUC**		**AUC**	
None	0.635	±0.099	0.701	±0.101	0.500	±0.000	0.679	±0.093	0.605	±0.101
	Resampling Techniques									
SMOTE	0.655	±0.085	0.688	±0.073	0.684	±0.070	0.660	±0.098	0.613	±0.099
ROS	0.640	±0.096	0.684	±0.091	0.657	±0.060	0.673	±0.090	0.608	±0.099
RUS	0.672	±0.087	0.649	±0.096	0.670	±0.087	0.640	±0.102	0.624	±0.096
ENN	0.662	±0.093	0.651	±0.098	0.498	±0.000	0.649	±0.121	0.618	±0.011
	Classic Ensembles									
ADB1	0.675	±0.076	0.696	±0.092	0.696	±0.079	0.585	±0.125	-	-
M1	0.671	±0.085	0.682	±0.101	0.622	±0.077	0.655	±0.102	-	-
BAG	0.691	±0.084	0.696	±0.084	0.555	±0.051	0.683	±0.079	-	-
Decorate	0.638	±0.096	0.668	±0.088	0.500	±0.000	0.629	±0.077	-	-
	Boosting-based Ensembles									
SBO	0.676	±0.073	0.648	±0.125	**0.713**	**±0.031**	0.643	±0.083	-	-
RUSB	0.661	±0.101	0.686	±0.094	**0.716**	**±0.066**	**0.723**	**±0.076**	-	-
	Bagging-based Ensembles									
OBAG	0.679	±0.077	0.696	±0.095	**0.731**	**±0.084**	0.689	±0.092	-	-
UBAG	0.699	±0.080	0.691	±0.102	**0.728**	**±0.086**	0.697	±0.093	-	-
SBAG	0.695	±0.080	**0.700**	**±0.105**	**0.739**	**±0.082**	**0.702**	**±0.084**	-	-
	Cost-sensitive Classification									
MetaCost	0.567	±0.094	0.661	±0.093	0.500	±0.000	0.631	±0.089	-	-
CS-Classifier	0.636	±0.110	0.661	±0.093	0.535	±0.051	0.656	±0.085	-	-
	Class-balanced Ensembles with a Cost-sensitive Classifier									
CS-OBAG	0.693	±0.093	**0.702**	**±0.099**	**0.731**	**±0.072**	0.694	±0.099	-	-
CS-UBAG	0.695	±0.088	**0.700**	**±0.089**	**0.725**	**±0.088**	0.695	±0.093	-	-
CS-SBAG	0.690	±0.084	**0.701**	**±0.108**	**0.731**	**±0.086**	**0.702**	**±0.091**	-	-

Highlighted in bold are the algorithms that built prediction models with AUC scores ≥0.7.

Table 19. Sub-set of algorithms that allowed building predictive models with AUC scores ≥0.7. Highlighted in bold and grey is the algorithm with the highest F-score.

Technique	**Performance measures**							
	AUC		**TP rate (%)**		**TN rate (%)**		**F-score**	
ADTree	0.701	±0.101	31.1	±19.5	91.4	±4.5	0.346	±0.212
SBAG [ADTree]	**0.700**	**±0.105**	**51.1**	**±13**	**81.2**	**±9.8**	**0.440**	**±0.149**
CS-OBAG [ADTree]	0.702	±0.099	63.3	±16.6	67.7	±9	0.399	±0.080
CS-UBAG [ADTree]	0.700	±0.089	53.3	±14.6	79.3	±8.8	0.432	±0.130
CS-SBAG [ADTree]	0.701	±0.108	66.7	±15.7	67.7	±7.8	0.417	±0.091
SBO [SMO]	0.713	±0.031	34.4	±26.4	83.7	±14.7	0.377	±0.049
RUSB [SMO]	0.716	±0.066	15.6	±13	92.6	±5	0.248	±0.101
OBAG [SMO]	0.731	±0.084	57.8	±10.2	74.7	±9.1	0.423	±0.106
UBAG [SMO]	0.728	±0.086	59.1	±9.4	74.2	±9.7	0.438	±0.115
SBAG [SMO]	0.739	±0.082	62.2	±13	72.6	±9.4	0.432	±0.110
CS-OBAG [SMO]	0.731	±0.072	80	±14.6	49.3	±12.7	0.399	±0.055
CS-UBAG [SMO]	0.725	±0.088	77.8	±13.9	54	±7.3	0.378	±0.063
CS-SBAG [SMO]	0.731	±0.086	78.9	±14.3	50.7	±9.3	0.377	±0.057
RUSB	0.723	±0.076	61.1	±31.1	79.3	±7.6	38.5	±12.4
SBAG	0.702	±0.084	48.9	±15	71.2	±15.7	39.6	±10.3
CS-SBAG	0.702	±0.091	53.3	±22.7	72.3	±10.3	36.6	±12.1

