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Youth Football Injury Epidemiology: A Prospective Study on Workload and Musculoskeletal Risk Factors

Dissertação elaborada com vista à obtenção do grau de Mestre em Treino de Alto Rendimento

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Abstract

Purpose: (A) To characterize the epidemiology of injury at an elite youth football academy. (B) To investigate the differences between injured and non-injured elite youth footballers in musculoskeletal screening and workload variables, for lower extremity non-contact soft tissue injuries; and for groin located and muscular type injuries.

Methods: (A) Prospective analysis of time-loss injuries from one hundred eighty-four elite youth male football players (age: 16.2±2.2 yrs) in a Portuguese academy (U14-U23) during the 2019-2020 season. Injury frequency, burden, incidence, and patterns were calculated. (B) A match-paired case approach was used to investigate differences between injured (n= 56) and non-injured (n= 56) groups for preseason musculoskeletal screening variables (passive knee fall out (PKFO), adductor squeeze (ASQZ), adductor squeeze bodyweight ratio ($ASQZ/BW_{ratio}$), dorsiflexion lunge test (DLT); single-leg countermovement jump (SL-CMJ)) and workload variables before injury (Cumulative sum; monotony; strain; acute: chronic workload ratio (ACWR); week to week change) using internal load (sRPE). Groin located injuries (n=14 vs n=14) and muscular injuries (n= 27 vs n=27) were also investigated.

Results: (A) A total of 129 time-loss injuries were observed. Injuries were more frequent in training but had a higher incidence and burden rate in match context. Overall incidence was 2.7 per 1000 hours, and burden rate 59.3 days lost per 1000 hours. The thigh was the most frequent location. Quadriceps was the most injured muscle group, mainly by sprinting and shooting mechanisms. Moderate injuries were more frequent, with a mean of 21.9±28 days lost to injury. Under 17 was the most affected team, with the highest-burden cross-product. (B) $ASQZ/BW_{ratio}$ was higher in non-injured players compared with injured players for lower body non-contact (0.64±0.11 vs 0.59±0.11; p=0.025) and groin injuries (0.64±0.08 vs 0.54±0.11; p=0.007). No other workload and musculoskeletal variable had significant differences between groups.

Conclusions: Characteristics of injury incidence, burden, and patterns differ among squads in elite youth football. Non-contact injuries in pre-adolescent players remain frequent, representing a threat to the young football player's safe development. $ASQZ/BW_{ratio}$ could be used to identify risk of injury for lower body non-contact and groin injuries. More data is necessary to clarify which musculoskeletal and workload factors are relevant to youth football injury occurrence.

Keywords: epidemiology; injury incidence; injury burden; workload; musculoskeletal screening; youth football; risk factors; football injury; load monitoring; injury prevention

Resumo

Objetivo: (A) Caracterizar a epidemiologia de lesões numa academia de futebol jovem de elite. (B) Investigar as diferenças entre jogadores lesionados e não lesionados para variáveis músculo-esqueléticas e carga de treino, para lesões sem contacto de membro inferior de tecidos moles; e para lesões localizadas na púbis e lesões do tipo muscular.

Métodos: (A) Análise prospetiva de lesões de cento e oitenta e quatro jogadores de futebol jovem de elite (idade, 16.2±2.2 anos) numa academia portuguesa (U14-U23) durante a época 2019-2020. A frequência, carga, incidência e padrões das lesões foram calculados. (B) Foi utilizada uma comparação entre pares para investigar as diferenças entre grupos lesionado (n= 56) e não lesionado (n= 56) para as variáveis músculo-esqueléticas de pré-época (queda passiva do joelho (PKFO), força de adutores (ASQZ), rácio força de adutores e de peso corporal (ASQZ/BWratio), teste de dorsiflexão em *lunge* (DLT); salto de contramovimento unilateral (SL-CMJ)) e variáveis de carga de treino (soma cumulativa; monotonia; *strain*; rácio agudo: crónico (ACWR); diferença entre semanas) usando carga interna (sRPE). Lesões localizadas na virilha (n=14 vs n=14) e lesões do tipo muscular (n= 27 vs n=27) também foram investigadas.

Resultados: (A) Foram observadas um total de 129 lesões. As lesões foram mais frequentes em treino, mas com maior incidência e severidade em jogo. A incidência foi de 2.7 lesões /1000 horas, e a severidade de 59.3 dias perdidos /1000 horas. A coxa foi o local mais frequente. O quadríceps foi o grupo muscular mais lesionado, principalmente por sprint e remate. Lesões de severidade moderada foram mais frequentes, com 21.9±28 dias perdidos por lesão. Os Sub17 foram a equipa mais afetada. (B) O ASQZ/BWratio foi mais elevado em jogadores sem lesão, em comparação com os jogadores lesionados (0.64±0.11 vs 0.59±0.11; p=0.025; d=0.401) para lesões do membro inferior sem contacto e lesões na virilha (0.64±0.08 vs 0.54±0.11; p=0.007; d=1.107). Nenhuma outra variável músculo-esquelética ou de carga de treino apresentou diferenças significativas entre grupos.

Conclusões: As características de incidência de lesão diferem entre equipas de futebol jovem de elite. As lesões sem contacto em jogadores jovens continuam frequentes, representando uma ameaça para o seu desenvolvimento saudável. O rácio ASQZ/BWratio poderá ser usado para determinar risco de lesão do membro inferior e, mais especificamente, para lesões localizadas na púbis.

Palavras-chave: epidemiologia; incidência de lesões; carga de treino; testes músculo-esqueléticos; futebol jovem; fatores de risco; lesões no futebol; monitorização da carga; prevenção de lesões

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List of abbreviations

/1000h – per 1000 hours of exposure

75%Hop - 75% of maximum hop and stick

A:C – Acute: chronic ratio

ABD – Abduction

ACL – Anterior cruciate ligament

ACWR – Acute chronic workload ratio

ADD – Adduction

AKE – Active knee extension

ASQZ – Adductor squeeze

$ASQZ/BW_{ratio}$ – Adductor squeeze / bodyweight ratio

AU – Arbitrary units

BMI – Body mass index

CI - Confidence interval

cm – centimetres

CMJ – countermovement jump

d – Cohen’s d

DLT_{diff} – Dorsiflexion lunge test absolute difference dominant/non-dominant

DLT_{ratio} – Dorsiflexion lunge test ratio dominant/non-dominant

ECC – Eccentric

ERot – External rotation

ES – Effect size

EWMA – Exponentially weighted moving average

GPS – Global positioning system

h - hours

H:Q – Hamstring-quadriceps ratio

HAGOS - Hip and groin outcome score

HHD – Handheld dynamometry

HR – Hazard ratio

HSR – High speed running

IB_{Matrix} – Injury burden cross-product of severity x incidence

IB_{rate} – Injury burden rate (days lost to injury per 1000 hours exposure)

ICC - Intraclass correlation coefficient

II – Injury incidence (number of injuries per 1000 hours exposure)

IKD – Isokinetic dynamometry

IOC - International Olympic committee

IR – Injury risk

IRot – Internal rotation

ISO – Isometric

Kg – Kilograms

LE – Lower extremity

LID – Low intensity distance

MA – Medical attention injury

min – Minutes

MON - Monotony

MON W-1 Monotony Week -1

MON W-2 - Monotony Week -2

MON W-3 - Monotony Week -3

MON W-4 - Monotony Week -4

MSK – Musculoskeletal

N – Newton

NCI – Non-contact injury

NCIR – Non-contact injury risk

º - degrees

OR – Odds ratio

p – P-value

PCMA - Pre-competition medical assessment

PHE - Periodic health examination

PKE – Passive knee extension

$\text{PKFO}_{\text{diff}}$ – Passive knee fall out absolute difference dominant/non-dominant

$\text{PKFO}_{\text{ratio}}$ - Passive knee fall out ratio dominant/non-dominant

PPE - Pre-participation examination

PROM – Patient-reported outcome measures

pVGRF – Peak vertical ground reaction force

r – Nonparametric effect size

RA – Rolling average

RI – Risk of injury

ROM – Range of motion

RPE – Rate of perceived exertion

RR – Relative Risk

RR – Risk ratio

RX – Radiography

SJ – Squat jump

$\text{SL-CMJ}_{\text{diff}}$ – Single leg countermovement jump absolute difference dominant/non-dominant

$\text{SL-CMJ}_{\text{ratio}}$- Single-leg countermovement jump ratio dominant/non-dominant

SLHD – Single leg hop for distance

SLR – Straight leg raise

sRPE – session rate of perceived exertion

sRPE sum - Cumulative sRPE sum

sRPE sum W-1 - Cumulative sRPE sum week -1 (AU)

sRPE sum W-2 - Cumulative sRPE sum week -2 (AU)

sRPE sum W-3 - Cumulative sRPE sum week -3 (AU)

sRPE sum W-4 - Cumulative sRPE sum week -4 (AU)

sRPE sum W-5 - Cumulative sRPE sum week -5 (AU)

STI – Soft tissue injury

STR – Strain

STR W-1 - Strain Week -1

STR W-2 - Strain Week -2

STR W-3 - Strain Week -3

STR W-4 - Strain Week -4

t – Independent samples T-test statistic

TJ – Tuck jump

TL – Time-loss injury

TRIMP – Training impulse

U – Mann-Whitney test statistics

U23, 19, 17, 16, 15, 14 – Under age 23, 19, 17, 16, 15, 14

Vs - versus

W-2 to W-1 - Week -2 to week -1 change (%)

W-3 to W-2 - Week -3 to week -2 change (%)

W-4 to W-3 - Week -4 to week -3 change (%)

W-5 to W-4 - Week -4 to week -3 change (%)

W-5, -4, -3, -2, -1 – Week prior to injury -5, -4, -3, -2, -1

Yrs – Years

1. Introduction

Football is a contact sport with multiple repeated high-speed efforts, multidirectional movements as sprinting, jumping, pivoting, cutting, kicking, and rapid changes of direction, making it a sport with high injury risk (Hart et al., 2019). Modern football increased in high-intensity running and sprinting distance (30–35 %), previously linked with non-contact soft tissue injuries (Barnes et al., 2014; Buckthorpe et al., 2019; McCall et al., 2015).

As previous injury is a non-modifiable lifelong factor, it is critical to avoid the first injury. The impact that an injury has on an athlete's career is beyond physical impairment. Career ending or long-term injuries have psychological, financial, and impact on a player’s future health (Dallinga et al., 2012; Hägglund et al., 2013). The impact of an injury on a professional football club can also be measured by the financial losses with injured players wages (Hughes et al., 2019; Price et al., 2004). Avoiding injuries ensures high player availability and allows coaches to have most of the squad available for training and select their best starting players for competition (Ekstrand, 2016). Moreover, lower injury rates have been linked with higher team financial and competitive success (Hägglund et al., 2013).

The development of youth football players in professional clubs' academies involves early exposure to high training loads (Bowen et al., 2017). This is necessary to prepare players for the increasing demands of contemporary professional match play (Barnes et al., 2014). Nevertheless, with insufficient time to recover and adapt, this repetitive stress can lead to injury (Drew et al., 2016). Youth and Professional football differ in injury incidence (matches and training), but not in the pattern of injury location (Lower Limb - Thigh, Groin, Ankle, Knee), injury type (strains, sprains, and contusions), suggesting a common feature of injury (Pfirrmann et al., 2016). Injury impact on youth football must be considered from the player's development standpoint as extended periods of absence will impact player involvement in skill and physical development activities and participation in competitive match play (Price et al., 2004).

Injuries are multifactorial and cannot be fully prevented, but the risk of injuries can certainly be reduced (Van der Horst et al., 2014). To establish injury prevention programs, it is important to identify risk factors associated with the occurrence of injury (Chamari et al., 2016). Van Mechelen et al. (1992), suggested a 4 steps injury prevention model. First, identify the problem, establishing the extent of the injury. Nowadays, despite having more resources, injury incidence in professional football remains high, with players missing 37 days due to injury each season, most commonly in lower extremities due to non-contact soft tissue injuries (Ekstrand et al., 2011). The second step of the model is to establish the aetiology, mechanisms, and injury risk factors. Most frequent risk factors can be divided into a) Intrinsic (previous injury (Arnason et al., 2004; Bourne et al., Mosler et al., 2018), age (Hägglund et al., 2006; Hägglund et al., 2013), strength (peak force) imbalances (Bourne et al., 2019; Moreno-Pérez et al., 2019; Van Dyk et al., 2017), and articular range of motion/flexibility imbalances (Arnason et al., 2004; Fousekis et al., 2012; Paul et al., 2014)), which can be identified through medical and musculoskeletal screening, also known as periodic health examination (PHE) (Gabbe et al., 2004), and b) Extrinsic factors (hours of exposure, and high absolute, relative, chronic and acute workload, which can be monitored through absolute (cumulative sum of internal or external load) and relative workload metrics (Acute: Chronic Workload Ratio (ACWR)), monotony and strain) (Bowen et al., 2019; Delecroix, et al., 2018).

Workload can have both a protective or harmful effect on injury risk (Hulin et al., 2014; Schwellnus et al., 2016; Soligard et al., 2016), depending on how athletes musculoskeletal characteristics respond to an external load stimulus (Clarke et al., 2013; Schwellnus et al., 2016; Soligard et al., 2016). Workload derivate ACWR has been the most common external risk factor studied in recent research (Bowen et al., 2019, 2017; Jones et al., 2019; Wind et al., 2017), but as it still lacks consensus on specifications and methodology, its association with injury is conflicting and questionable (Burgess, 2017; Bowen et al., 2020; Fanchini et al., 2018; Impellizzeri et al., 2020; Impellizzeri et al., 2020a, 2020b; Lolli et al., 2020; Sedeaud et al., 2020; Wang et al., 2020). Recent research (Dalen-Lorentsen et al., 2020; Impellizzeri et al., 2020a, 2020b; Lolli et al., 2017; Williams et al., 2017) highlighted the mathematical flaws of ACWR as a predictive tool to injury occurrence. However, the same authors reinforce the importance of monitoring workload and its influence on injury occurrence.

During the review of the literature, it has been suggested (Bacon et al., 2017; Delecroix et al., 2019; Delecroix et al., 2018; Hägglund et al., 2006; Hägglund et al., 2013; McCall et al., 2018) that further investigation on injury aetiology mechanisms was needed to inform practice and implement more efficient strategies on injury reduction. Only three other studies (Esmaeili, Hopkins, et al., 2018; Esmaeili, Stewart, et al., 2018; Møller et al., 2017) analysed the musculoskeletal screening, workload, and its relationship with injury occurrence. However, none of these investigations was conducted in a football context, neither characterize musculoskeletal screening variables and workload in the same study as suggested before (Hughes et al., 2017). Also, there have been several individual risk factors studies in football. However, to our knowledge, no other study has investigated the differences between injured and non-injured youth football players regarding musculoskeletal screening tests and workload metrics on injury occurrence in an elite level football academy.

This research aims to answer Mechelen's injury prevention model first two steps, describing the injury epidemiology extent, to further assess the musculoskeletal and workload factors characteristics of non-contact soft-tissue lower body injured and non-injured elite youth football players.

1.1 Purpose of the study

The aim of the present thesis is threefold, divided into two parts.

Part A aims to characterize an elite youth football academy's epidemiology, with the different injury patterns frequency, incidence, and burden.

Part B aims to investigate the differences between injured and non-injured elite youth footballers for musculoskeletal screening and workload variables in the most frequent injuries identified in the first part of this thesis. Part B1 will focus on lower body non-contact soft tissues injuries, and B2 will specifically focus both on the groin and muscle injuries.

For B1, it was hypothesized that injured and non-injured athletes would exhibit no differences for musculoskeletal and internal workload variables in lower body non-contact soft tissue injuries.

As for B2, it was hypothesized that injured and non-injured athletes for groin located injuries exhibit differences for some local musculoskeletal tests (e.g., ASQZ or $ASQZ/BW_{ratio}$) but not internal workload variables. Moreover, injured, and non-injured athletes for muscular type injuries would exhibit no differences in internal workload variables and musculoskeletal variables.

In more detail, the research questions were:

1- What is the incidence, burden, and injury patterns during a season in an elite male youth football academy? (Aim A)

2- Do pre-season musculoskeletal variables, including isometric strength, mobility, and jump outcomes, differ between non-contact soft tissue lower body injured and non-injured youth football players? (Aim B1)

3- Do absolute and relative derived workload variables differ between non-contact soft tissue lower body injured and non-injured youth football players before injury? (Aim B1)

4- Do musculoskeletal and workload variables differ between injured and non-injured youth football players before injury, within specific clusters of groin located injury and muscular injury type? (Aim B2)

1.2 Relevance of the study

Injury occurrence is an event that negatively affects every stakeholder involved in sports. It has detrimental effects associated with player value, financial costs of the injured player, team sporting success, and most importantly, in youth football, player development. Injury is multifactorial, thus difficult to prevent fully. The first event of injury becomes a non-modifiable risk factor that is highly associated with a future injury event. To establish effective injury reduction plans, there is a need-to-know which modifiable factors are relevant to an injury event. Mobility, isometric strength, and workload factors have been associated with injury in football. Although, most of these authors have studied each factor independently. Also, none has studied musculoskeletal variables and workload relationship with injury epidemiology in elite youth football.

Previously, it has been highlighted (Bacon et al., 2017; Bianco et al., 2016; Bowen et al., 2017; Brink et al., 2010; Delecroix, Delaval, et al., 2019; Ergün et al., 2013) the need to further characterize injury epidemiology in youth football and to study which factors are related with injury.

Under the most current injury prevention model, the problem was established by characterizing the population regarding its injury profile. Secondly, based on the epidemiological characteristics studied, data will be explored for differences between injured and non-injured footballers, typically used pre-season musculoskeletal tests, and workload metrics used for training monitoring.

Therefore, this study will help characterize the current epidemiological injury extent in the academy, helping practitioners make an informed decision of which factors should be considered to screen and monitor for injury risk reduction. Indirectly, it may help the players' athletic development, allowing them to participate in sports free from injury safely.

This investigation will improve the audit of injuries in the studied elite football academy and state the relevance of the medical department in the institution. It may improve the communication between departments, providing objective and evidence-based information regarding injury risk factors and future prevention strategies.

2. Literature Review

This literature review aims to summarise the research that has investigated the epidemiology of injury in football, football injury risk factors screening, and the relationship of workload with injury. Specifically, it will focus on relevant literature in youth football, highlighting the problem that injuries represent in football, the need for prevention, the different injury causation models, and the effect of different workload types in injury. It justifies the "why" on undertaking the current research and provides a detailed evidence background to be interpreted with this research's findings. It is divided into three parts: youth football injury epidemiology, football injury risk factors and musculoskeletal screening, and finally, workload and injury in football.

2.1 Injury Epidemiology

Injury epidemiology is important to characterize injury occurrence, identifying risk factors and the impact of each of these on injury, ultimately helping to develop effective injury prevention strategies (Ekstrand et al., 2011). Epidemiology characterizes injury using prevalence, incidence, burden, and patterns. Patterns of injury include injury location, type, side, mechanism, severity, context, and recurrence (Fuller et al., 2006). Football is a sport with vast epidemiological research; nevertheless, there are different methodological approaches, with different reporting, injury definitions, and population heterogeneous characteristics, making it difficult to compare findings and results (Fuller et al., 2006). Being aware of these limitations, injury definition, incidence, burden, and pattern characteristics are described below.

2.1.1 Injury reporting and definition

Injury can be defined using medical attention (MA) or time-loss (TL) injury definition (Fuller et al., 2006). When a player receives medical attention after any complaint is referred to as a ‘‘medical attention" (MA) injury. When training or match is absent due to injury, it is referred to as a ‘‘time-loss" (TL) injury (Fuller et al., 2006). Despite being most supported for research purposes, it fails to account for overuse injuries that do not affect participation while symptoms are managed.

Injury reporting can be difficult as it relies on multiple factors as practitioner experience, report methods, and athlete honesty. Usually, injury surveillance systems report injuries by an electronic questionnaire filled by the medical team. In the case of retrospective investigations, it is reported using a player individual questionnaire. To minimise errors with information recall, usually found in this type of retrospective designs, Fuller et al. (2006) suggested that authors should use a prospective cohort design or injuries to be recorded by the medical team.

2.1.2 Injury incidence, injury burden rate and injury burden matrix

To report injury statistics in sports, injury incidence (II) and burden rate (IBR) are usually used (López-Valenciano et al., 2020). Injury incidence is defined as the number of injuries per 1000 hours (h) of exposure (training, match or combined), accounting for the exposure time at risk (Ekstrand et al., 2011). Recently Bahr et al. (2018) suggested that injury burden rate should be used in adjunct with injury incidence, as incidence was incomplete to define injury risk. Injury burden rate reports the total number of days lost to injury per 1000h of exposure (training, match or combined). Moreover, it has been previously suggested to represent burden as a cross-product in a joined metric of severity (mean days lost) and incidence, using an injury burden matrix (Bahr et al., 2020; Materne et al., 2020). This approach represents incidence and severity cross-product using a graphic matrix, with burden represented by isoquant curves (points of similar value). With a higher burden, the darker the shade in the graphic (Bahr et al., 2020; Martínez-Silván et al., 2020; Materne et al., 2020).

Injury incidence can be affected by several factors such as culture, age (Bult et al., 2018), level of play (Deehan et al., 2007), physical demands of the game (Barnes et al., 2014), and type of population (Larruskain et al., 2018; Pfirrmann et al., 2016). In youth football, the literature reports different population samples, from 32 to 528 football players, from different age groups (U9 and U21), with total injuries ranging from 44 to 3,805 injuries, and total exposure time ranging from 2,690.2 to 29,346.2 hours. These different methodological characteristics will have a direct effect on injury incidence, which ranges from 0.4 to 21.1 injuries /1000h of player exposure in youth football (Bacon et al., 2017; Bianco et al., 2016; Bowen et al., 2017; Brink et al., 2010; Delecroix et al., 2019; Ergün et al., 2013; Larruskain et al., 2018; Le Gall et al., 2006; Nilsson et al., 2016; Price et al., 2004; Renshaw & Goodwin, 2016; Tears et al., 2018)

After a thorough literature review, thirteen authors have reported injury incidence per 1000 player hours and injury patterns in youth football. Research is summarized in Table 1. The highest injury incidence was found in Bowen et al. (2017), with 2 seasons long, 32 players (U18-U21) from an elite level academy in England, reporting 137 injuries, with injury incidence of 21.1 (95%CI 15,4-29.0), with 7.9 and 33.5 in training and match, respectively. On-legs exposure time and injury burden were not reported. On the other hand, Price et al. (2004), with elite-level youth players from 38 English academies, reported a total of 3,805 injuries over 2 seasons. Of the studies found, it has the lowest injury incidence of 0.4. Also, on-legs exposure and injury burden were not reported. For exposure, Le Gall et al. (2006) reported the longest exposure of 237,600 h (205,920 h training and 31,680 h match), during ten seasons, with 528 French elite youth players.

Given that injury burden rate can be considered a recent injury statistic (Bahr et al., 2018), only two other investigations (Larruskain et al., 2018; Tears et al., 2018) reported it in youth football. Tears et al. (2018) found that knee injuries had the highest injury burden in younger (U12-U15) and older youth players (U16-U18), respectively 10.3 and 9.0 injury days lost per 1000 h exposure.

Injury burden rate is more often analysed in male professional footballers (Ekstrand et al., 2013; Hägglund et al., 2013; Werner et al., 2019). In the study of Ekstrand et al. (2016), with professional players, hamstring related injury represents the highest injury burden rate of injury with 19.7 injury days lost per 1000h. The adductor-related injury burden rate was 9.1 (Werner et al., 2019). The UEFA injury study reported an average burden rate of 37 (2-89) days lost per 1000h training and 456 (149-976) days lost per 1000h of match play. More specifically, muscle injury burden rate was 33 (9-124) and ligament injury 22 (1-58) (Ekstrand, 2017).

Injury is also related to the age group squad, despite the literature not being consistent with findings (Jones et al., 2019). That can be explained with different exposure times, playing level, context, and cultural playing style. Young older aged players (U18-U21) were found to have the highest injury rate during training than the younger age groups (Price et al., 2004). However, Le Gall et al. (2006) found that those younger players (U14) suffered more injuries in training. Older players were more often injured during matches. This can be explained by the increase in competitiveness or workload exposure (Price et al., 2004).

2.1.3 Injury Patterns

Injury patterns are used to characterize the injury event. Usually, location, type, mechanisms, and severity are reported as prevalence or incidence per 1000h. Over the years, match demands have increased, although soft tissue non-contact lower extremity injuries incidence has remained the same (Barnes et al., 2014; Ekstrand et al., 2013). Soft tissue non-contact injuries are more prevalent with high speed/sprint exposure and high metabolic demanding contexts (Jaspers et al., 2018).

In youth football, injury location varies widely, changing accordingly the definition of injury used. The location of injuries can be recorded using the categories listed by

Fuller et al. (2006), using individual categories. Overall, the lower extremity is the most common injury location, representing 70-85% of the total number of injuries. In lower extremities, thigh, hip/groin, and ankle are the most common cited location subgroups. Thigh represents 7.06-34.5% of total injuries, accounting for most frequent injuries (hamstring and quadriceps). Injury incidence in the reviewed literature goes from 0.43-2.42 injuries /1000 h. Another prevalent injury site is the hip/groin 9.0-33.0% of total injuries, with the incidence ranging from 0.27-1.62 injuries per 1000 h. Ankle represents the third most common injury site, with 6.9-30.59% of total injuries and incidence of 1.1-2.1. Other reported lower extremity injury sites are knee (10.4-20.0% / 0.23-1.1 /1000h), foot (7.06-9.0% / 0.36-2.1 per 1000h), lower leg/Achilles (5.2%-14.0%/0.15-0.87 /1000h), and sometimes in isolation, quadriceps, hamstring, hip and groin (Bacon, et al., 2017; Bianco et al., 2016; Bowen et al., 2017; Ergün et al., 2013; Larruskain et al., 2018; Le Gall et al., 2006; Nilsson et al., 2016; Price et al., 2004; Tears et al., 2018).

The type of injury in youth football does not differ from professional football (Pfirrmann et al., 2016). Muscular injury is the most commonly reported type (20.9-55.2%), with hamstring, adductor, and quadriceps mainly affected (Bacon et al., 2017; Bianco et al., 2016; Brink et al., 2010; Ergün et al., 2013). Authors can distinguish between muscle and tendon injury, as the onset of injury is different (Brink et al., 2010). Ligament injuries represent the second most common type of injury, with 16-24% of total injuries, with contusion/haematoma and tendon injuries representing 20.69-30.6% and 3.4-13% of total injuries, respectively. It can also be represented with different onset characteristics, acute or gradual regarding the type of injury.

As the game's tactical and technical demands differ among cultures, so does injury mechanisms (Tierney et al., 2016). Injury mechanisms are frequently reported as non-contact, contact, overuse, and traumatic (Fuller et al., 2006). Mechanism subgroups include the game-specific actions that resulted in injury. The most common mechanism reported is running/sprinting 17%-19% (Nilsson et al., 2016; Price et al., 2004). Price et al. (2004) also reported other mechanisms such as being tackled (15%), twisting/turning (7%), tackling an opponent (7%), shooting (4%), and stretching (4%). Other authors reported traumatic (62.1-78%) (Ergün et al., 2013; Larruskain et al., 2018; Tears et al., 2018), and overuse (22-37.9%) as the main mechanism (Ergün et al., 2013; Larruskain et al., 2018; Tears et al., 2018), with 46%-72% non-contact (Bacon et al., 2017; Bowen et al., 2017; Larruskain et al., 2018) and 54%, contact injuries (Tears et al., 2018). In professional football players, a-year research of injury patterns with video analysis found that sprinting and lunging were the most frequent mechanisms of injury for the thigh, irrespective of muscle groups affected (Klein et al., 2020). Landing and changing of direction were associated with knee injuries, most specifically non-contact ACL injuries. While in ankle injuries, twisting and contact from contusion were most common (Klein et al., 2020).

To characterize how impactful is an injury, severity can be reported. It is classified into four categories depending on the days lost to injury. Minimal/slight represents (1-3 days), minor/mild (4-7 days), moderate (8-28) days lost, and severe represent (> 28 days) lost due to injury (Ekstrand et al., 2011; Fuller et al., 2006). In youth football, severity differs between age groups and population. Moderate and severe injuries are most common (24-44%) followed by minimal (7-40%), minor (17-55.2%), and severe injuries (3.4-31%) (Bianco et al., 2016; Ergün et al., 2013; Larruskain et al., 2018; Tears et al., 2018). Pfirrmann et al. (2016) found a greater occurrence of severe injuries in younger football players (14 to 16 years) than in older adolescents. This finding is backed by Renshaw et al. (2016), who reported that U16 players sustained a higher number of severe injuries and U18 players a higher number of moderate injuries. The literature suggests that severity is relatively high in youth football, with more traumatic mechanisms than professional players. Larruskain et al. (2018) reported a low average number of days lost to injury (6 days), while Bianco et al. (2016), Le Gall et al. (2006) and Read et al. (2018) reported 14, 15 and 21.9 days lost to injury, respectively. Fourteen days lost due to injury means that a player will miss 5-6% of a season (Bianco et al., 2016).

More detailed information about injury incidence and patterns in youth football is summarized in *Table 1*.