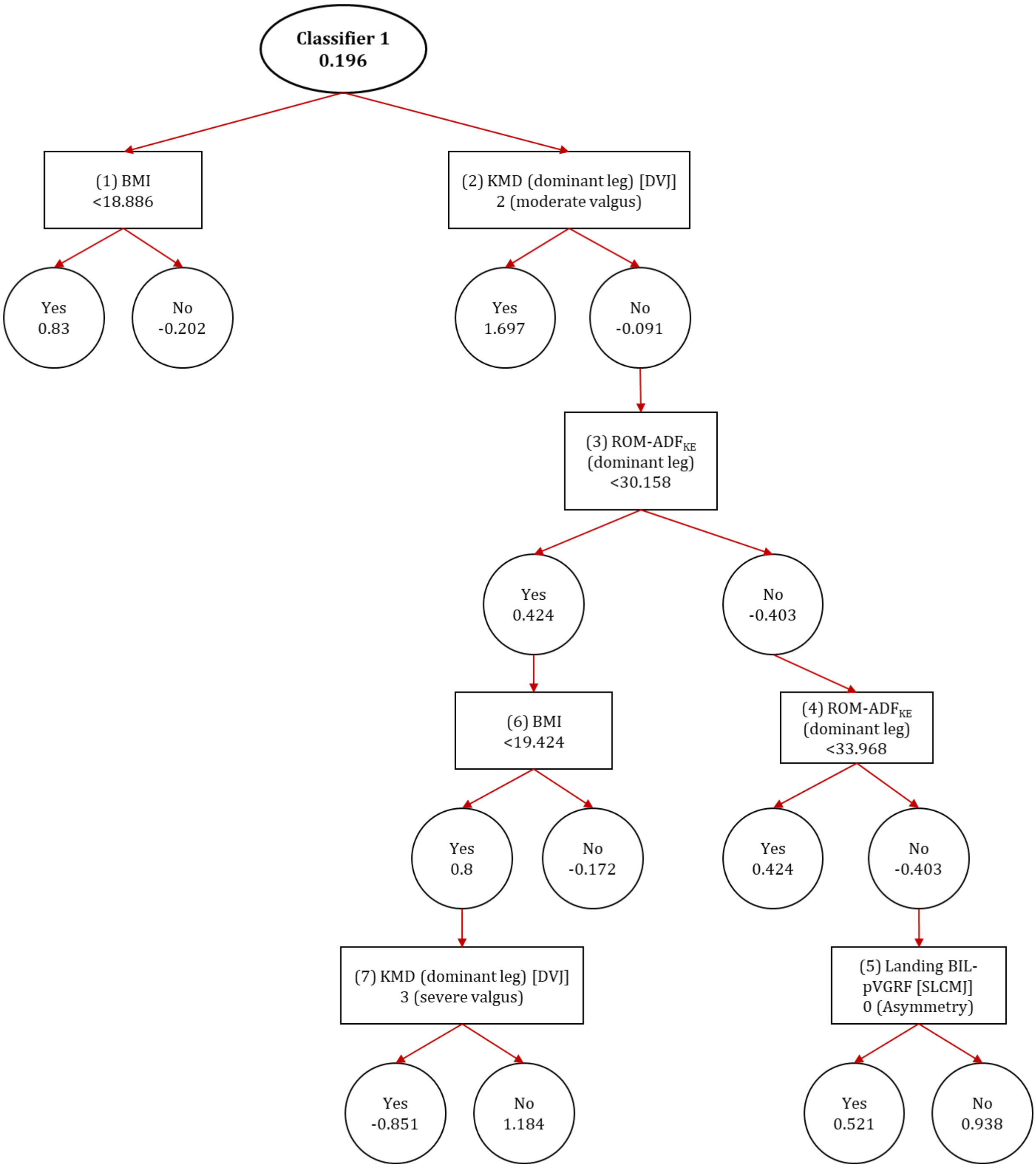


Figure 24. The features in the model are listed from the relatively most (top) to least (bottom) important by their global impact on the model. Dots representing the SHAP values for each feature value of an individual in the dataset are plotted horizontally next to the feature. Overlapping points are jittered in y-axis direction, so a sense of the distribution of the Shapley values per variable is achieved. The higher the absolute value (either positive or negative), the higher the importance in the classification decision-making process. Positive SHAP values represent a higher probability of a negative prediction (i.e., No injured). Each dot is colored by the value (i.e., measured value) of the feature for an individual, where blue represents the lower values (e.g., lower BMI score), and red the higher values (e.g., higher BMI scores).

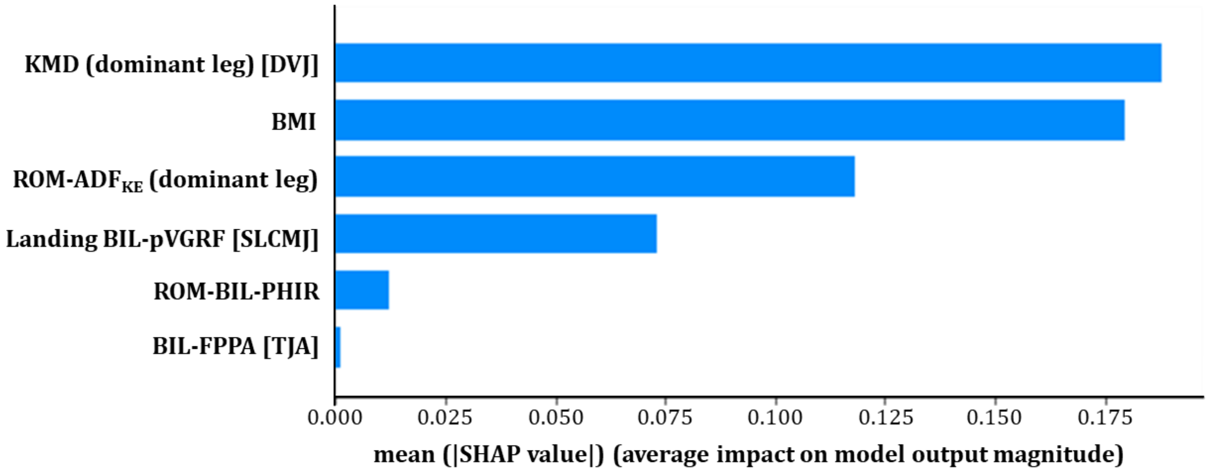


Figure 25. Graphical representation of the first classifier. Prediction nodes are represented by ellipses and splitter nodes by rectangles. Each splitter node is associated with a real valued number indicating the rule condition, meaning: If the feature represented by the node satisfies the condition value, the prediction path will go through the left child node; otherwise, the path will go through the right child node. The numbers before the feature names in the prediction nodes indicate the order in which the different base rules were discovered. This ordering can to some extent indicate the relative importance of the base rules. The final classification score produced by the tree is found by summing the values from all the prediction nodes reached by the instance, with the root node being the precondition of the classifier. If the summed score is greater than zero, the instance is classified as true (low risk of LE-ST injury).

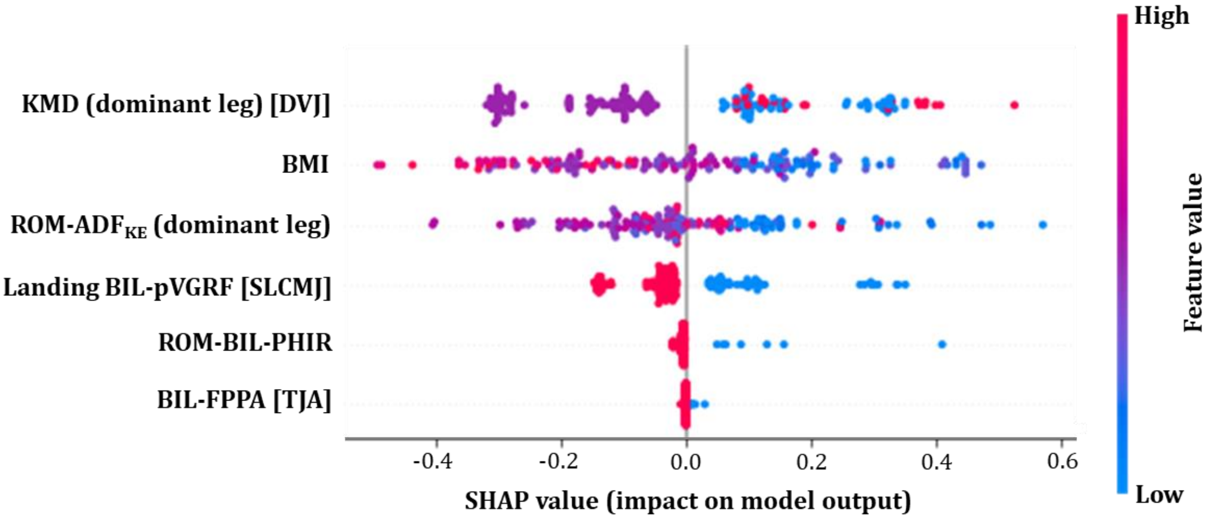


Figure 26. SHAP values for each feature.