Table 1 - Summary of injury epidemiology literature in male elite youth football players

References	**Design**	**Population**	**Type / total nº of injuries**	**Exposure (h)**	**II (Total)**	**II (Training)**	**II (Match)**	**IB_{rate} (Total)**	**Type of injury**	**Location**	**Severity**	**Mechanism/Context**
Bacon et al. (2017)	PL Cohort 2 seasons	41 players English (U18-U21)	Overall / n =85	8054.4	10.55	3.72	5.84	-	Muscular - 41.38% Contusion -20.69% Overuse - 10.34%;	Ankle - 30.59% Knee - 16.47% Groin - 12.94% Thigh - 7.06% Foot - 7.06%	Minimal - 40% Minor - 27.06% Moderate/Severe - 32.94%	Non-contact - 51.76% Contact - 42.35%
Bianco et al. (2016)	PL Cohort 1 season	80 players (U13-19)	Overall / n =107	83.360	1.28	1.15	2.84	-	Muscular - 1.11 Tendon - 0.17 /1000h	Lower limb - 0.20 hip/groin - 0.27 Thigh - 0.43 Knee - 0.23 Lower leg/Achilles - 0.15 /1000h	Minor - 0.53 Moderate - 0.62 Severe - 0.13 /1000h	-
Bowen et al. (2017)	PL Cohort 2 seasons	32 players English (U18-U21)	Overall / n =138	-	21.1	7.9	33.5	-	Contusion- 0.2 Ligament - 2.1 Muscular - 1.9 Tendon - 0.6 /1000h	Ankle/foot - 2.1 Knee 1.1 Hip/groin - 1.3 Quadriceps - 0.3 Hamstring - 0.8 /1000h	Minimal - 1.3 Minor - 1.4 Moderate - 2.0 Severe - 1.4 /1000h	Non-contact (Match - 9.9; Training - 5.6) Contact (Match - 24.2; Training - 2.3) /1000h
Brink et al. (2010)	PL Cohort 2 seasons	Dutch (15 to 18 years)	Overall / n =320	6700	-	6.74	26.65	-	Muscular/tendon- 43.1% Ligament -25% Bone - 2.5%	Lower extremity (85%)	-	-

Delecroix et al. (2019)	PL Cohort 5 seasons	122 players French (U19-U21)	Overall / n =489	-	U19 - 7.6 U21 - 9.6	-	-	-	-	-	-	Non-contact - 68,5% Contact - 31,5%
Ergün et al. (2013)	PL Cohort 3 seasons	52 players (U17-U19)	Overall / n =44	2390.2	12.1	7.4	30.4	-	Muscular - 55.2% Ligament - 0%. Tendon - 3.4%; Contusion - 20.7%	Thigh - 34.5% Hip/Groin - 27.6% Knee - 10.4% Lower leg - 6.9% Ankle - 6.9% Foot - 3.4%	Slight - 0% Minimal - 55.2% Mild - 17.3% Moderate - 24.1% Severe - 3.4%	Overuse - 37.9% Traumatic - 62.1%
Larruskain et al. (2018)	PL Cohort 5 seasons	50 players (Age 25 ±4)	Overall / n =85	38878	8.31	4.78	29.86	116	Muscular - 3.68 Ligament - 2.13 Contusion - 1.52 Tendon - 0.41 Fracture - 0.10 /1000h	Lower limbs - 7.33 Hip/groin - 1.62 Thigh - 2.42 Hamstring - 1.52 Quadriceps - 0.44 Knee - 0.95 Meniscus/cartilage - 0.18 Lower leg - 0.87 Ankle - 1.11 Foot/toe - 0.36 /1000h	Minimal - 2.57 Minor - 2.44 Moderate - 2.34 Severe - 0.95 /1000h	Traumatic - 4.01 Overuse - 4.19 Contact - 2.37 Non-contact - 5.81 /1000h
Le Gall et al. (2006)	PL Cohort 10 seasons	528 players French (U14, U15, U16)	Overall / n =1152	237600	4.8	3.9	11.2	-	Contusion - 30.6% Ligament - 16.7% Muscular - 15.3% Tendon - 9.4% Fracture - 5.9% Meniscus - 2.2%	Thigh - 24.5 Ankle - 17.8% Knee - 15.3% Foot - 8.2% lower leg - 5.2% Hip - 2.2%;	Minimal - 31% Minor - 29.3% Moderate - 29.9% Severe - 9.9%	Training - 69.1% Match - 30.9%

Nilsson et al. (2016)	PL Cohort 2 seasons	43 players (U19)	Overall / n =61	10368	6.8	5.88	15.5	-	Muscular - 53% Ligament - 24%	Lower extremity - 93% Hip/groin – 33 Thigh - 26% Ankle - 18%	Minimal - 7% Minor - 21% Moderate - 41% Severe - 31%	Sprinting - 17% Overuse - 10% Shooting - 6% Fall - 5% Unknown - 5% Hop/landing - 4% Tackled/tackling - 3% Stretching - 2% Collision - 2%
Price et al. (2004)	PL Cohort 2 seasons	English (9-19 years)	Overall / n =3805	-	0.4	-	-	-	Muscular - 31%; Ligament - 20%. Tendon - 5%; Fracture - 4%	Thigh - 19% Ankle 19% Knee - 18% Lower leg - 10% Groin - 9% Foot - 8%	Minimal - 10% Minor 23% Moderate - 44% Severe - 22%	Sprinting 19% Tackled - 15% Twisting/turning - 7% Tackling - 7% Shooting - 4% Stretching - 4% Match - 50.4% Training - 48.7%
Read et al. (2018)	PL Cohort 1 season	357 players (10-18 years)	Overall / n =99	-	1.32	-	-	-	Muscular – 20.9 Ligament – 16.9 Other Cause – 16.3 Growth – 6.6 Overuse – 4.3 Tendon – 4.3	Lower extremity - 78% Knee – 20 % Ankle – 18.3 % Quadriceps – 9.5 % Foot – 7.3 Groin – 7.2 Hamstring – 6.1 Hip – 5.5 Lower back – 5.0 Calf – 2.1	Minimal - 14.7% Minor - 20.4% Moderate - 42.9% Severe- 22%	Non-contact - 62.1%
Renshaw et al. (2016)	PL Cohort 1 season	181 players (U9-U18)	Overall / n =127	29346.15	4.33	2.51	8.86	-	Muscular - 46%; Ligament - 16%; Tendon - 13%	-	-	Non-contact - 72% Training - 50% Match - 32%
Tears et al. (2018)	PL Cohort 6 seasons	6 Elite English academies (U12 - U18)	Overall / n =882	1179.86	2.5	1.5	24.1	0.2 - 12.6	Muscular - 29% Contusion - 24% Ligament - 17% Tendon - 13% Synovitis - 7% Fracture - 4% Other bone - 3% Meniscus/Cartilage -2%	Thigh - 17% Lower leg/Achilles - 14% Knee - 14% Hip/Groin - 16% Ankle - 14% Foot - 9%	Slight - 12% Minimal 20% Minor - 17% Moderate - 30% Severe - 21%	Overuse - 22% Traumatic - 78% Contact - 54% Non-Contact - 46% Match - 33% Training - 59%

IB_{rate} - Injury burden rate per 1000h; II – Injury incidence per 1000h; PL Cohort – Prospective Longitudinal Cohort; U9-U19 - Under age 9 -19

2.2 Injury Risk Factors and Musculoskeletal Screening

2.2.1 Preseason screening and injury

In sports, screening for medical conditions is a common practice. Screening assessments are traditionally done in the pre-season period and have been given various titles such as periodic health examination (PHE) or pre-competition medical assessment (PCMA). The International Olympic Committee (IOC) released a consensus (Ljungqvist et al., 2009), where PHE would be used to offer medical clearance to participate in sports screening for medical and musculoskeletal conditions.

PHE aims to examine athletes physical and physiological characteristics, aiming to identify who is at the greatest risk of sustaining an injury. Potential risk factors for injury and illness can then be identified and addressed in this populations (Bahr, 2016; Haddad et al., 2017; Ljungqvist et al., 2009; Van Dyk et al., 2017).

In recent years, a controversy around PHE has emerged (Bahr, 2016). This is explained due to the number of multiple individual risk factors reporting a statistical association with injury occurrence, claiming to predict injury. In line with Bahr (2016), screening tests do not predict injury but can help categorize athletes in different risk levels, making it possible to implement injury reduction plans. This type of methodology does not consider the multifactorial causation of injury, which differs from player to player, making it difficult to identify which factors will predispose the athlete to injury. Aware of this limitation, Dallinga et al. (2012) suggested that risk factors should be examined using a variety of individual conjoined specific tests.

2.2.2 Injury causation and prevention models

Several external risk factors may develop during a season and predispose players to injury (Bahr, 2016). The multiple aetiological characteristics of injury make it difficult to prevent, but the risk of injuries can certainly be reduced (van der Horst et al., 2014). To prevent the first event of injury and intervene in the multifactorial causation of injury, Van Mechelen et al. (1992) injury prevention model suggests identifying the problem, establishing the aetiology and mechanisms of injury and only then intervene and design preventive measures. Finally, the effectiveness of the preventive measures should be assessed by repeating the first step.

An athlete owns a wide range of characteristics that go from musculoskeletal variables to non-modifiable characteristics such as age and gender (Arnason et al., 2004). Any of these characteristics can be causal or protective depending on the modelling factors that the athlete is exposed to (Bourne et al., 2019). Two athletes with the same physical characteristics, with the same inciting event, but with a different background on training resilience may have different injury outcomes. Regarding non-contact injuries, individual risk factors are unlikely to cause an injury independently, as injuries are multifactorial (Hughes et al., 2018).

To explain injury, causation models have evolved. The first study to identify the need for investigation in injury mechanisms and epidemiology was Van Mechelen et al. (1992), as mentioned before. Later, Meeuwisse (1994), proposed that an athlete's intrinsic risk factors, when exposed to external factors and an inciting event, predisposed the athlete to injury. Later on, the same author (Meeuwisse et al., 2007) modified the model including different outcomes and adaptations after exposure. The model reflected a dynamic relationship between the different factors on the probability of injury.

Although already taking into account the multifactorial nature of the injury and the different relationship between factors on the outcome of injury, Bittencourt et al. (2016) highlighted the limitation of linear interaction between isolated factors, as proposed in the previous models. Bittencourt et al. (2016) suggested a model that accounted for the complex interaction among different factors (web of determinants), resulting in regularities (risk profile) that predispose to a pattern, thus resulting in injury. This embraces the complex nature of the sports injury, which is represented in Figure 1.

More recently, with the current increase of literature supporting the association of workload with injury (Drew et al., 2016), only one model (Windt et al., 2017) has considered workloads to contribute to injury mitigation in an injury prevention framework, shown in Figure 2 (Windt et al., 2017).

Another important but commonly undervalued contributor to injury prevention is communication between all the stakeholders involved. Football, being a team sport environment with multiple professionals involved, should have a holistic approach to prevention with contribution from all the involved. It has been shown that better communication between the medical team and head coach (Ekstrand et al., 2019) head coach leadership style (Ekstrand et al., 2019) reduced the injury rate.

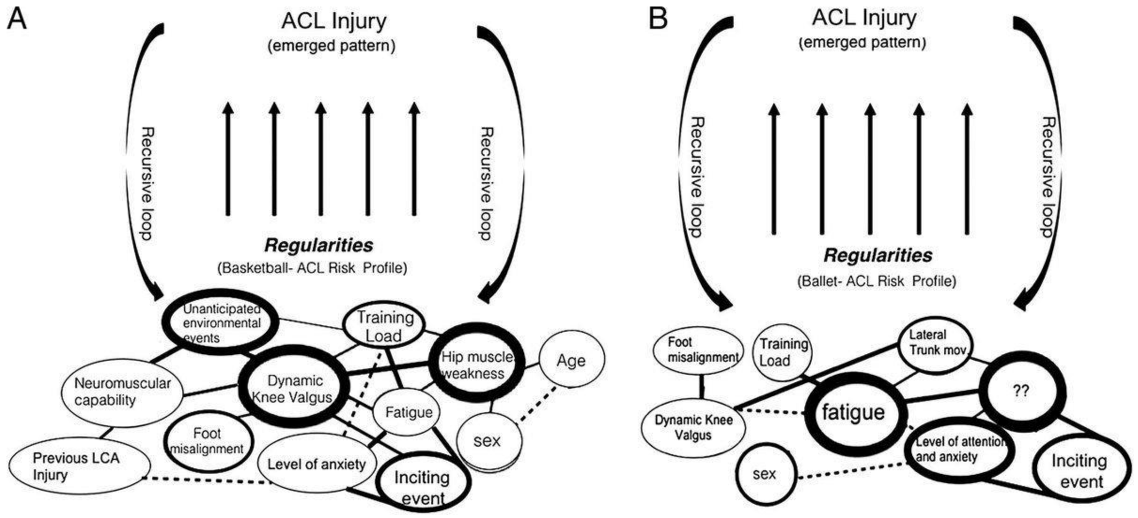


Figure 1- Complex systems web of determinants model (Bittencourt et al., 2016)

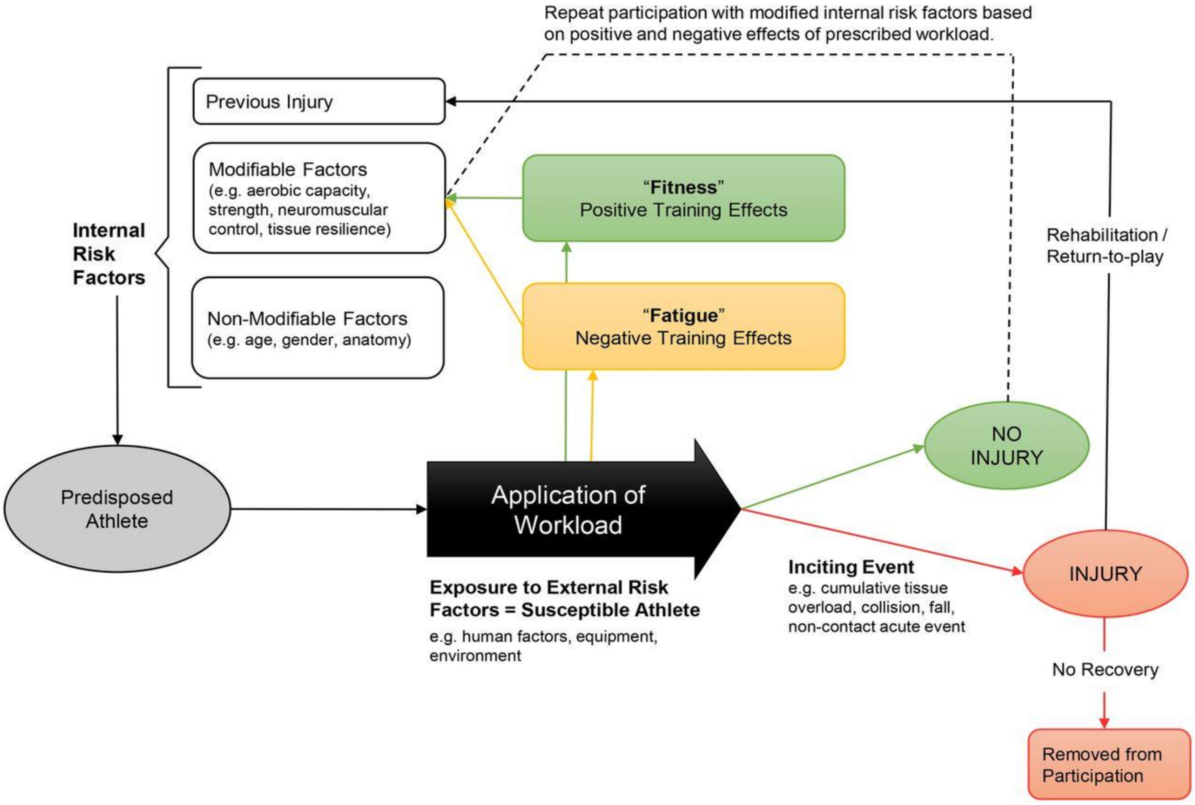


Figure 2 - The workload injury aetiology model (Windt & Gabbett, 2017)

2.2.3 Risk Factors

To prevent injury, there is the need to identify which factors are more relevant to injury occurrence. Risk or prognostic factors can serve as moderators (protective effect) or aggravators (negative effect) depending on the context. These factors can range from musculoskeletal, anthropometric, biomechanical, and environmental. Also, risk factors can be classified into intrinsic or external to the athlete, being subdivided into modifiable (e.g. physical qualities as strength, flexibility, stability, fitness, motor control and coordination) or non-modifiable (e.g. age, previous injury, anatomy, and gender) (Amraee et al., 2017; Engebretsen et al., 2010; Hägglund et al., 2006). When these factors are identified, prevention plans can be implemented. Research has shown good results with prevention plans using exercises for local muscles strengthening or with the FIFA 11+ warmup plan, reducing hamstring injuries (51%) (Al Attar et al., 2017), adductor injuries (41%) (Harøy et al., 2019), or general lower extremities (39%) (Thorborg et al., 2017).

Below, the literature on the most relevant intrinsic factors is described.

a) Age

Despite age being one of the most studied risk factors, authors are conflicted when considering it as a future risk factor for future injury (Arnason et al., 2004; Bourne et al., 2019; Engebretsen et al., 2010; Hägglund et al., 2013).

It has been found that older players were at higher risk of injury (Arnason et al., 2004). A study with 1401 male elite football players investigating muscle injuries found that older players had a two-times increase in the incidence of calf injuries (Hägglund et al., 2013). Moreover, advanced age was found to increase the risk of injury in 357 elite male youth football players (Read et al., 2018). For hamstring strains especially, age is recognised to be a significant injury risk factor, with increased odds for sustaining an injury of 1.78 for each year increase in age (Henderson et al., 2010).

Regarding authors that consider age, a potential predictor of injury risk for ankle injuries, Fousekis et al. (2012) found a trend for younger players (OR = 0.28; 95% CI, 0.061-1.24, P = 0.092) to be at higher risk of injury. For hamstring injuries, Engebretsen et al. (2010a) considered age a candidate predictor of high injury risk (OR, 1.25; 95% CI, 0.96-1.63).

Although being consistently associated with injury, some contradicting findings persist. Engebretsen et al. (2010b) studied which risk factors were associated with a groin injury in 508 male football players. The authors found previous acute groin injury

(OR=2.60; 95% CI, 1.10-6.11) and weak adductor muscles (OR=4.28; 95% CI, 1.31-14.0) to be significantly positively associated with an increased risk of groin injuries. Furthermore, Bourne et al. (2019) and Kofotolis et al. (2007) did not find any effect of advancing age or prior injury on future injury risk, on hip/groin and ankle injuries, respectively. Other investigation with 197 male elite football players found no association between age and overall injury occurrence (Hägglund et al., 2006).

b) Previous injury

Previous injury has been the strongest and most common risk factor associated with a future injury. Most of the authors agreed with previous injury as a future predictor of injury regardless of injury location (Arnason et al., 2004; Bourne et al., 2019; Engebretsen et al., 2010; Mosler et al., 2018)

For Groin, previous injury significantly increased the risk of a future event (OR= 2.60; 95% CI, 1.10-6.11) (Engebretsen et al., 2010b). For lower-body injuries, previous injury was a strong risk factor for hamstring strains (OR = 11.6; P < 0.001), groin strains (OR = 7.3; P = 0.001), knee sprains (OR = 4.6) and ankle sprains (OR = 5.3)(Arnason et al., 2004). In hamstring injuries, previous acute hamstring injury was a significant risk factor, having more than twice the risk of sustaining a new hamstring injury (OR= 2.62; 95% CI, 1.54-4.45) (Engebretsen et al., 2010a). Moreover, players with a previous hamstring, groin, and knee injury were two to three times more likely to suffer an identical injury in the following season (Hägglund et al., 2006; Hägglund et al., 2013; Kofotolis et al., 2007).

Although the overwhelming evidence presented defending previous injury as an injury risk factor, some other authors found no association of advancing age or prior hip/groin injury on future injury risk (Bourne et al., 2019).

c) Strength

Muscle strength (peak force) imbalances have been among the most cited risk factors regarding lower-body injuries. Over time, several authors have found muscle strength (isometric or dynamic tasks) to be associated with the most common injuries in football (Ekstrand et al., 2011) as acute muscle injuries (Arnason et al., 2004; Fousekis et al., 2012; Hägglund et al., 2013; Van Dyk et al., 2017), osteoarticular injuries (Amraee et al., 2017; Arnason et al., 2004; Hägglund et al., 2006; Kofotolis et al., 2007), and overuse groin injuries (Engebretsen et al., 2010; Moreno-Pérez et al., 2019; Mosler et al., 2018).

Isokinetic dynamometry (IKD) is a tool that is used often to measure peak force in specific body parts (Paul et al, 2015). It has been widely used to assess imbalances between limbs usually using a hamstring:quadriceps (H:Q) ratio and side to side differences (Van Dyk et al., 2017). The H:Q ratio has been studied as a risk factor for muscle and osteoarticular injuries (Henderson et al., 2010; Van Dyk et al., 2016). Despite some authors recognize its value for previously injured players, it still lacks consensus when establishing risk of injury, as previously it was unable to predict future injury (Dallinga et al., 2012; Van Dyk et al., 2016).

For groin injuries, weak adductor muscles (OR= 4.28; 95% CI, 1.31-14.0) were significantly associated with increased risk (Engebretsen et al., 2010). Isometric hip abduction and adduction peak force imbalances favouring the dominant limb were associated with a reduced likelihood of future groin injury in professional soccer players (Bourne et al., 2019). Other authors found that low adductor isometric squeeze peak force was associated with groin injury occurrence (429.8 ± 100 injured vs 564 ± 58.7 N non-injured) (Moreno-Pérez et al., 2019). Lower isometric peak force increased the probability of suffering a groin injury by 72%. Also, when normalized to body weight, values of peak force lower than 6.971 N/kg increased the probability to suffer a groin injury by 83%(Moreno-Pérez et al., 2019). Furthermore, eccentric adduction peak force was also associated with the risk of adductor-related injuries (Mosler et al., 2018).

Regarding muscle injuries, eccentric hamstring (OR=3.88; 95%) and quadriceps (OR=5.01; 95%) peak force asymmetries were found to be associated with a greater risk of sustaining a muscle strain (Fousekis et al., 2011). Nevertheless, isolated strength related measurements were previously unable to predict the risk of hamstring injuries (Van Dyk et al., 2017).

Not only high force – low velocity muscle contractions have been associated with lower extremity injury in elite youth football athletes. Read et al., (2018) found that single leg countermovement jump (SL-CMJ) asymmetry was the most prominent risk factor for U11-U12 (OR 0.90, $p = 0.04$) and U15-U16 (OR 0.91, $p < 0.001$) squads.

d) Flexibility/Range of motion (ROM)

Flexibility or range of motion (ROM) as a risk factor has been frequently cited regarding lower-body injuries.

Some authors showed significant correlations between specific tests assessing ankle dorsiflexion, hip internal rotation and hip anteversion for injury prediction. Authors considered restricted ROM an important factor for severe non-contact injuries (ACL) in male athletes (Amraee et al., 2017).

Regarding muscle injuries, quadriceps flexibility asymmetries are described as a risk factor (OR=4.98) for injuries in this muscle group (Fousekis et al., 2011). For hamstring injuries, less flexible players had 1.29 increased odds for each 1º decrease in hip flexion ROM (Henderson et al., 2010). Moreover, differences between passive knee extension ROM (HR= 0.97; P = 0.008) and ankle dorsiflexion ROM (HR= 0.93; P = 0.02) between injured and uninjured groups were associated with higher injury risk (Van Dyk et al., 2018). The absolute passive knee extension and ankle dorsiflexion differences between groups were 1.8° and 1.4 cm, respectively, associated with *small* effect sizes (d=0.2). These findings lead the author to consider them as weak risk factors for hamstring injuries (Van Dyk et al., 2018).

For groin injuries, a decreased ROM in hip abduction was found to be a risk factor in youth footballers (OR = 0.9; P = 0.05) (Arnason et al., 2004). Nevertheless, Engebretsen et al. (2010b) found hip external rotation to be a weak factor for groin injuries. Also, Mosler et al. (2018) assessed hip mobility and bony hip morphology for groin injuries, finding no association with groin injuries.

This review on injury risk factors highlights the complex nature of the injury and the need to find which modifiable factors are relevant to protect the player. A brief review of the most relevant musculoskeletal risk factors and screening tests is summarized in *Table 2.*

Table 2 - Summary of injury risk factors literature in male elite football players

References	Participants	Nº injuries - Location / II per 1000h / [Context]	Outcome/Risk Factors	Screening Test /Tool	Main Findings
Amraee et al. (2017)	52 Professional	53 - ACL	Ankle dorsiflexion ROM Internal tibia torsion knee genu recurvatum Hip IR and ER ROM Hip anteversion	Ankle ROM (º) Supine Knee ROM (º) Hip ROM (º) Seated Craig's test	A decreased ROM in ankle dorsiflexion, hip IR, and increased hip anteversion were statistically significant predictors for developing non-contact ACL ligament injuries.
Arnason et al. (2004)	306 Professional	244 - Lower body overall / [Training – 2.1 Match – 24.6]	Previous injury Anthropometrics Flexibility Leg extension power CMJ Peak O2 uptake Joint stability	Injury Questionnaire Analytic Hip extension and ABD knee flexion and extension Linear encoder CMJ and SJ (cm) Incremental treadmill protocol	Older players were at higher RI in general. For hamstring strains, age and previous injury were significant risk factors. Also, for groin strains, previous injury and decreased ROM in hip ABD were significant. Previous injury was a risk factor for knee and ankle sprains.
Bourne et al. (2019)	152 Professional	24 - Groin	Hip/groin strength PROM Age Previous injury	Hip ADD and ABD in 60/90º and supine position. HAGOS	Hip ABD imbalance, favouring the preferred kicking limb, higher levels of hip ADD and ABD strength, and higher HAGOS values, reduced the likelihood of future hip/groin injury. Age or prior hip/groin injury had any effect on RI.
Engebretsen et al. (2010a)	508 Professional	76 - Hamstring	Hamstring strength Clinical Examination Hamstring and hip ROM Previous injury	Nordic Hamstring strength test AKE (º) Thomas test (º) Palpation	Previous injury doubles the risk of sustaining a new hamstring injury. Function score, age, and player position were candidate predictors of high IR.

Engebretsen et al. (2010b)	508 Professional	61 - Groin / 0.6 [Training – 0.3 Match – 1.8]	Function Previous injury Age Clinical examination Groin strength	Groin Outcome Score ASQZ 40m sprint CMJ	Previous acute groin injury and weak adductor muscles were significantly associated with increased risk of groin injuries
Fousekis et al. (2012)	100 Professional	17 - Ankle / 0.47	Ankle IKD Flexibility Proprioception Previous injury Lateral dominance traits	IKD (several velocities) Ankle dorsiflexion and plantarflexion ROM (º) Kinaesthetic stabilimeter (Prokin-200)	ECC IKD ankle flexion strength asymmetries increased BMI, and increased body weight was significant for non-contact ankle injury RI. Age and asymmetries in ankle laxity were candidate predictors of RI.
Fousekis et al. (2011)	100 Professional	38 – Muscular (Hamstring – 16 Quadriceps – 7)	Muscle strength Flexibility Proprioception Anthropometry Knee joint stability Previous injury	IKD (several velocities) IKD H:Q ratio Knee ROM (º) Kinaesthetic stabilimeter (Prokin-200)	Players with asymmetries in ECC hamstring strength, leg length and no previous injury were at greater RI. Players with ECC strength and flexibility asymmetries in their quadriceps, also heavier and shorter players, were at greater RI for quadriceps injury. Previous injury was not considered a risk factor.
Hägglund et al. (2006)	197 Professional	1089 - Overall / 7.6	Previous injury Age Anthropometry	Injury Questionnaire	Players with previous injury were at greater RI in the following season, 2 to 3 times more likely to suffer future injury. Age was not associated with an increased IR.
Hägglund et al. (2013)	1401 Professional	2123 - Muscular (Adductors - 523 Hamstrings – 900 Quadriceps - 394 Calf - 306)	Previous injury Age Limb dominance Playing position Match and training exposure	Injury Questionnaire	Previous injury increased IR for muscle injuries. Older players had twice the RI for a calf injury. Away matches were associated with reduced rates of adductor and hamstring injuries. Quadriceps injuries were more frequent during the preseason, whereas adductor, hamstring, and calf injury rates increased during the in-season.
Henderson et al. (2010)	36 Professional	14 - Hamstring	Anthropometry Flexibility Lower limb strength and power, speed, and agility	IKD (several velocities) YoYoIE Test CMJ and SJ SLR ROM (º)	Odds for injury increased ×1.78 for each 1-year increase in age, ×1.47 for each 1 cm increase in SJ and ×1.29 for each 1º decrease in active hip flexion. Older, more powerful, and less flexible soccer players were at greater risk of sustaining a hamstring injury.

Kofotolis et al. (2007)	312 Amateur	208 - Ankle / 3.24	Previous Injury	Injury Questionnaire	Age was not a significant predictor of ankle sprain occurrence. Previous injury was associated with an ankle sprain (60.5%).
Moreno-Pérez et al. (2019)	71 Professional	18 - Groin / [Training – 0.3 Match – 5.5]	Hip ADD strength	ASQZ ASZQ/BW ratio	ADD strength was lower in the groin-injured group. ADD strength below 465.33 N increased RI by 72%. ASQZ/BW$_{ratio}$ below 6.971 N/kg increased RI by 83%.
Mosler et al. (2018)	438 Professional	113 - Groin/Hip / 1.0	Pain provocation Hip ROM (º) Hip strength Hip RX exam Previous injury	FADIR and FABER Hip IR and ER 90º ROM Hip IR Prone ROM PKFO Hip ABD ROM HHD ADD/ABD ECC ASQZ	Previous injury and ECC ADD strength were associated with the RI of the hip/groin. Higher and lower 1 SD than normal ECC ADD strength was associated with higher RI in adductor. No other MSK test was associated with the RI.
Paul et al. (2014)	20 Youth	Groin/ Hip	Hip flexibility Hip ADD/ABD strength	PKFO HHD	HHD and the PKFO test are reliable tools to measure changes in hip strength and flexibility
Read et al. (2018)	357 Youth (10-18 years)	99 - Lower body	Lower limb power and strength Maturational Offset	SLHD 75%Hop SLCMJ TJ	pVGRF asymmetry was the most relevant risk factor in U11- U12 and U15-U16. Maturational offset, lower right leg SLCMJ pVGRF relative to BW and older age were also significantly associated with high RI in U13-U14, U15-U16 and U18.
Van Dyk et al. (2017)	413 Professional	66 - Hamstring	Muscle strength Previous injury Playing position	IKD (several velocities) Nordic hamstring strength IKD H:Q Ratio	Isolated strength and IKD H:Q ratio could not predict RI for the hamstrings. Age and playing position were associated with an increased RI for the hamstrings.