7.4 Discussion

The present study has applied contemporary statistical approaches derived from Machine Learning and Data Mining environments to build a robust (AUC = 0.700) screening model based on six pre-season field-based measures to predict LE-ST injuries in male youth football players. In particular, the model developed allows to successfully identify one out of every two (TP rate = 51.1%) and four out of every five (TN rate = 81.2%) youth male football players at high or low risk of suffering a LE-ST injury throughout the in-season phase, respectively.

The ability of the model built in the current study to predict LE-ST injuries is similar to the one obtained in the model developed by Oliver et al. [67] (AUC = 0.663, TP rate = 55.6%, TN rate = 74.2%) but lower than the one reported by Rommers et al.'s model [68] (AUC = 0.850, TP rate = 85%), both using elite-level male youth football players. Three different arguments may partially explain the higher performance scores reported by Rommers et al.'s model [68] compared to those shown in the prediction models built by Oliver et al. [67] and us.

The first argument that may be used to explain these differences in models' performance is the larger number of players that were enrolled in the study conducted by Rommers et al. [68] (*n* = 734) in comparison with Oliver et al.'s study [67] (*n* = 355) and the current research (*n* = 260). In studies dealing with class imbalance problems, such as the LE-ST injury phenomenon, in which the number of injured players (minority class) prospectively reported is always much lower than the non-injured players (majority class) [107–110], large sample sizes may be required to ensure having enough instances in the minority class to avoid them being considered as noise by the learning algorithms during the process of building models. In this sense, Japkowicz & Stephen [338] demonstrated that the error rate caused by imbalanced class distribution decreases when the number of examples of the minority class is representative. Therefore, in the model built by Rommers et al. [68], patterns that were defined by injury players could have been better learned and this may have positively impacted on its predictive ability.

The second argument relies in the fact that the imbalance ratio (IR = ∑injured players / ∑non-injured players) of the dichotomic class variable (injury yes or no) in Rommers et al.'s study [68] (IR = 0.69) approximately doubles and triples the ones reported in both Oliver et al.'s study [67] (IR = 0.39) and the current study (IR = 0.21), respectively. Differences in the injury definition used (any medical attention injury [Rommers et al. [68]] vs. only lower extremity non-contact injury [Oliver et al. [67] and us]) may partly explain that nearly half of the elite youth football players prospectively followed up by Rommers (300 players out of the 734 total players recruited) sustained an injury that refrain them from sport participation for at least four days (mild to severe injuries), while both Oliver et al.'s study (99 injured players out of 355 players recruited) and the current research reported that less than 28% of the players followed had an injury of such severity. The more specific definition (such as the LE-ST injury used in our study), the better understanding of the risk factors underlying the most burdensome injuries happened in youth football. However, class distribution (i.e., the proportion of instances [e.g., football players] belonging to each class [injured vs non-injured] in a data-set) plays a key role in classification problems. Highly imbalance data sets usually tend to suffer from class overlapping and/or small disjuncts, which difficult classifier learning [108]. Thus, although Oliver et al. [67] and the current study have used learning algorithms specially designed to deal with class imbalance problems and acceptable validity results were reported, the lower IR in the study of Rommers et al. [68] may have allowed lower misclassification rates and hence, better accuracy scores.

Finally, the last aspect that might have also played a key role in the higher predictive ability observed in the model built by Rommers et al. [68] is the less exigent resampling method applied to determine its ability to predict injuries. In particular, Rommers et al. [68] used a hold out with 20% of the same as test data to assess the predictive ability of its model whereas Oliver et al. [67] employed a five-fold cross validation technique and the presented study repeated 1000 times this filed-fold cross validation procedure in an attempt to achieve a more accurate estimation of the models' performance. It has been suggested that the k-fold cross validation is a more powerful preventive technique against model performance overfitting than the hold out because the validation metrics calculated for each fold are combined to give an overall estimate of the model's performance, reducing the risk of accidentally getting a really optimistic test data [313,339].

Another main finding of the current study is that of the 135 potential risk factors obtained from the different questionnaires and field-based tests carried out during the pre-season testing session conducted in each football team, only six (Table 17) were finally selected as the most important features related to LE-ST injuries. This subset comprised by an anthropometric parameter (BMI), three neuromuscular measures (KMD in the dominant leg [DVJ], landing BIL-pVGRF [SLCMJ] and BIL-FPPA [TJA]) and two joint ROMs (ROM-ADF$_{KE}$ in the dominant leg and ROM-BIL-PHIR) allowed to build a robust model to predict LE-ST injuries in male youth football players. Therefore, one of the main advantages of the model presented in this study is that only five minutes are needed to run the screen in a single player, unlike Rommers et al.'s model [68] that requires 20 measures obtained from a questionnaire and five different field-based tests, which can take longer than 45 min to collect all of them in a single player. The six measures selected have been consistently identified as primary injury risk factors for LE-ST injuries in several prospective and biomechanical studies conducted in pediatric athlete population [53,59,67,69]. As it is shown in Figure 25, a higher knee medial displacement (i.e., dynamic knee valgus) of the dominant leg in DVJ (SHAP score = 0.19), higher body mass index (SHAP score = 0.18), lower ADF_{KE} ROM of the dominant leg (SHAP score = 0.12) and the presence of asymmetries in pVGRF at landing from SLCMJ (SHAP score = 0.07) were identified as the four most important predictor for LE-ST injury. Bilateral differences > 8° and 10% in PHIR ROM (SHAP score = 0.01) and FPPA measured through the TJA maneuver (SHAP score < 0.01), respectively, affected the prediction for a smaller amount. It is out of the scope of this study describing the potential mechanisms that justify the reasons why each of these six measures itself might increase the risk of suffering a LE-ST injury in this cohort of football players. These six measures are considered modifiable risk factors and hence, some strategies can be implemented to optimise their values in each of the football players to ensure a situation with low probability of suffering a LE-ST injury. In this sense, previous studies have demonstrated that the regular application of short (not more than 20-25 min) bouts of multi-component exercises during training sessions can significantly improve, among other aspects, the neuromuscular control and performance and help to control body mass in team sport athletes (including young football players) [194,199,340]. Therefore, these multi-component programs may be powerful tools to be used by practitioners as preventive measures in those football players categorised at high risk of LE-ST injury.

Finally, it should be highlighted that simulations ran in our laboratory showed that giving the four basic algorithms used in this study (C4.5, ADTree, SMO and KNN) the opportunity to select by themselves (according to their own criteria) the most relevant variables did not allow to improve the predictive performance of the models but increase its complexity. Furthermore, simulations were also run with other attribute evaluators (such as InfoGain and Correlations) to select relevant features and none of them improved the performance scores presented in this study.