Van Dyk et al. (2018)	438 Professional	78 - Hamstring	Ankle Dorsiflexion and hamstring ROM	ADL test AKE test PKE test	PKE and ADL were associated with the RI. Absolute differences between the groups were 1.8° and 1.4 cm, respectively, with *small* ES. Deficits in PKE and ADL were weak risk factors for a hamstring injury.

75%Hop - 75% of maximum hop and stick; º - degrees; ABD – Abduction; ACL – Anterior cruciate ligament; ADD – Adduction; ADL – Active Dorsiflexion Lunge; AKE – Active Knee Extension; ASQZ – Adductor squeeze test; ASZQ/BW$_{ratio}$ – Adductor squeeze test to bodyweight ratio; BMI – Body Mass Index; CI - Confidence interval; cm – Centimetres; CMJ – Countermovement jump; ECC – Eccentric; IR – Internal Rotation; ER – External Rotation; ES – Effect size; H:Q – Hamstring-Quadriceps ratio; HAGOS - Hip and Groin Outcome Score; HHD – Hand Held dynamometry; HR – Hazard Ratio; II – Injury incidence per 1000h; IKD – Isokinetic dynamometry; ISO – Isometric; m – Metre; MSK – Musculoskeletal; N – Newtons; OR – Odds ratio; PKE – Passive Knee Extension; PKFO – Passive Knee Fall out; PROM – Patient Reported outcome measures; pVGRF - SLCMJ peak landing vertical ground reaction force; RI – Risk of injury; RX – Radiography; ROM – Range of motion; SJ – Squat Jump; SLCMJ – Single leg countermovement jump; SLHD – Single leg hop for distance; SLR – Straight leg raise; TJ – Tuck Jump; U11, -12, -13, -14, -15, -16, - 18 – Under age 11, -12, -13, -14, -15, -16, - 18; YoYoIE – YoYo intermittent endurance test

2.3 Workload

The workload is well described as an important risk factor for injury. With a wide amount of research on workload and injury relationship, a review was scrutinized below and summarized in *Table 3.*

In sports, to objectively assess a training intervention's effect, workload needs to be objectively quantified. One of the first models to describe fitness and fatigue, considering the dose-effect response that training had on physical performance, was the model proposed by Banister et al. (1975). The model described the positive and negative responses to training, resulting in a status of fitness or fatigue, respectively. To quantify the adaptions from training, authors have conceptualized mathematical models that accounted for training effects over time and its interference in injury occurrence (Banister et al., 1992; Kibler et al., 1992).

Most recently, a metric describing the responses to training accounting for the training status (i.e., chronic training loads) was introduced (Gabbett, 2016; Hulin et al., 2014). This metric termed acute:chronic workload ratio (ACWR), is based on the first model proposed by Banister et al. (1975). ACWR compares the acute training load (e.g., one training week) with the chronic training load (e.g., one to three weeks), creating a ratio (i.e., acute training load: chronic training load). The ACWR aims to understand better the impact of acute and chronic load relationship on athletic performance, intending to reduce injury risk.

The ACWR can be calculated using internal or external training load measures and different mathematical approaches (Hulin et al., 2016; Murray et al., 2017), raising some conflict among peers (Jones et al., 2017; Wang et al., 2020).

Multiple other authors have studied the association of workload with injury in team sports, using several metrics to quantify load with injury (Bowen et al., 2019; Delecroix, Delaval et al., 2019; Delecroix et al., 2018; Delecroix, Mccall et al., 2019; Fanchini et al., 2018; Jaspers et al., 2018; Malone et al., 2017). The ACWR has been prospectively associated with injury incidence in several team sports, making it one of the most used tools for workload monitoring and management (Gabbet et al., 2007; Gabbet et al., 2011; Hulin et al., 2014).

More recently, the validity of the ACWR calculated as a rolling average (RA) has been questioned (Impellizzeri et al., 2020; Impellizzeri et al., 2020a, 2020b; Lolli et al., 2020). This method fails to account for the decaying nature of a training stimulus over time, and it may not accurately represent the athlete’s responses to training (Williams et al., 2017). For example, the chronic load using a RA approach considers equally a session performed the day before and a session occurring 28 days before. To answer this problem, the exponentially weighted moving average (EWMA) method proposed by Williams et al. (2017) has shown to be more sensitive to detect increases in injury risk at higher ACWR ranges (Murray et al., 2017; Williams et al., 2017).

Association of injury with workload is not only a problem of absolute (high or low) workload. How the athletes cope with the training process to increase fitness with progressive overload should focus, especially knowing that younger athletes have lesser workload tolerance (Gabbett et al., 2007; Gabbett et al., 2011; Hulin et al., 2014).

As mentioned before (see 2.2.2), an injury event is multifactorial, so it is the training process. The effects of training are modulated by appropriate manipulations of training variables (Halson, 2014). Poor load and fatigue management and insufficient recovery strategies may lead to maladaptation, like immunosuppression, injury, or overtraining (Cunanan et al., 2018; Tavares et al., 2017).

To address this problem, workload monitoring and management should be a key concept in injury prevention to minimise injury risk (Drew et al., 2016). To better understand how load can be monitored, managed and which metrics are of interest, the most relevant literature is discussed below.

2.3.1 Workload monitoring, quantification, and management

A well-known training principle among practitioners is the individualization principle and states that each athlete will respond differently (internal load) to the same external load (Wallace et al., 2014). To have greater detail on how athletes respond to training, monitoring and quantifying training responses are commonly used.

Monitoring training load can provide an objective explanation for changes in performance. It is possible to retrospectively assess training responses, plan and adapt training loads, to reduce injury risk and overtrain (Halson, 2014). Previously Brink et al. (2010) prospectively monitored stress, recovery, and incidence of medical problems in elite youth football players highlighting the role of monitoring as a prevention strategy for this population. Different consensus on workload, risk of injury and workload monitoring have been published before, highlighting the different workload quantification methods (Bourdon et al., 2017; Schwellnus et al., 2016; Soligard et al., 2016).

Internal load is critical to determine the appropriate stimulus for adequate physiological adaptation to an external stimulus. Measures of internal load, as training impulse (TRIMP), heart rate and session rating of perceived exertion (sRPE), have been reported for monitoring the training process, as these measures incorporate the individual’s physiological stress responses (Wallace et al., 2014). A few limitations have been pointed to these measures. TRIMP requires technical and laboratory resources to properly take advantage of this method, making it difficult to use in everyday practice with team sports (Wallace et al., 2014). Moreover, heart rate is largely influenced by day-to-day random variations (Sammito & Böckelmann, 2016; Sookan & Mckune, 2012). On the other hand, the sRPE method proposed by Foster et al. (2001) has been suggested by several authors to be a more reliable, valid, ecological, and user-friendly tool (Coutts et al., 2003; Haddad et al., 2017; Wallace et al., 2009). SRPE is obtained rapidly by the product of the perceived rate of exertion (RPE) with session duration, requiring no technology (Coutts et al., 2003; Impellizzeri et al., 2004; Wallace et al., 2009). The acute:chronic workload ratio based on sRPE with 1:3 and 1:4 ratios has shown significant associations with non-contact injuries in elite football players (McCall et al., 2018). Moreover, the consensus on monitoring workload recommends using sRPE as a training monitoring tool (Bourdon et al., 2017).

Despite some limitations that need to be considered, including the use of non-validated sRPE scales and dishonest responses by the influence of external factors, it can be very useful (Coyne et al., 2018). As shown, the importance and reliability of subjective internal measures of training load are well supported.

Workloads can also be presented as absolute or relative derived metrics. Absolute loads are the summation of load values over a given period. Relative loads are those that consider its application over time and express variations in load between periods (Bourdon et al., 2017; Schwellnus et al., 2016; Soligard et al., 2016). Relative loads are usually derived from absolute load and reported as a mathematical calculation or ratio, as the ACWR previously mentioned. Workload and ACWR characteristics are more detailed in a supplementary chapter (*see 8.1*).

2.3.2 Workload and injury in football

In football, there is a never-ending question to find the solution for injury occurrence. To try to solve this problem, and despite inherent limitations of some workload metrics, recent authors have examined the relationship between absolute and derived metrics (ACWR) with non-contact injury in football (Bacon et al., 2017; Bowen et al., 2019, 2017; Dalen-Lorentsen et al., 2020; Delecroix, Delaval et al., 2019; Delecroix et al., 2018; Fanchini et al., 2018; Jaspers et al., 2018; Lolli et al., 2020; Malone et al., 2018; Malone et al., 2017; McCall et al., 2018; Raya-González et al., 2019).

The findings in the literature are controversial, as some researchers found positive associations between workload and injury in football and hence, suggesting the monitoring of workloads are important in the prevention of injury (Bacon et al., 2017; Bowen et al., 2019, 2017; Delecroix et al., 2018; McCall et al., 2018). While other researchers are more critical, as their findings were in disagreement with the added value of the workload/ACWR to predict injury in athletes (Dalen-Lorentsen et al., 2020; Delecroix, Delaval, et al., 2019; Jaspers et al., 2018; Lolli et al., 2020; Raya-González et al., 2019).

Workload has been reported in both absolute (cumulative week load) and relative derived workload (ACWR) (Bacon & Mauger, 2017; Bowen et al., 2020, 2017; Lolli et al., 2020). Different thresholds of high and low absolute cumulative loads have been associated with increased injury risk (Gabbett 2010; Gabbett et al., 2016). Using internal load, Malone et al. (2017) observed that players were at increased risk of injury when high values of one week cumulative training loads of ≥1500 to ≤2120 arbitrary units (AU) were experienced. Moreover, when the cumulative loads of two and three weeks prior to injury were high, players had an increased risk of a contact injury (Tiernan et al., 2020). These findings are consistent among authors (Jaspers et al., 2018).

The ACWR is a derived metric widely studied in the literature. This metric highlights that not only high or low absolute values of training, but the interaction between them might help explaining injury (Gabbett, Hulin, et al., 2016). Rapid increases in weekly acute load were found to be likely responsible for soft-tissue injuries, both in the week of injury and in the subsequent week (Bowen et al., 2017; Gabbett, 2016; Gabbett, Hulin, et al., 2016). Nevertheless, the ACWR methodology still lacks consensus among authors. From the 13 investigations summarized in *Table 3*, some have studied the association of internal load (sRPE) and ACWR with injuries (Dalen-Lorentsen et al., 2020; Fanchini et al., 2018; Lolli et al., 2020; Malone et al., 2017; McCall et al., 2018; Raya-González et al., 2019). Others studied ACWR with both internal (sRPE) and/or external (GPS locomotive measures), and its relationship with injury (Bacon & Mauger, 2017; Bowen et al., 2020, 2017; Jaspers et al., 2018; Malone et al., 2018).

All these authors used a RA method, differing mostly in acute and chronic timeframes (A:C). The timeframes used by the authors ranged from acute 3 to 7 days, and chronic 7, 14, 21, and 28 days. In respect of the coupling for acute and chronic weeks, coupled and uncoupled ratios were used, where the acute week is left out the denominator (Bowen et al., 2019, 2017; Delecroix, Delaval, et al., 2019; Delecroix et al., 2018; Fanchini et al., 2018).

Some authors have recently raised methodological and conceptual concerns about ACWR role in injury prediction (Impellizzeri et al., 2020; Lolli et al., 2020). The measure of different exposures, mathematical pitfalls, ratios, workload quantification, time windows, reference categories, injury definitions, random sample size, missing data, and different types of injury and load reporting were some of the methodological concerns stated by Impellizzeri et al. (2020).

Accounting for these methodological concerns, Dalen-Lorentsen et al. (2020) recently performed a cluster randomised controlled trial among elite youth footballers to assess if an ACWR load management based intervention could be successful in reducing injury likelihood. The author found no between-group differences in health problems prevalence, suggesting that this specific load management intervention was unsuccessful. It highlights the inconsistent and conflicting findings in the literature.

Other workload variables to measure within-week changes have been reported to be associated with injury (Delecroix, Mccall, et al., 2019). Monotony and strain are usually used to quantify the within-week variation (Delecroix, Mccall, et al., 2019). Monotony and strain have been proposed to be associated with injury firstly by Foster (1998). To study its value with academy football players, Brink et al. (2010) found that increases in monotony (OR = 2.59) and strain (OR = 1,01) were associated with increased injury rates, however only in traumatic injuries. These findings were also observed in professional football players (Delecroix, Mccall, et al., 2019). Both authors highlighted that these two metrics should be monitored in combination with other factors to reduce the injury (Delecroix, Mccall, et al., 2019).

To summarize, there is a vast number of research with conflicting evidence to support the use of workload metrics for injury prevention purposes. Despite the associations with injury found in the literature, it is important to mention that association does not equal causation (Hulin et al., 2019). When using ACWR as an injury predictive tool, concerns regarding methodological procedures, with questionable statistics and overstated conclusions have been raised before (Dalen-Lorentsen et al., 2020; Impellizzeri et al., 2020; Impellizzeri et al., 2020a, 2020b; Lolli et al., 2017; Williams et al., 2017). Despite this controversy, researchers agree that workload monitoring and its management provide objective support for physical development and injury risk reduction. The inconsistent findings on workload metrics are relevant, as authors should try to clarify which tools can differentiate between injured and non-injured athletes. The literature suggests that it should be used with caution and the best available methodological options, not aiming to predict injury.

The main literature characteristics on workload and injury relationship are summarized in *Table 3*.

Table 3 - Summary of workload and injury literature in football

References	Design	Population	Level of Play	Injury Type / nº of injuries	II (/1,000h)	Workload measure	ACWR model (A:C ratio)	ACWR Methods	Main Findings
Bacon et al. (2017)	PL cohort 2 seasons	41 male Age 17.8 ±1.1 (U18/U21)	Elite Youth	CInj and NCI / n = 85	10.55	-	Cumulative weekly training loads	3 categories using SD	TD significantly predicted overuse injury incidence rates.
Bowen et al. (2017)	PL cohort (1 team) 2 seasons	32 male Age 17.3 ±0.9 (U18/U21)	Elite Youth	CInj and NCI / n = 138	12.1	-	RA (7: 14 / 21 / 28) Uncoupled	6 z score categories (Very low as reference)	ACC over 3 weeks was associated overall and NCIR. NCIR was higher when high acute HSD matched low chronic HSD. Cinj risk was greatest when A:C TD and ACC ratios were very high (1.76 and 1.77). Cinj were related to one weekly 'spikes' in several workload metrics.
Bowen et al. (2019)	PL cohort (1 team) 3 seasons	33 male Age 25.4 ±3.1	Elite Professional	Non reported / n = 132	13.3	-	RA (7: 14 / 21 / 28) Uncoupled	6 z-score categories (Very low as reference)	When CL was low, ACWR >2 increased NCI 5–7 times. Spike in workload was associated with increased IR, although with higher chronic loads, RI reduced. A spike in DCC was associated with the greatest NCIR.