7.4.1 Limitations

The current study has a number of limitations that must be acknowledged. The first potential limitation is the population used. The sport background of participants was non-elite young football players and the generalisability to other sport modalities and level of play cannot be ascertained. Although all the measures recorded during the screening session are purported as LE-ST injury risk factors, there are a number of other measures from different questionnaires and field-based tests not included in this study (due to time constraints) which have been associated with LE-ST injury (e.g., trunk stability measures, relative leg stiffness, and change of direction kinematics [265,341]) and that may have improved the ability to predict LE-ST injuries in this cohort of young athletes. Likewise, the complex interaction of growth, maturity timing and tempo across players of varying age and maturity along with the fact that a non-single type of injury (e.g., hamstring strains, ACL tears) was analysed may have reduced the ability of the feature selection algorithm applied to the data set to reduce its dimensionality (through deleting redundant and not relevant measures), and thus could have penalised the performance of the model. Future studies should assess whether (or not) the use of more homogeneous samples, in terms of maturity status, and focusing the attention on single types of injury may increase the predictive ability of the screening models. Another limitation of the current study is that only the first occurring injury of every player was considered in the analysis. Consequently, because players can sustain multiple injuries over one season, the analysis does not reflect the complete picture. Furthermore, players were only tested at the end of the pre-season seasons and then monitored injuries over the entire season. Anthropometric, physical fitness, neuromuscular capability and biomechanical measures change over the course of the season due to training and natural development [69,271], which may have negatively impacted on model ability to predict injuries. Therefore, future studies should conduct the screening session every few months in order to have accurately assessments closer to the time of injury.

7.5 Conclusions

Thanks to the application of novel machine learning techniques, the current study has developed a screening model based on six field-based measures that showed moderate (AUC score = 0.700, TPrate = 51.1% and TNrate = 81.2% determined through the exigent repeated cross-validation resampling technique) for identifying young football players at risk of LE-ST injury. Furthermore, and thanks to the SHAP approach, it is possible to determine the influence of each risk factor selected (i.e., BMI, KMD [dominant leg] in the DVJ, landing BIL-pVGRF [SLCMJ], BIL-FPPA [TJA], ROM-ADF$_{KE}$ [dominant leg] and ROM-BIL-PHIR) in the prediction model (injury yes vs. injury no). Given that these measures require little equipment to be recorded and can be employed quickly (approximately 5 min) and easily by trained staff in a single player, the model developed in this study should be included as an essential component of the injury management strategy in youth football.

7.6 Appendices

Appendix 17. TRIPOD checklist.

	Item	Recommendation	# Page
Title and abstract			
Title	1	Identify the study as developing and/or validating a multivariable prediction model, the target population, and the outcome to be predicted.	185
Abstract	2	Provide a summary of objectives, study design, setting, participants, sample size, predictors, outcome, statistical analysis, results, and conclusions.	36
Introduction			
Background/ objectives	3a	Explain the medical context (including whether diagnostic or prognostic) and rationale for developing or validating the multivariable prediction model, including references to existing models	185, 186
	3b	Specify the objectives, including whether the study describes the development or validation of the model, or both	187
Methods			
Source of data	4a	Describe the study design or source of data (e.g., randomized trial, cohort, or registry data), separately for the development and validation datasets, if applicable	187, 188
	4b	Specify the key study dates, including start of accrual; end of accrual; and, if applicable, end of follow-up	188
Participants	5a	Specify key elements of the study setting (e.g., primary care, secondary care, general population) including number and location of centres.	187
	5b	Describe eligibility criteria for participants.	187
	5c	Give details of treatments received, if relevant.	NA
Outcome	6	Clearly define the outcome that is predicted by the prediction model, including how and when assessed	193
	6b	Report any actions to blind assessment of the outcome to be predicted.	NA
Predictors	7a	Clearly define all predictors used in developing the multivariable prediction model, including how and when they were measured	188, 193
	7b	Report any actions to blind assessment of predictors for the outcome and other predictors	NA
Sample size	8	Explain how the study size was arrived at.	NA
Missing data	9	Describe how missing data were handled (e.g., complete-case analysis, single imputation, multiple imputation) with details of any imputation method	194
Statistical analysis methods	10a	Describe how predictors were handled in the analyses	194, 195
	10b	Specify type of model, all model-building procedures (including any predictor selection), and method for internal validation	195, 196
	10c	For validation, describe how the predictions were calculated	194

	Item	Recommendation	# Page
	10d	Specify all measures used to assess model performance and, if relevant, to compare multiple models.	194-196
	10e	Describe any model updating (e.g., recalibration) arising from the validation, if done.	NA
Risk groups	11	Provide details on how risk groups were created, if done.	194, 196
Development vs. validation	12	For validation, identify any differences from the development data in setting, eligibility criteria, outcome, and predictors.	194
Results			
Participants	13a	Describe the flow of participants through the study, including the number of participants with and without the outcome and, if applicable, a summary of the follow-up time. A diagram may be helpful.	197
	13b	Describe the characteristics of the participants (basic demographics, clinical features, available predictors), including the number of participants with missing data for predictors and outcome.	189
	13c	For validation, show a comparison with the development data of the distribution of important variables (demographics, predictors, and outcome).	NA
Model development	14a	Specify the number of participants and outcome events in each analysis.	197
	14b	If done, report the unadjusted association between each candidate predictor and outcome.	202
Model specification	15a	Present the full prediction model to allow predictions for individuals (i.e., all regression coefficients, and model intercept or baseline survival at a given time point).	201, 202
	15b	Explain how to use the prediction model.	198
Model performance	16	Report performance measures (with CIs) for the prediction model	200
Model updating	17	If done, report the results from any model updating (i.e., model specification, model performance).	NA
Discussion			
Limitations	18	Discuss any limitations of the study (such as nonrepresentative sample, few events per predictor, missing data).	205
Interpretation	19a	For validation, discuss the results with reference to performance in the development data, and any other validation data.	203
	19b	Give an overall interpretation of the results, considering objectives, limitations, results from similar studies, and other relevant evidence.	203-205
Implications	20	Discuss the potential clinical use of the model and implications for future research.	206

Appendix 18. Description of the personal or individual injury risk factors recorded.

Name	**Labels**
Player position	Goalkeeper, Defender, Midfielder or Forward
Chronological age (y)	Numeric
Age group	U12, U14, U16 or U19
Dominant leg	Right, Left or Two-footed
Years of playing football (y)	Numeric
Training frequency (days)	Numeric
Body mass (kg)	Numeric
Stature (cm)	Numeric
Body mass index (kg/m^2)	Numeric
Leg length (cm)	Numeric
Tibia length (cm)	Numeric
Maturity offset	Numeric
Age at peak height velocity	Numeric

Appendix 19. Description of the psychological injury risk factors recorded.