Dalen-Lorentsen et al., (2020)	RCT 1 season	482 - 178 females; 278 males (U19)	Elite Youth	All health Problems	-	sRPE	RA (7:28)	-	The between-group difference in health problem prevalence was 1.8% points with no reduction in the likelihood of reporting a health problem. No differences found between groups.
Delecroix, Delaval, et al., (2019)	PL cohort (2 teams) 5 seasons	122 male, (U19/U21)	Elite Youth	Lower Body / n = 489 (NCI - 335 + Cinj - 155)	U 19 - 7.6 U21 - 9.6	sRPE	RA (7: 7 / 14 / 21 / 28) Coupled	No Grouping	There was no association between absolute or ACWR with U19, while there was an association between 3 and 4 weeks' cumulative absolute workload for U21.
Delecroix, McCall, et al., (2018)	PL cohort (5 teams) 1 season	130 male	Elite Professional	Lower body NCI / n = 237	7.4	sRPE	RA (7: 14 / 21 / 28) Coupled	3 z score categories (Middle as reference)	II was higher when ACWR 7:28 was < 0.85 vs > 0.85 and with ACWR 7:21 > 1.30 vs < 1.30. None of the ACWR combinations showed high sensitivity or specificity.
Fanchini et al. (2018)	PL cohort (1 team) 3 seasons	34 male Age 26 ± 5	Elite Professional	Non reported / n = 72	5.1	sRPE	RA (7: 14 / 21 / 28) Coupled	4 categories	Supports the association between sRPE, especially ACWR with NCI. While significantly associated, no ability to predict injury at an individual player level.

Jaspers et al. (2018)	PL cohort (1 team) 2 seasons	35 male Age 23.2 ±3.7	Elite Professional	Non reported / n = 64	5.8	sRPE	RA (7:28) Coupled	3 categories (Lowest as reference)	No most likely harmful effects were found. High ACWR for HSR should be avoided. Protective effects were found, and medium ACWR is recommended for number ACC-DCC, and sRPE.
Lolli et al. (2020)	PL cohort (1 team) 3 seasons	Male	Elite Professional	Hamstring / n = 30	-	sRPE	Cumulative 7 / 14 / 21 / 28 sRPE week to week changes sRPE and Exposure (min)	-	Corrected odds for the RPE, sRPE, exposure and cumulative sRPE for all the physical load periods were not relevant for a hamstring injury.
Malone et al. (2017)	PL cohort (2 teams) 1 season	48 male Age 25.3 ±3.1	Elite Professional	Non reported / n = 75	1.6	sRPE	RA (7:28) Coupled	4 categories (Lowest as reference)	ACWR between 1.00 and 1.25 was protective. Higher intermittent-aerobic capacity offers greater injury protection to spikes in workload.
Malone et al. (2018)	PL cohort 1 season	37 male Age 25 ±3	Elite Professional	Lower body soft tissue / n = 75	16.2	sRPE (field and gym)	RA (3:21) Coupled	4 categories (Lowest as reference)	HSR ACWR 3:21 >1.25 and sprint ACWR 3:21 > 1.35 increased RI. Higher chronic loads (≥2584 AU) and better intermittent aerobic fitness were protective.

McCall et al. (2018)	PL cohort (5 teams) 1 season	171 male Age 25.1 ±4.9	Elite Professional	NCI / n = 123	-	sRPE (field and gym)	RA (7: 7 / 14 / 21 / 28) Coupled	Four percentile categories	ACWR windows 7:21 and 7:28 were associated with NCI. ACWR 7:28 of 0.97-1.38 and > 1.38 increased RI compared to ACWR of 0.60-0.97. ACWR 7:21 > 1.42 compared with 0.59-0.97 displayed 1.94 times higher RI. Both ACWR windows showed poor predictive power.
Raya-González, et al. (2019)	PL cohort (1 team) 1 season	22 male Age 18.6 ±0.6 (U19)	Elite Youth	NCI / n = 27	4.64	sRPE	RA (7:28) Coupled	No Grouping	No association was found for weekly load and ACWR with injury occurrence. The analysed load markers showed poor ability to predict injury occurrence.

ACC – Number of accelerations; ACWR – Acute Chronic workload ratio; CI – Coefficient interval; CInj – Contact injury;DCC – Number of decelerations; GPS – Global Positioning Systems, HSR – High-speed running distance; II – Injury incidence per 1000h; IR – Injury Risk; LBI – Lower-body injury; LID – Low intensity distance; min – minutes; NCI – Non-contact injury; NCIR – Non-contact injury risk; Nº - Number; PL cohort – Prospective longitudinal cohort study; RA – Rolling Average; RCT – Randomized controlled trial; RPE – Rate perceived exertion; RR – Relative Risk; SPR – Sprint distance; sRPE – Session Rated perceived exertion; STI – Soft tissue injury; TD – Total distance; U18 – Under age 18; U19 – Under age 19; U21 – Under age 21

3. Methodology

This study methodology was divided into two parts, part A and B (B1 and B2):

3.1 Part A - Injury epidemiological study

3.1.1 Experimental Design

In part A, a description of injury epidemiology was undertaken in a Portuguese elite male football academy during one season, with a total of 184 players from the U14 to U23 age groups. Injuries sustained in football training and matches, and daily training individual exposure (h) were recorded within 8 months (July to March) during the 2019-2020 season. A prospective descriptive analysis was performed to investigate injury frequency, incidence, burden, and patterns (severity, location, general type, specific type, mechanisms, injuries per position).

3.1.2 Participants

All players present in the academy were asked to take part in this study. A total of 184 male youth football players from an elite Portuguese football academy (age: 16.2 ± 2.2; range:13 to 23), from different age groups squads (U23, U19, U17, U16, U15, U14). Injuries were only accounted if an athlete was injured during training or match in the football club. Written informed consent both in Portuguese and English was obtained from each participant legal guardian when underage. An external person to the study collected the consent to prevent any conflict caused by the dependent physiotherapist/athlete relationship from the author. This investigation sample was a convenience sampling, as the author is a physiotherapist in the same institution.

Trial athletes, athletes that left the assessment period, players who were injured at the time of the musculoskeletal assessment were excluded from the study. Athletes with no exposure or injury surveillance data recorded over the surveillance time and who did not want to participate in the study were also not considered.

3.1.3 Data collection

All musculoskeletal injuries sustained were prospectively recorded by the academy medical staff (four physiotherapists and two medical doctors) in a standardised electronic format established on the FIFA consensus (Fuller et al., 2006). Injury record form can be found in *appendix file III (see 8.3)*.

Each team had an experienced, fully dedicated physiotherapist, with the support of the current study's main researcher, and all injuries were examined in cooperation with two academy sports physicians. Referral to a surgeon, specialist or imaging was requested if required/necessary to consolidate diagnosis. Each team's physiotherapist submitted their injury information of all discharged injured players to the main researcher, who reviewed and consolidated all data weekly. Injuries not sustained in the football training or matches, or any data related to sickness or other general medical conditions were excluded from the analysis.

3.1.4 Definition of injury and reporting

Injury was defined as any lower extremity ‘time-loss’ injury sustained during training or competition that resulted in missing 3 training sessions or 1 match. Injury characteristics were registered according to FIFA injury consensus (Fuller et al., 2006). Injury date, days of absence, date of full participation, the context of injury, location, type, severity, side, mechanism, limb dominance, number of season injuries were recorded. A player was considered injured until the medical staff allowed full participation in match selection training and availability. Injury absence was measured as the number of days from injury occurrence to full participation. Injury severity was classified based on the number of days missed, including slight (1 – 3 days), minor (4 – 7 days), moderate (8 – 28 days) and severe (> 28 days). General injury mechanism was defined regarding contact or non-contact. A contact injury was defined as when an incident with clear contact or collision from another player, the ball, or another object occurred. Traumatic injuries were defined as injuries that resulted from a specific, identifiable event. Overuse injuries were defined as injuries caused by repeated microtrauma without a single identifiable event. Specific injury mechanism was defined accordingly with the specific physical action that led to an injury. Exposure was defined as the training or match duration in hours (h). The total number of training sessions and match fixtures were also accounted for each player individually and each team age group.

3.1.5 Data analysis

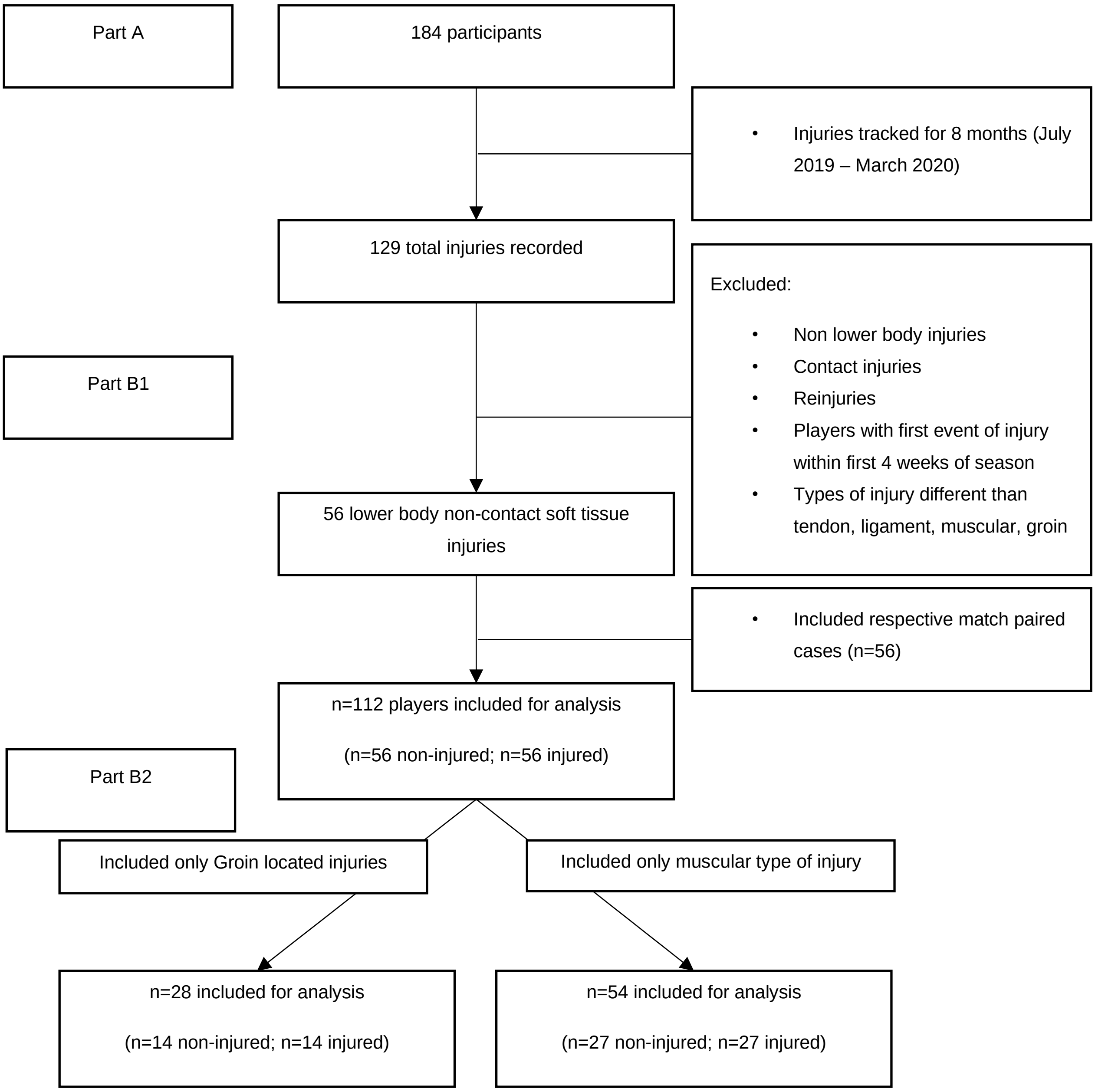
Descriptive statistics of variables were presented as mean± standard deviation (SD), frequency, and expressed in percentage (relative to the corresponding squad and to the entire academy). Injury incidence was quantified based on time-loss injury data as the total number of injuries per 1000 hours of exposure (training, match play, or combined), severity, and general type of injury for each age group. Injury burden rate was quantified based on time-loss injury data as the total number of days lost to injury per 1000 hours of exposure (training, match play, or combined) (Bahr et al., 2018). Injury matrix burden isoquant curves were calculated using the cross-product of incidence (injuries /1000h) x severity (mean days lost to injury).

Injury incidence was calculated using the following formula: Number of *injuries (N)/ SUM* $\sum$ *exposure (h)* × *1000 h*). Injury burden was calculated as the mean number of days lost per injury/ *SUM ∑* exposure (h) x 1000 h). Total *SUM ∑ and mean days lost to injury* were also calculated. The frequency of injuries categorized by type, mechanism, location, and context, are presented as absolute and relative values (percentage of total injuries). No data was lost since the injury data were normalized relative to exposure (Bahr et al., 2018; Hägglund et al., 2013).

3.2 Part B

3.2.1 Participants

In part B analysis, participant inclusion and exclusion criteria are outlined in the following diagram.



3.2.2 Experimental design

In part B1, the non-contact lower body soft tissue injuries observed in part A were further investigated. To ensure that athletes were comparable, a match paired case approach was performed, using team, position, and age as criteria to pair injured and non-injured athletes. For Part B1, the aim was to investigate the differences between injured and non-injured elite youth footballers for musculoskeletal screening and workload variables on lower body non-contact soft tissues injuries, and B2 on both groin and muscle injuries.

Firstly, the differences between injured (n= 56) and non-injured (n= 56) groups was tested for the following musculoskeletal screening tests: $\mathrm{PKFO_{diff}}$, $\mathrm{PKFO_{ratio}}$, ASQZ, $\mathrm{ASQZ/BW_{ratio}}$, $\mathrm{DLT_{diff}}$, $\mathrm{DLT_{ratio,}}$ $\mathrm{SL\text{-}CMJ_{diff}}$ and $\mathrm{SL\text{-}CMJ_{ratio}}$; and the following workload variables: sRPE sum (week -5, -4, -3, -2, -1), MON (week -4, -3, -2, -1),STR (week -4, -3, -2, -1), $\mathrm{RA_{coupled}}$ and $\mathrm{RA_{uncoupled}}$ A:C (7:28) ratio, $\mathrm{EWMA_{coupled}}$ and $\mathrm{EWMA_{uncoupled}}$ A:C (7:28) ratio, week to week change (%) (W-5 to W-4, W-4 to W-3, W-3 to W-2, W-2 to W-1). Secondly, in part B2, because some tests conducted (e.g., ASQZ) are more location-specific (groin), and there was a high prevalence of muscular injuries (33.3% of total injuries) and groin located injuries (15.6% of total non-contact injuries) observed in part A, the differences of musculoskeletal and workload variables between injured and non-injured athletes for clusters of groin located injuries (n=28) and muscular type of injury (n= 54), were further investigated.

3.2.3 Data collection

During the pre-season (July), the players undertook a comprehensive musculoskeletal screening battery that took part during the club’s mandatory periodic health examination.

Before the testing, participants were instructed about each test's protocol, and submaximal trials were used as familiarization and warm-up. The players from each team performed the screening on different days. The physiotherapist implemented the tests responsible for each team, with the author of this study present in all sessions. Data of each screening test was registered in a digital record.

The intensity and exposure of all training sessions were registered daily by each team's strength and conditioning coach, using the modified Borg CR-10 RPE (Rate of Perceived Exertion) scale, with ratings obtained from each player within 30 minutes after the end of each training session. SRPE in arbitrary units (AU) for each player was then derived by multiplying RPE and session duration (min). When a player did not train, sRPE was considered 0 for that given day. The number of training and matches lost to injury were also recorded. Missing data of exposure and RPE was handled using daily team averages, and when not possible, with individual average as suggested by Wang et al. (2020).

3.2.4 Musculoskeletal tests

The tests performed for flexibility/mobility were passive knee fall out test (PKFO) and dorsiflexion lunge test (DLT), reported in centimetres (cm). Symmetry was calculated as the absolute difference and ratio of the dominant and non-dominant side, respectively. For peak force, the adductor squeeze test (ASQZ) and single-leg countermovement jump test (SL-CMJ) were performed and reported in kilograms (kg) and cm, respectively. Moreover, peak force values for groin squeeze were normalized to body mass.

The strength tests have previously good intra- and inter-tester reproducibility (Mesquita et al., 2018; Moreno-Pérez et al., 2017). Similarly, the flexibility tests conducted also showed good reproducibility (Malliaras et al., 2009; O'Brien et al., 2018; Powden et al., 2015). The detailed procedures for each test are described in *appendix file II (see 8.2).*

3.2.5 Workload variables

The duration was defined as the training or match duration in minutes (min). The total number of training sessions and match fixtures were also accounted for each player individually and each team age group.

The intensity was determined using the modified Borg CR-10 rate of perceived exertion (RPE) scale, from 0-10, with '2'=easy, '5'=hard, '10'=maximal. Players answered the question "How hard was your workout?" 30 min after every session/match. Each player was confidentially questioned and could not see the values rated by the other participants. All players were familiarized with this method.

To quantify the absolute workload in AU, the sRPE method proposed by Foster et al. (2001) was used, multiplying the training or match intensity by the session's duration. This method has shown to be a reliable measure of the internal training load. Gabbett et al. (2007) found that the correlation between training heart rate and sRPE, and training blood lactate concentration and sRPE, was 0.89 and 0.86, respectively.

The following absolute and relative derived workload metrics were used (Table 11):

a) Weekly cumulative sRPE

The cumulative sum of weekly sRPE was calculated for weeks -5, -4, -3, -2, -1 relative to the day of injury.

b) Acute: Chronic Workload Ratio (ACWR)

For the ACWR calculation, two methods with two different coupling options with 7 days acute and 28 days chronic time-window were used. The RA coupled method was calculated by dividing the cumulative seven days of acute load (-1week) by the cumulative average of the last 28 days of chronic load (four weeks).

The EWMA was calculated using the following formula proposed by Williams et al. (2017): *EWMA today = Load today x λa + ((1- λa) x EWMA yesterday)*. Where *λa* is a value between 0 and 1 that represents the degree of decay, with higher values discounting older observations in the model faster. The *λa* is calculated as: *λa = 2/ (N + 1). N* is the chosen time decay constant, with an acute 7 days and chronic 28 days. This method assigns a decreasing weighting to each older load value, thereby giving more weighting to the athlete's recent load.

c) Monotony and Strain

Training monotony is a measure of day-to-day variability of training load each week and was calculated as the mean sRPE daily load divided by the standard deviation of the load over a week. Training strain is a measure of the weekly training stimulus's overall stress and was calculated as the weekly sRPE load multiplied by monotony (Esmaeili, Hopkins, et al., 2018).

d) Week to week change

Week to week change was calculated as the difference between week -5 to week-4, week -4 to week – 3, week -3 to week – 2, week -2 to week -1, and was reported in percentage (%).

3.2.6 Data analysis

Descriptive statistics were calculated for all variables. For part B1, normality was assumed according to the central limit theorem (n=56). For part B2, normality was tested using the *Kolmogorov-Smirnov test*. Additionally, the assumption of homogeneity of variances was tested using *Levene's test*. When equal variance was satisfied, an *independent samples t-test* was used to compare injured and non-injured athletes. When normality was not verified, independent samples *Mann-Whitney U test* was used to compare both groups. The level of significance for all the tests was set at p-value <0.05. *Cohen's D/ r effect size* was calculated post hoc (*d / r* = 0.20 - *small* effect; d / r = 0.50 - *moderate* effect; d / r = 0.80 - *large* effect) (Cohen, 2013). Data were analysed using IBM SPSS Statistics 22.0 (IBM corp., Armonk, NY, USA).

3.3 Ethics and data use

Data usage complied with the 1964 Declaration of Helsinki standards, reviewed in 2013 (World Medical Association, 2013). Previously to analysis, players were given an individual identification code to hide their identity, guaranteeing personal data protection in compliance with the European parliament general data protection registry (Kubben et al., 2018). To avoid dependency, participants were informed by an intermediate person (not related to the investigation) that participation should be willing, with the possibility of being removed from the study at any time if desired. The players who were willing to participate were given an intermediate person's informed consent, explaining the main goals and procedures to be signed for each one. To the under-aged participants, informed consent was obtained from the legal tutor.

All data belonging to the club was used from the mandatory PHE procedure, injury surveillance and workload monitoring. A formally signed requirement was obtained from the club direction board and clinical director for data usage in the present study.

There was no financial costs or compensation associated with this study. All athletes are protected by the club's football safety participation insurance, which is demanded participation in training and competition. There was no funding or financial benefit from any entity for the research team.

There are no known risks associated with this study. The participants will benefit from taking part in the study to contribute to the research of the sports medicine field.

After the study is completed, all the participants will be informed and receive a copy of the study and each individual report of his risk factors and future injury reduction strategies.

There is no conflict of interests. All procedures were approved by the Ethics Committee of the Faculty of Human Kinetics, University of Lisbon, CEIFMH Nº13/2021, and is attached in *appendix file IV (see 8.4)*.

4. Results

Part A – Injury epidemiological study

All age groups teams were observed over a period of one season. Demographic characteristics are described in Table 4.

A total of 129 time-loss injuries were recorded, of which 23.5% (n=30) occurred in matches, 71.3% (n=92) in training and 5.2% (n=7) in national duty, resulting in a total of 2826 days of absence from training or match participation. A total of 25.6% (n=33) occurred in contact context and 74,4% (n=96) in non-contact circumstances. A total of 47695.4 hours of exposure were recorded, with 44103.6h of training and 3591.8h of match fixtures. A total incidence of 2.7 injuries per 1000h of exposure, with an injury burden rate of 59.3 days lost per 1000h of exposure. On average, an injury took 21.9±28 days to recover, with 70% of all players suffering at least one injury during the season. Moderate (7-28 days) injuries were the most common severity, with 55.8 % of total injuries. Midfielders were the most frequently injured position (n=33, 25.6% of total injuries), followed by centre backs (n=27, 20,9% of total injuries) and full backs (n=26, 20.2% of total injuries). The most frequent injured age group was the U17 team (n=30, 23.3% of total injuries), with the highest injury burden (92.7 days lost per 1000h).

The different age groups injury prevalence, days of time-loss, severities of all type of injuries and player position are described in Table 5, Table 6, and Table 7.

Injuries were distributed by location, with lower extremities being the most common injury site (91.5%). Injuries on the rest of the body were less frequent (8.5%). In contact and non-contact type of injury, the lower body was the most frequent location representing 81.8% of total contact and 94.8% of total non-contact injuries. The distribution of injuries by location is displayed in Figure 3.

Muscle injury was the most frequent injury type (n=43, 33.3% of total injuries), with 16.6 ±12.4 days of mean time-loss and 0.90 incidence per 1000h. Of muscle injuries, the U23 age group was the most affected team (n=12, 27.9% of total injuries), being quadriceps the most frequently injured muscle group (n=22, 51.2% of total muscle injuries), with both shooting and sprinting as the main injury mechanisms (n=6, 27.3% of quadriceps mechanisms of injury). Muscle injuries prevalence and mechanism of injury of the different muscle groups per team are displayed in Table 9 and Table 10.

The burden of injury by squads and injury type is illustrated by the risk matrix Figure 4 and Figure 5, respectively. Moreover, injury type severity and frequency are illustrated in Figure 6.

Table 4 - Demographic characteristics

Players Characteristics	***Players***	***Age (Y)***	***Height (m)***	***Body Mass (kg)***	***BMI (kg/m^2)***
Team	***N***	***Mean ±SD***	***Mean ±SD***	***Mean ±SD***	***Mean ±SD***
U23	26	19.9±1.3	1.82±0.07	73.5±7.6	22.3±1.6
U19	27	18.0±0.8	1.81±0.07	71.2±7.7	21.9±1.8
U17	25	16.8±0.4	1.79±0.07	68.2±5.9	21.2±1.3
U16	25	16.0±0.2	1.76±0.1	64.3±8.1	20.9±2.5
U15	32	14.9±0.2	1.74±0.08	61.1±7.4	20.2±1.7
U14	49	13.7±0.4	1.63±0.01	49.9±9.6	18.5±1.8
Total	184	16.2±2.2	1.74±0.01	62.9±11.8	20.5±2.3

Table 5 - Injury Severity per age group

Severity			***Slight (1- 3 days)***			***Minor (4- 7 days)***			***Moderate (8- 28 days)***			***Severe (>28 days)***			
	Days lost to injury	***Injury Burden***	***Injuries***	***Severity Category Injuries***	***Injury Incidence***	***Injuries***	***Severity Category Injuries***	***Injury Incidence***	***Injuries***	***Severity Category Injuries***	***Injury Incidence***	***Injuries***	***Severity Category Injuries***	***Injury Incidence***	***Total Injuries***
Team	***SUM ∑ (N)***	***(/1000h)***	***N (%Total)***	***%***	***(/1000h)***	***N (%Total)***	***%***	***(/1000h)***	***N (%Total)***	***%***	***(/1000h)***	***N (%Total)***	***%***	***(/1000h)***	***SUM ∑ (N)***
U23	322	48.2	1 (0.8%)	5.0%	0.15	3 (2.3%)	15.0%	0.45	14 (10.9%)	70.0%	2.09	2 (1.6%)	10.0%	0.30	20
U19	371	42.9	1 (0.8%)	4.5%	0.12	5 (3.9%)	22.7%	0.58	13 (10.1%)	59.1%	1.50	3 (2.3%)	13.6%	0.35	22
U17	889	92.7	2 (1.6%)	6.7%	0.21	5 (3.9%)	16.7%	0.52	13 (10.1%)	43.3%	1.36	10 (7.8%)	33.3%	1.04	30
U16	368	59.5	0 (0.0%)	0.0%	0.00	7 (5.4%)	33.3%	1.13	10 (7.8%)	47.6%	1.62	4 (3.1%)	19.0%	0.65	21
U15	598	67.8	0 (0.0%)	0.0%	0.00	1 (0.8%)	5.0%	0.11	15 (11.6%)	75.0%	1.70	4 (3.1%)	20.0%	0.45	20
U14	278	35.7	0 (0.0%)	0.0%	0.00	6 (4.7%)	37.5%	0.77	7 (5.4%)	43.8%	0.90	3 (2.3%)	18.8%	0.39	16
Total	2826	59.3	4	3.1%	0.08	27	20.9%	0.57	72	55.8%	1.51	26	20.2%	0.55	129

Table 6 - Injury context characteristics

Context	***Training***								***Match***								***Total (includes National team)***							
	Sessions	***Injuries***	***Injuries / Athlete***	***Exposure***	***Injury Incidence***	***Total days lost to injury***	***Mean days lost to injury***	***Injury Burden***	***Sessions***	***Injuries***	***Injuries / Athlete***	***Exposure***	***Injury Incidence***	***Total days lost to injury***	***Mean days lost to injury***	***Injury Burden***	***Sessions***	***Injuries***	***Injuries / Athlete***	***Exposure***	***Injury Incidence***	***Total days lost to injury***	***Mean days lost to injury***	***Injury Burden***
Team	***Mean ±SD***	***N (%)***	***N***	***SUM Σ (h)***	***(/1000 h)***	***SUM Σ (N)***	***Mean ±SD***	***(/1000 h)***	***Mean ±SD***	***N (%)***	***N***	***SUM Σ (h)***	***(/1000 h)***	***SUM Σ (N)***	***Mean ±SD***	***(/1000 h)***	***Mean ±SD***	***N (%)***	***N***	***SUM Σ (h)***	***(/1000 h)***	***SUM Σ (N)***	***Mean ±SD***	***(/1000 h)***
U23	143±*32*	12 (13%)	0.46	5888.2	2.0	123	10.3±*5.1*	20.9	22±*9*	8 (27%)	0.31	796.9	10.0	199	24.9±*16.4*	249.7	165±*37*	20 (16%)	0.77	6685.1	3.0	322	16.1±*13.2*	48.2
U19	168±*44*	12 (13%)	0.44	8004.5	1.5	154	12.8±*6.2*	19.2	18±*10*	9 (30%)	0.33	633.5	14.2	140	15.6±*15.8*	221.0	185±*49*	22 (17%)	0.81	8638.0	2.5	371	16.9±*17.2*	42.9
U17	173±*30*	23 (25%)	0.92	9113.1	2.5	697	30.3±*44.4*	76.5	13±*7*	5 (17%)	0.20	478.0	10.5	103	20.6±*10.1*	215.5	186±*31*	30 (23%)	1.20	9591.1	3.1	889	29.6±*39.5*	92.7
U16	136±*45*	15 (16%)	0.60	5701.6	2.6	250	16.7±*13.7*	43.8	16±*5*	4 (13%)	0.16	485.9	8.2	42	10.5±*5.0*	86.4	152±*47*	21 (16%)	0.84	6187.5	3.4	368	17.5±*14.2*	59.5
U15	143±*35*	17 (18%)	0.53	8037.9	2.1	559	32.9±*41.5*	69.5	21±*8*	2 (7%)	0.06	779.1	2.6	26	13.0±*7.0*	33.4	164±*36*	20 (16%)	0.63	8817.0	2.3	598	29.9±*38.9*	67.8
U14	102±*19*	13 (14%)	0.27	7358.3	1.8	170	13.1±*12.5*	23.1	10±*7*	2 (7%)	0.04	418.4	4.8	52	26.0±*17.0*	124.3	113±*22*	16 (12%)	0.33	7776.7	2.1	278	17.4±*16.8*	35.7
Total	141±*42*	92 (100%)	0.50	44103.6	2.1	1953	21.2±*30.9*	44.3	16±*9*	30 (100%)	0.16	3591.8	8.4	562	18.7±*14.8*	156.5	158±*46*	129 (100%)	0.70	47695.4	2.7	2826	21.9±*28.0*	59.3