Name	**Labels**
Anxiety-Trait	Numeric
Profile of Mood States (POMS)	
Tension	Numeric
Depression	Numeric
Anger	Numeric
Vigour	Numeric
Fatigue	Numeric
Confusion	Numeric
Friendliness	Numeric
Psychological Characteristics related to the Sport Performance (CPRD)	
Stress control	Numeric
Performance evaluation	Numeric
Motivation	Numeric
Mental skills	Numeric
Team cohesion	Numeric
Global score	Numeric

Appendix 20. Measures obtained from the Jump tests.

Name	Labels	
	Dominant leg	**Non-dominant leg**
Tuck Jump Assessment (TJA)		
FPPA	≤0 (none), 1–9 (minor), 10–20 (moderate), >20 (severe)	≤0 (none), 1–9 (minor), 10–20 (moderate), >20 (severe)
BIL-FPPA	No Asymmetry or Asymmetry	
HF_IC (°)	Numeric	
KF_IC (°)	Numeric	
ADF_IC (°)	Numeric	
HF_PF (°)	Numeric	
KF_PF (°)	Numeric	
ADF_PF (°)	Numeric	
HF_ROM (°)	Numeric	
KF_ROM (°)	Numeric	
ADF_ROM (°)	Numeric	
Drop Vertical Jump (DVJ)		
H (cm)	Numeric	
CT (ms)	Numeric	
RSI (mm/ms)	Numeric	
FPPA	≤0 (none), 1–9 (minor), 10–20 (moderate), >20 (severe)	≤0 (none), 1–9 (minor), 10–20 (moderate), >20 (severe)
BIL-FPPA	No Asymmetry or Asymmetry	
KMD	≤0 (none), 0.1-3.0 (minor), 3.1-6.0 (moderate), >6.0 (severe)	≤0 (none), 0.1-3.0 (minor), 3.1-6.0 (moderate), >6.0 (severe)
BIL-KMD	No Asymmetry or Asymmetry	
KASR	Varus or Valgus	
KSD (cm)	Numeric	
HF_IC (°)	Numeric	
KF_IC (°)	Numeric	
ADF_IC (°)	Numeric	
HF_PF (°)	Numeric	
KF_PF (°)	Numeric	
ADF_PF (°)	Numeric	
HF_ROM (°)	Numeric	
KF_ROM (°)	Numeric	
ADF_ROM (°)	Numeric	
Countermovement Jump (CMJ)		
H (cm)	Numeric	

Name	**Labels**	
	Dominant leg	**Non-dominant leg**
Single-leg countermovement jump (SLCMJ)		
H (cm)	Numeric	Numeric
BIL-H	No Asymmetry or Asymmetry	
Take-off pVGRF (N·kg^{-1})	Numeric	Numeric
Landing-pVGRF (N·kg^{-1})	Numeric	Numeric
pLFT (ms)	Numeric	Numeric
Take-off BIL-pVGRF	No Asymmetry or Asymmetry	
Landing BIL-pVGRF	No Asymmetry or Asymmetry	
BIL-pLFT	No Asymmetry or Asymmetry	
Horizontal Jump tests		
SLJ (cm)	Numeric	
SHD (% leg length)	Numeric	Numeric
SHD-BIL	No Asymmetry or Asymmetry	

SLJ: standing long jump; SHD: single hop for distance; H: height; CT: contact time; RSI: reactive strength index; FPPA: frontal plane projection angle; HF: hip flexio; KF: knee flexion; ADF: ankle dorsiflexion; IC: initial contact; PF: peak flexion; ROM: range of motion; KSD: knee separation distance; KASR: knee-to-ankle separation ratio; KMD: knee medial displacement; pVGRF: peak vertical ground reaction force; pLFT: peak landing force timing; BIL: bilateral ratio.

Appendix 21. Measures obtained from the ROM-Sport battery.

Name	**Labels**	
	Dominant Leg	**Non-Dominant Leg**
ROM-PHF$_{KF}$ (°)	Numeric	Numeric
ROM-PHF$_{KE}$ (°)	Numeric	Numeric
ROM-PHE (°)	Numeric	Numeric
ROM-PHABD (°)	Numeric	Numeric
ROM-PHABD$_{HF}$ (°)	Numeric	Numeric
ROM-PHADD (°)	Numeric	Numeric
ROM-PHIR (°)	Numeric	Numeric
ROM-HER (°)	Numeric	Numeric
ROM-PKF (°)	Numeric	Numeric
ROM-ADF$_{KE}$ (°)	Numeric	Numeric
ROM-ADF$_{KF}$ (°)	Numeric	Numeric
ROM-BIL-PHF$_{KF}$	No Asymmetry or Asymmetry	
ROM-BIL-PHF$_{KE}$	No Asymmetry or Asymmetry	
ROM-BIL-PHE	No Asymmetry or Asymmetry	
ROM-BIL-PHABD	No Asymmetry or Asymmetry	
ROM-BIL-PHABD$_{HF}$	No Asymmetry or Asymmetry	
ROM-BIL-PHADD	No Asymmetry or Asymmetry	
ROM-BIL-PHIR	No Asymmetry or Asymmetry	
ROM-BIL-PHER	No Asymmetry or Asymmetry	
ROM-BIL-PKF	No Asymmetry or Asymmetry	
ROM-BIL-ADF$_{KE}$	No Asymmetry or Asymmetry	
ROM-BIL-ADF$_{KF}$	No Asymmetry or Asymmetry	

ROM: range of motion; PHF$_{KF}$: passive hip flexion with the knee flexed; PHF$_{KE}$: passive hip flexion with the knee extended; PHE: passive hip extension; PHABD: passive hip abduction; PHABD$_{HF}$: passive hip abduction at 90° of hip flexion; PHADD: passive hip adduction; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF$_{KE}$: passive ankle dorsiflexion with the knee extended; ADF$_{KF}$: passive ankle dorsiflexion with the knee flexed; BIL: bilateral ratio.

Appendix 22. Measures obtained from the Y-Balance test.

Name	**Labels**	
	Dominant Leg	**Non-Dominant Leg**
YBalance-Anterior (%leg length)	Numeric	Numeric
YBalance-PosteroMedial (%leg length)	Numeric	Numeric
YBalance-PosteroLateral (%leg length)	Numeric	Numeric
BIL-YBalance-Anterior	No Asymmetry or Asymmetry	
BIL-YBalance-PosteroMedial	No Asymmetry or Asymmetry	
BIL-YBalance-PosteroLateral	No Asymmetry or Asymmetry	
YBalance-Composite (%leg length)	Numeric	Numeric

BIL: bilateral ratio.

Appendix 23. Measures obtained from the Sprint.

Name	**Labels**
10m-Sprint (s)	Numeric
20m-Sprint (s)	Numeric
10to20m-Sprint (s)	Numeric
Vmax ($m \cdot s^{-1}$)	Numeric
M_F0 ($N \cdot kg^{-1}$)	Numeric
V(0) ($m \cdot s^{-1}$)	Numeric
Pmax ($W \cdot kg^{-1}$)	Numeric
DRF (%)	Numeric
FV ($N \cdot s \cdot m^{-1} \cdot kg^{-1}$)	Numeric
RF-10m ($N \cdot kg^{-1}$)	Numeric
RFPeak (%)	Numeric

Vmax: maximal velocity; M_F0: theoretical maximal force; V(0): theoretical maximal velocity; Pmax: maximal power; DRF: decrease in the ratio of horizontal-to-resultant force; FV: slope of the force-velocity relationship; RF: ratio of the net horizontal-to-resultant force; RFPeak: maximal ratio of horizontal-to-resultant force.

Appendix 24. Scheme of the algorithms selected in data set.

Lower extremity non-contact soft tissue injuries
SBAG [ADTree]
(1) meta.AttributeSelectedClassifier '-E \"CfsSubsetEval -P 1 -E 1\" -S \"GreedyStepwise -B -T -1.7976931348623157E308 -N -1 -num-slots 1\" -W meta.MultiSearch -- -E FM -search \"weka.core.setupgenerator.MathParameter -property classifier.classifier.numOfBoostingIterations -min 5.0 -max 50.0 -step 1.0 -base 10.0 -expression I\" -class-label 1 -algorithm \"meta.multisearch.DefaultSearch -sample-size 100.0 -initial-folds 2 -subsequent-folds 10 -initial-test-set . -subsequent-test-set . -num-slots 1\" -log-file /Applications/weka-3-8-3 -S 1 -W meta.Bagging -- -P 100 -S 1 -num-slots 1 -I 100 -W meta.FilteredClassifier -- -F \"supervised.instance.SMOTE -C 0 -K 3 -P 250.0 -S 1\" -S 1 -W trees.ADTree -- -B 10 -E -3 -S 1' -1151805453487947577

PART III

CONCLUSIONS

8

CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

8.1 General conclusions

The five studies presented in this doctoral thesis (a) provide a comprehensive overview of the incidence, burden, and pattern of injuries in youth football players, in general, as well as an specific picture of the extent of the injury problem in Spanish male youth football teams, in particular, (b) improve the understanding about the influence of growth and maturation on potential risk factors such as flexibility and neuromuscular control measures, and (c) present a *user friendly* screening model to identify youth footballers at high or low risk for non-contact lower extremity soft tissue injuries by applying novel Machine Learning techniques. These findings may assist clinicians, grass-roots coaches, and physical trainers in the decision-making process of injury prevention.

The main conclusions of this thesis are listed below:

Study 1. *Epidemiology of injuries in male and female youth football players: a systematic review and meta-analysis*.

1. Youth football players are at high risk of injury, especially during match play.
2. Male youth football players tend to sustain predominantly muscle/tendon injuries to the thigh.
3. Although slight/minimal injuries are the most common, the number of severe injuries is very alarming.
4. The incidence rate of injuries increases with advances in chronological age, and the risk of sustaining an injury during matches is higher in elite (high-level) than sub-elite (low-level) male youth players.

Study 2. *Incidence, burden, and pattern of injuries in Spanish male youth football players: a prospective cohort study.*

5. Spanish male youth football players are also at high risk of injury; one in three boys is likely to sustain a time-loss injury over the course of a competitive season.
6. Hamstring muscle injuries represent the most burdensome diagnosis.
7. There is an increased risk of overuse injuries during the adolescent growth spurt, resulting in players around the peak height velocity suffering the highest time loss from playing football.

Study 3. *Effects of age and maturation on lower extremity range of motion in male youth football players.*

8. No significant differences in lower extremity range of motion are reported regarding the chronological age and maturity status of youth football players.
9. A large percentage of total number of youth players shows restrictions on passive hip flexion with knee extended, passive knee flexion, and ankle dorsiflexion with knee flexed range of motion measures.
10. No bilateral differences between dominant and non-dominant legs are identified.

Study 4. *Reliability, validity, and maturation-related differences of frontal and sagittal plane landing kinematic measures in drop jump and tuck jump screening tests.*

11. Both the drop jump and the tuck jump tests are reliable tools to assess frontal and sagittal plane lower-extremity landing kinematics using 2-dimensional video-analysis in youth football players.
12. Landing technique is task-dependent, and greater knee valgus in the frontal plane and reduced hip and knee flexion patterns in the sagittal plane can be expected for the tuck jump assessment.
13. The tuck jump reflects different strategies to control the impact force during landings across maturation groups, with players classified in the pre-pubertal group displaying a higher dynamic valgus but also increased hip and knee flexion angles (especially at initial contact) compared to players at circa-pubertal and post-pubertal groups.

Study 5. *A novel machine learning approach to determine the risk of lower extremity soft tissue injury in male youth football players.*

14. The limited ability to accurately predict a future soft tissue (muscle, tendon and/or ligament) injury in youth football players reinforces the multifactorial and complex nature of sport injuries.

15. Dynamic knee valgus, body mass index, joint range of motion (ankle dorsiflexion), and asymmetries (hip internal rotation range of motion, dynamic knee valgus and vertical ground reaction forces at landing) have been identified as primary risk factors for increasing the risk of suffering a new soft tissue injury in male youth football players.

8.2 Limitations and recommendations for future research

This doctoral thesis is not without limitations. Most of them have been discussed in each of the different studies previously presented (chapters 3 to 7). In addition, this section highlights some general limitations that can be used as a starting point for future research:

1. *To describe the injury profile of different cohorts of youth athletes*. This doctoral thesis has provided the injury profile of young male footballers showing the incidence, burden, and pattern of injuries in this population. However, this injury profile may likely differ for female players and other team sports. Based on the reduced number of studies and the low quality of evidence regarding the injury incidence in female youth football players, more research is needed to accurately determine the injury profile in this sex. Furthermore, potential differences according to the injury pattern (location, type, and severity) should be analysed across chronological ages, maturity states, and levels of play. Special attention should be also paid to youth-specific occurrences, such as growth-related injuries.

2. *To deepen understanding of the interaction between growth and maturation and injury risk.* While estimating maturity status using the predictive equation proposed by Mirwald et al. [221] has been a commonly accepted method in applied settings, the reported standard error of approximately 6 months, and the lower accuracy to predict the age at peak height velocity when the player is further away from this age, limits its use. In this sense, the method based on the percentage of final estimated adult height proposed by Khamis and Roche [342] has been recently recommended as a feasible and more accurate alternative [343]. Therefore, future studies should consider this non-invasive equation to analyse potential interactions between maturity and other injury risk factors. Likewise, youth players are in a process of continuous but non-linear developmental changes until reaching adulthood and thus, anthropometric measures and maturation may experience periods of rapid changes over the course of the season. The analysis of the maturity tempo and growth rates could better describe then the influence of maturation process on injury risk than the maturity status at a singular time point.

3. *To extend the analysis of abnormal kinematic patterns to other body locations and high-impact dynamic actions*. In this thesis, it has been analysed the kinematic pattern of the knee joint in the frontal plane, and hip, knee, and ankle joints in the sagittal plane during landing tasks. However,

other kinematic patterns such as increased frontal plane trunk [344,345] and pelvic [346] motions have been also proposed as potential risk factors for non-contact knee injuries, so future studies should evaluate the reliability, validity, and possible maturation-related differences for these kinematic variables. Due to their importance as injury mechanisms [341], acceleration and deceleration as well as cutting manoeuvres should be assessed to provide a holistic view of the movement competency of young players.

4. To include more evidence-based risk factors in the prediction model. Despite a range of variables that had been previously proposed in the existing literature as potential injury risk factors were assessed, there are several personal, psychological and neuromuscular measures that have been associated with lower extremity soft tissue injuries in youth athletes (e.g., trunk stability [265], muscle stiffness [265]) not included in the prediction model (due to time constraints). Probably, the inclusion of additional variables that can be collected from different questionnaires and field-based tests might improve the ability to predict injuries of the proposed model. Based on the variability of anthropometric measures and motor competency along the youth participation in sport, a focus on a particular age range and/or developmental stage could also increase the ability of the prediction model to identify players at high risk of sustaining an injury.

5. To develop injury prediction models that consider variations in players' health status over the course of the competitive season. Although including new tests for the assessment of additional evidence-based risk factors could improve the accuracy of the prediction model, it should be noted that preseason screening batteries will still offer a static picture of the physical, physiological, and psychological status of youth football players at this specific time-point. However, anthropometric and motor performance measures may change over the course of the season due not only to natural development but also to training and competition adaptations. Therefore, future studies need to examine if the implementation of screening batteries at different time points of the competitive season (and thus closer to the time of injury events) may help the understanding of other potential factors such as accumulated fatigue, improving the ability to predict injuries.

6. To implement preventive measures once players at high risk are identified. The sequence of prevention of sports injuries [16–18] establishes that once the extent of the problem and the aetiology are studied, the next steps are to design and implement preventive strategies based on the data obtained, and subsequently assess the effectiveness of the preventive measure applied. Thus, another limitation of this thesis and a future line of investigation is the need to corroborate in a real-world context the results of the last study (*Chapter 7*), establishing individualised preventive programmes and based on the identified risk factors for those players who present a higher risk of injury.

9

CONCLUSIONES, LIMITACIONES Y RECOMENDACIONES PARA FUTURAS INVESTIGACIONES

9.1 Conclusiones generales

Los cinco estudios presentados en esta tesis doctoral (a) proporcionan una visión global de la incidencia, las consecuencias y el patrón de las lesiones que se producen en jóvenes jugadores de fútbol, en general, así como una imagen específica de la magnitud del problema de las lesiones en los equipos de fútbol españoles, en particular; (b) amplían el conocimiento acerca de la influencia del proceso de crecimiento y maduración de los deportistas sobre otros posibles factores de riesgo, tales como la flexibilidad y el control neuromuscular; y (c) presentan un modelo de predicción de fácil utilización para identificar a aquellos futbolistas con alto o bajo riesgo de lesión en los tejidos blandos de las extremidades inferiores (sin contacto) mediante la aplicación de novedosas técnicas estadísticas derivadas del Aprendizaje Automático. Estos resultados pueden ayudar a los médicos, entrenadores y preparadores físicos en el proceso de toma de decisiones para la prevención de lesiones en el fútbol base.

A continuación, se enumeran las principales conclusiones obtenidas para cada uno de los cinco estudios presentados:

Estudio 1. *Epidemiología de lesiones en jóvenes jugadores de fútbol masculino y femenino: una revisión sistemática con meta-análisis*.

1. Los jóvenes jugadores presentan un alto riesgo de lesión, especialmente durante los partidos.
2. Las lesiones más frecuentes en chicos son de tipo músculo-tendinosas y se producen en el muslo.
3. Aunque las lesiones de menor gravedad (1-3 días de baja) son las más comunes, el número de lesiones severas en jóvenes futbolistas es alarmante.

4. La ratio de incidencia de lesiones incrementa con el avance de la edad, y el riesgo de sufrir una lesión en partidos es mayor para los jugadores de alto nivel (élite) en comparación con los de bajo nivel (sub élite).

Estudio 2. *Incidencia, consecuencias y patrón de lesiones de los jóvenes jugadores de fútbol en España: un estudio prospectivo de cohorte*.

5. Los jugadores de fútbol españoles también presentan un alto riesgo de lesión; uno de cada tres chicos podría sufrir una lesión que conlleve ausencia de la práctica del deporte a lo largo de una temporada competitiva.
6. Las lesiones musculares de isquiosurales representan el diagnóstico más grave.
7. Existe un mayor riesgo de lesión por sobreuso durante el periodo conocido como *estirón* puberal, lo que hace que los jugadores que se encuentran en torno al pico de velocidad de crecimiento sufran la mayor pérdida de tiempo de práctica del fútbol como consecuencia de las lesiones.

Estudio 3. *Efecto de la edad y la maduración sobre el rango de movimiento de la extremidad inferior en jóvenes jugadores de fútbol.*

8. No se han reportado diferencias significativas para el rango de movimiento de la extremidad inferior con respecto a la edad cronológica y el estado madurativo de los jóvenes jugadores de fútbol.
9. Un gran porcentaje del número total de jugadores analizados ha demostrado valores de rango de movimiento limitados para la flexión de cadera con rodilla extendida, flexión de rodilla y dorsiflexión de tobillo con rodilla flexionada.
10. No se han identificado diferencias bilaterales entre pierna dominante y no dominante para el rango de movimiento articular.

Estudio 4. *Fiabilidad, validez y diferencias relacionadas con el estado madurativo de varias medidas cinemáticas analizadas en el aterrizaje tras un salto para el plano frontal y sagital en las pruebas de drop jump y tuck jump.*

11. Tanto el drop jump como el tuck jump son herramientas fiables para el análisis cinemático en 2 dimensiones de la extremidad inferior en el plano frontal y sagital durante la maniobra de aterrizaje tras un salto.
12. La técnica de aterrizaje depende de la tarea. De acuerdo con los resultados obtenidos, un mayor valgo de rodilla en el plano frontal y una reducción de los patrones de flexión de cadera y rodilla en el plano sagital podría ser esperado durante el tuck jump en comparación con el drop jump.

13. El tuck jump refleja diferentes estrategias para controlar la fuerza de impacto durante el aterrizaje en función del estado madurativo, con los jugadores clasificados en el grupo prepuberal mostrando un mayor valgo dinámico pero también mayores ángulos de flexión de cadera y rodilla (especialmente en el contacto inicial) en comparación con los jugadores de los grupos circa-puberal y post-puberal.

Estudio 5. *Una novedosa aproximación basada en técnicas de Aprendizaje Automático para determiner el riesgo de lesión en tejido blando de la extremidad inferior en jóvenes jugadores de fútbol.*

14. La limitada capacidad para predecir con precisión una futura lesión del tejido blando (músculo, tendón y ligamento) en jóvenes jugadores de fútbol refuerza la naturaleza multifactorial y compleja de las lesiones deportivas.
15. El valgo dinámico, el índice de masa corporal, el rango de movimiento articular (dorsiflexión de tobillo), y las asimetrías (rango de movimiento de la rotación interna de cadera, valgo dinámico y pico de fuerza reactiva durante el aterrizaje tras un salto) han sido identificados como principales factores para el incremento del riesgo de sufrir una nueva lesión del tejido blando en jóvenes jugadores de fútbol.

9.2 Limitaciones y futuras líneas de investigación

La presente tesis doctoral no está exenta de limitaciones. La mayoría de ellas han sido comentadas en cada uno de los diferentes estudios desarrollados anteriormente (capítulos 3 a 7). En este apartado se destacan, por tanto, algunas limitaciones generales que pueden servir de punto de partida para futuras investigaciones:

1. Describir el perfil lesional de diferentes cohortes de jóvenes deportistas. Esta tesis doctoral ha proporcionado el perfil de lesión de los jóvenes futbolistas mostrando la incidencia, las consecuencias y el patrón de las lesiones que se producen en esta población. Sin embargo, es probable que este perfil sea diferente para las jugadoras y para jóvenes practicantes de otros deportes de equipo. Dado el reducido número y la baja calidad de los estudios que han analizado la incidencia de lesiones en jóvenes jugadoras de fútbol hasta la fecha, se hacen necesarias nuevas publicaciones que determinen con precisión el perfil de lesiones en chicas futbolistas. Igualmente, sería recomendable un análisis pormenorizado de las posibles diferencias para el patrón de lesiones (localización, tipo y gravedad) en función de la edad cronológica, el estado madurativo y el nivel de juego de los deportistas. Especial atención debería ponerse en lesiones específicas y únicas de estas edades, tales como aquellas relacionadas con el crecimiento.

2. Profundizar en el estudio de la interacción entre el crecimiento y la maduración del deportista y el riesgo de lesión. Si bien la estimación del estado de madurez mediante la ecuación predictiva propuesta por Mirwald et al. [221] ha sido un método tradicionalmente aceptado para su aplicación en el contexto real, el error estándar reportado de aproximadamente 6 meses, y la menor precisión para predecir la edad en la que se alcanza el pico de velocidad de crecimiento a medida que el jugador se aleja de esta edad, limita su uso. Recientemente, el método basado en la estimación del porcentaje de la estatura final adulta propuesto por Khamis y Roche [342] ha sido recomendado como una alternativa factible y más precisa [343]. Por lo tanto, los estudios futuros deberían considerar esta ecuación no invasiva para analizar las posibles interacciones entre maduración y otros factores de riesgo. Además, los jóvenes jugadores se encuentran en un proceso de continuos cambios (no lineales) en el desarrollo hasta llegar a la edad adulta y, por lo tanto, las medidas antropométricas y la maduración pueden experimentar periodos de rápido cambio a lo largo de la temporada. En consecuencia, el análisis del *tempo* madurativo podría describir mejor la influencia de este proceso de desarrollo biológico en el riesgo de lesión en el deporte.

3. Ampliar el análisis de posibles alteraciones en patrones cinemáticos a otras localizaciones corporales y acciones dinámicas de alto impacto. En esta tesis se ha analizado el patrón cinemático para la articulación de la rodilla en el plano frontal, y de las articulaciones de la cadera, rodilla y tobillo en el plano sagital en acciones de aterrizaje tras un salto. Sin embargo, otros patrones cinemáticos como el aumento de los movimientos del tronco [344,345] y de la pelvis [346] en el plano frontal también han sido propuestos como potenciales factores de riesgo de lesión de rodilla, por lo que futuros estudios deberían extender la evaluación de la fiabilidad, la validez y las posibles diferencias relacionadas con la maduración a estas variables cinemáticas. Debido a su importancia como mecanismos de lesión [341], la aceleración y desaceleración, así como las maniobras de cambio de dirección, deberían ser evaluadas para proporcionar una visión holística de la competencia motora de los jóvenes jugadores.

4. Incluir más factores de riesgo previamente evidenciados en el modelo predictivo. A pesar de que en esta tesis doctoral se han evaluado numerosas variables identificadas previamente como posibles factores de riesgo de lesión, existen todavía varias medidas personales, psicológicas y neuromusculares que se han asociado con las lesiones de los tejidos blandos de las extremidades inferiores en los jóvenes deportistas (e.g., la estabilidad del tronco [265], la rigidez muscular [265]) no incluidas en el modelo presentado (debido a limitaciones temporales). Probablemente, la inclusión de nuevas variables obtenidas por medio de diferentes cuestionarios y pruebas de campo podría mejorar la capacidad de predicción de lesiones de los modelos propuestos. Teniendo en cuenta la variabilidad de las medidas antropométricas y de la competencia motriz a lo largo de la participación de los jóvenes en el deporte, centrarse en un rango de edad y/o una etapa de desarrollo concreta también podría aumentar la capacidad del modelo de predicción para identificar a aquellos jugadores con alto riesgo de sufrir una lesión.

5. Desarrollar modelos de predicción de lesiones que tengan en cuenta las variaciones en el estado de salud de los jugadores a lo largo de la temporada competitiva. Aunque la inclusión de nuevas pruebas para la evaluación de factores de riesgo adicionales basados en la evidencia podría mejorar la exactitud del modelo de predicción, se debe tener en cuenta que las baterías de detección aplicadas durante la pretemporada seguirán ofreciendo una imagen estática del estado físico, fisiológico y psicológico de los jóvenes futbolistas en ese momento concreto. Sin embargo, las medidas antropométricas y de rendimiento motor pueden cambiar en el transcurso de la temporada debido no sólo al desarrollo natural, sino también a las adaptaciones derivadas del entrenamiento y la competición. Por lo tanto, futuras investigaciones deberían examinar si la aplicación de baterías de detección en diferentes momentos de la temporada competitiva (y, por lo tanto, más cerca del momento en que se producen las lesiones) puede ayudar a la identificación de otros factores potencialmente lesivos, como la fatiga acumulada, mejorando la capacidad de predecir las lesiones.

6. Aplicar medidas preventivas una vez identificados los jugadores en situación de alto riesgo de lesión. La *secuencia de prevención* de las lesiones deportivas [16–18] establece que, una vez estudiado el alcance del problema y su etiología, los siguientes pasos son el diseño y la implementación de estrategias preventivas a partir de los datos obtenidos, y la posterior evaluación de la eficacia de la medida preventiva aplicada. Por ello, otra de las limitaciones de esta tesis y una futura línea de investigación es la necesidad de corroborar en el contexto real los resultados del último estudio (*Capítulo 7*), estableciendo programas preventivos individualizados y basados en los factores de riesgo identificados para aquellos jugadores que presenten un mayor riesgo de lesión.

PART IV

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