Table 7 - Specific type of injury characteristics

Specific Type of Injury	***Position***						***Team***						***Incidence and Severity***			
	GK	***CD***	***WB***	***CM***	***W***	***AF***	***U23***	***U19***	***U17***	***U16***	***U15***	***U14***	***Frequency***	***Mean days lost to injury***	***Total days lost to injury***	***Injury Incidence***
	N (%Total)	***N (%Total)***	***N (%Total)***	***N (%Total)***	***N (%Total)***	***N (%Total)***	***N (%Total)***	***N (%Total)***	***N (%Total)***	***N (%Total)***	***N (%Total)***	***N (%Total)***	***N (%Total)***	***Mean ±SD***	***SUM ∑ (N)***	***(/1000h)***
Fracture	0 (0.0%)	3 (2.3%)	1 (0.8%)	1 (0.8%)	1 (0.8%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	2 (1.6%)	0 (0.0%)	0 (0.0%)	3 (2.3%)	6 (4.7%)	58.3 ±52.0	350	0.13
Other Bone Injury	1 (0.8%)	2 (1.6%)	3 (2.3%)	3 (2.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	3 (2.3%)	3 (2.3%)	1 (0.8%)	2 (1.6%)	9 (7.0%)	20.7 ±15.6	186	0.19
Dislocation	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	3.0 ±0.0	3	0.02
Ligament/Capsular	0 (0.0%)	7 (5.4%)	2 (1.6%)	6 (4.7%)	8 (6.2%)	6 (4.7%)	5 (3.9%)	11 (8.5%)	5 (3.9%)	3 (2.3%)	4 (3.1%)	1 (0.8%)	29 (22.5%)	14.8 ±10.5	430	0.61
Meniscus	0 (0.0%)	2 (1.6%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	0 (0.0%)	2 (1.6%)	1 (0.8%)	1 (0.8%)	0 (0.0%)	4 (3.1%)	104.5 ±74.9	418	0.08
Cartilage/Chondral	0 (0.0%)	1 (0.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	33.0 ±0.0	33	0.02
Muscle Injury	4 (3.1%)	8 (6.2%)	8 (6.2%)	14 (10.9%)	6 (4.7%)	3 (2.3%)	12 (9.3%)	4 (3.1%)	8 (6.2%)	6 (4.7%)	9 (7.0%)	4 (3.1%)	43 (33.3%)	16.6 ±12.4	715	0.90
Tendon	1 (0.8%)	0 (0.0%)	2 (1.6%)	1 (0.8%)	1 (0.8%)	1 (0.8%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	3 (2.3%)	2 (1.6%)	0 (0.0%)	6 (4.7%)	24.2 ±12.4	145	0.13
Contusion/Haematoma	0 (0.0%)	1 (0.8%)	3 (2.3%)	2 (1.6%)	1 (0.8%)	2 (1.6%)	0 (0.0%)	2 (1.6%)	1 (0.8%)	3 (2.3%)	1 (0.8%)	2 (1.6%)	9 (7.0%)	9.0 ±5.5	81	0.19
Concussion	0 (0.0%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	5.0 ±0.0	5	0.02
Nerve Injury	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	77.0 ±0.0	77	0.02
Synovitis	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	11.0 ±0.0	11	0.02
Overuse	0 (0.0%)	2 (1.6%)	6 (4.7%)	2 (1.6%)	3 (2.3%)	3 (2.3%)	2 (1.6%)	1 (0.8%)	7 (5.4%)	1 (0.8%)	1 (0.8%)	4 (3.1%)	16 (12.4%)	17.5 ±13.7	280	0.34
Other Injury	0 (0.0%)	1 (0.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	1 (0.8%)	0 (0.0%)	2 (1.6%)	46.0 ±25.0	92	0.04
Total	6 (4.7%)	27 (20.9%)	26 (20.2%)	33 (25.6%)	20 (15.5%)	17 (13.2%)	20 (15.5%)	22 (17.1%)	30 (23.3%)	21 (16.3%)	20 (15.5%)	16 (12.4%)	129	21.9 ±28.0	2826	2.70

Table 8 - General type of injury

General Type of Injury	***Contact***							***Non-Contact***						
	Contact Injuries	***Team Contact Injuries***	***Injuries / Athletes***	***Exposure***	***Injury Incidence***	***Total days lost to injury***	***Injury Burden***	***Non-Contact Injuries***	***Team Non-Contact Injuries***	***Injuries / Athletes***	***Exposure***	***Injury Incidence***	***Total days lost to injury***	***Injury Burden***
Team	***N (%Total)***	***%***	***N***	***SUM ∑(h)***	***(/1000h)***	***SUM ∑(N)***	***(/1000h)***	***N (%Total)***	***%***	***N***	***SUM ∑(h)***	***(/1000h)***	***SUM ∑(N)***	***(/1000h)***
U23	5 (3.9%)	15.2%	0.19	6685.1	0.7	83	12.4	15 (11.6%)	15.6%	0.58	6685.1	2.2	239	35.8
U19	11 (8.5%)	33.3%	0.41	8638.0	1.3	125	14.5	11 (8.5%)	11.5%	0.41	8638.0	1.3	246	28.5
U17	4 (3.1%)	12.1%	0.16	9591.1	0.4	52	5.4	26 (20.2%)	27.1%	1.04	9591.1	2.7	837	87.3
U16	8 (6.2%)	24.2%	0.32	6187.5	1.3	123	19.9	13 (10.1%)	13.5%	0.52	6187.5	2.1	245	39.6
U15	3 (2.3%)	9.1%	0.09	8817.0	0.3	83	9.4	17 (13.2%)	17.7%	0.53	8817.0	1.9	515	58.4
U14	2 (1.6%)	6.1%	0.04	7776.7	0.3	62	8.0	14 (10.9%)	14.6%	0.29	7776.7	1.8	216	27.8
Total	33 (25.6%)		0.18	47695.4	0.7	528	11.1	96 (74.4%)		0.52	47695.4	2.0	2298	48.2

Table 9 - Muscle injuries frequency

Muscle Injuries	***Hamstrings***	***Adductors***	***Quadriceps***	***Calf***	***Soleus***	***Total Muscle Injuries***
	N (% Team Muscle Injuries)	***N (% Team Muscle Injuries)***	***N (% Team Muscle Injuries)***	***N (% Team Muscle Injuries)***	***N (% Team Muscle Injuries)***	***N (% Total muscle injuries)***
U23	3 (25.0%)	2 (16.7%)	7 (58.3%)	0 (0.0%)	0 (0.0%)	12 (27.9%)
U19	3 (75.0%)	0 (0.0%)	1 (25.0%)	0 (0.0%)	0 (0.0%)	4 (9.3%)
U17	2 (25.0%)	2 (25.0%)	3 (37.5%)	1 (12.5%)	0 (0.0%)	8 (18.6%)
U16	3 (50.0%)	1 (16.7%)	2 (33.3%)	0 (0.0%)	0 (0.0%)	6 (14.0%)
U15	1 (11.1%)	0 (0.0%)	8 (88.9%)	0 (0.0%)	0 (0.0%)	9 20.9%)
U14	2 (50.0%)	1 (25.0%)	1 (25.0%)	0 (0.0%)	0 (0.0%)	4 (9.3%)
Total muscle group injuries (% Total Muscle injuries)	14 (32.6%)	6 (14.0%)	22 (51.2%)	1 (2.3%)	0 (0.0%)	43 (100.0%)

Table 10 - Mechanisms of muscle injuries

Muscle Injury Mechanism of Injury	***Hamstrings***	***Adductors***	***Quadriceps***	***Calf***	***Soleus***	***Total muscle injuries per mechanism***
	N (% Total muscle group injuries)	***N (% Total muscle group injuries)***	***N (% Total muscle group injuries)***	***N (% Total muscle group injuries)***	***N (% Total muscle group injuries)***	***N (% Total muscle injuries)***
Sprinting	9 (64.3%)	0 (0.0%)	6 (27.3%)	1 (100.0%)	0 (0.0%)	16 (38.1%)
Shooting	1 (7.1%)	0 (0.0%)	6 (27.3%)	0 (0.0%)	0 (0.0%)	7 (16.7%)
Passing/crossing	0 (0.0%)	3 (50.0%)	2 (9.1%)	0 (0.0%)	0 (0.0%)	5 (11.9%)
Stretching	2 (14.3%)	1 (16.7%)	1 (4.5%)	0 (0.0%)	0 (0.0%)	4 (9.5%)
Overuse	1 (7.1%)	2 (33.3%)	4 (18.2%)	0 (0.0%)	0 (0.0%)	7 (16.7%)
Collision	1 (7.1%)	0 (0.0%)	2 (9.1%)	0 (0.0%)	0 (0.0%)	3 (7.1%)
Deceleration	0 (0.0%)	0 (0.0%)	1 (4.5%)	0 (0.0%)	0 (0.0%)	1 (2.4%)

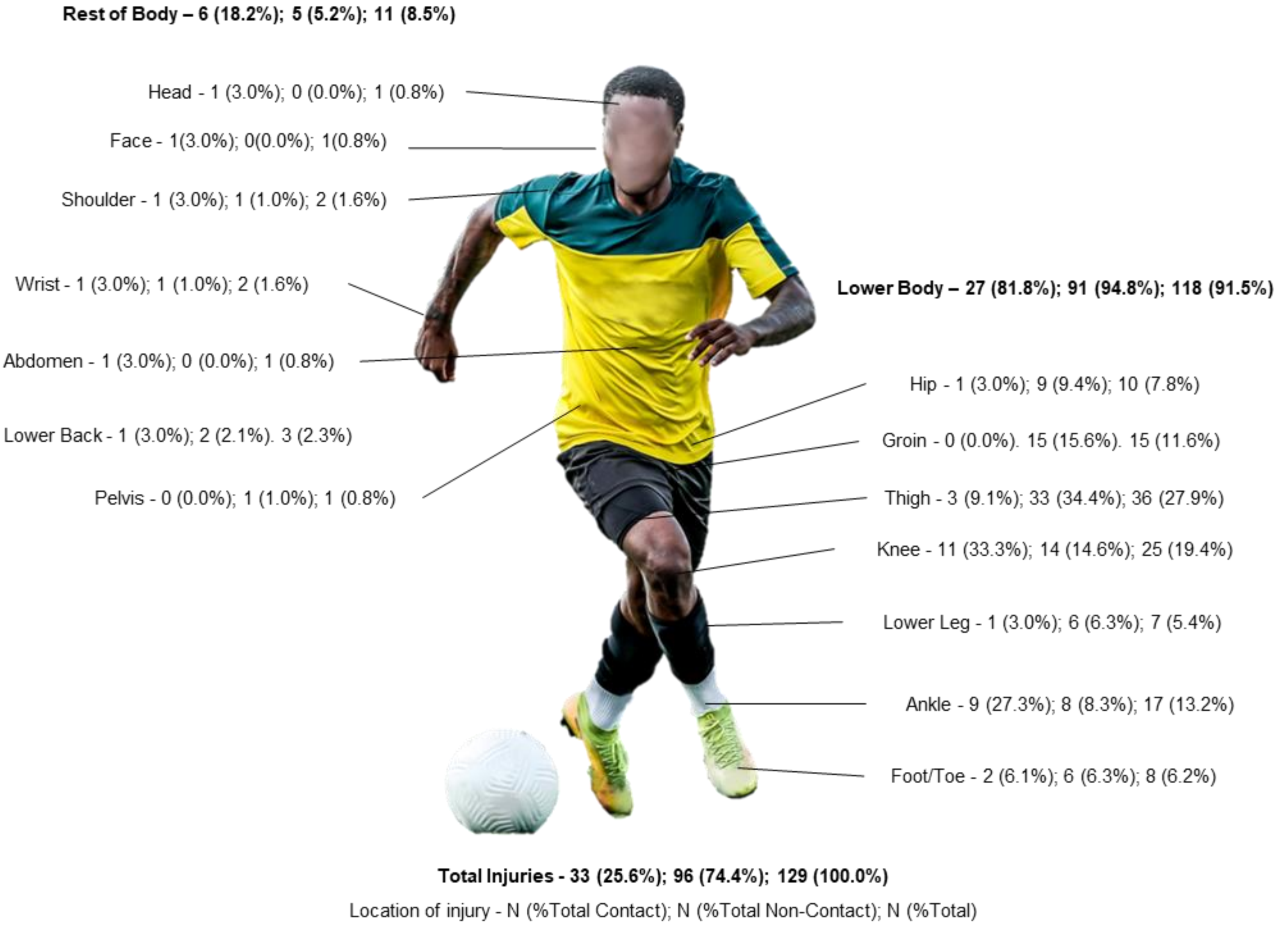


Figure 3 – Injury location distribution

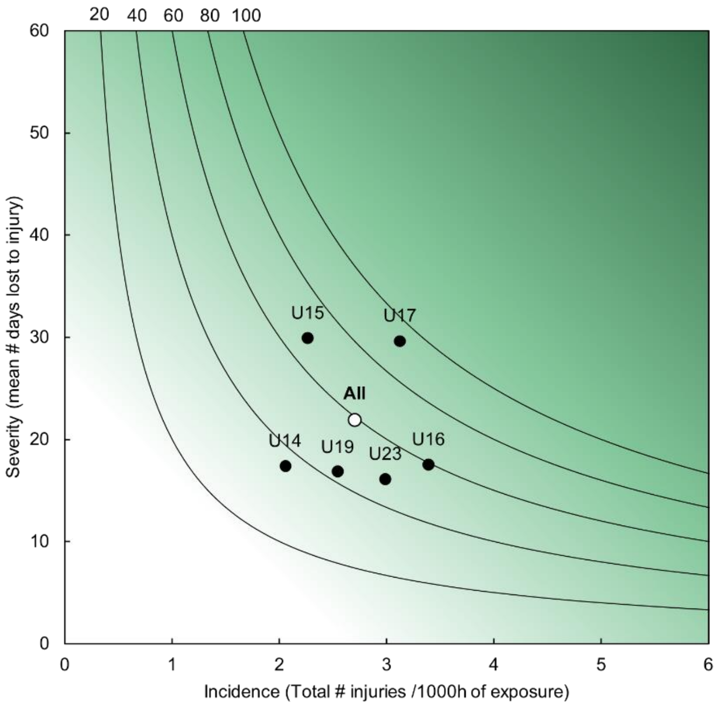


Figure 4 - Injury burden matrix illustrating the incidence and severity (mean days lost) per team. The isoquant curves (curved lines) represent points of equal burden. A darker shade represents a greater burden.

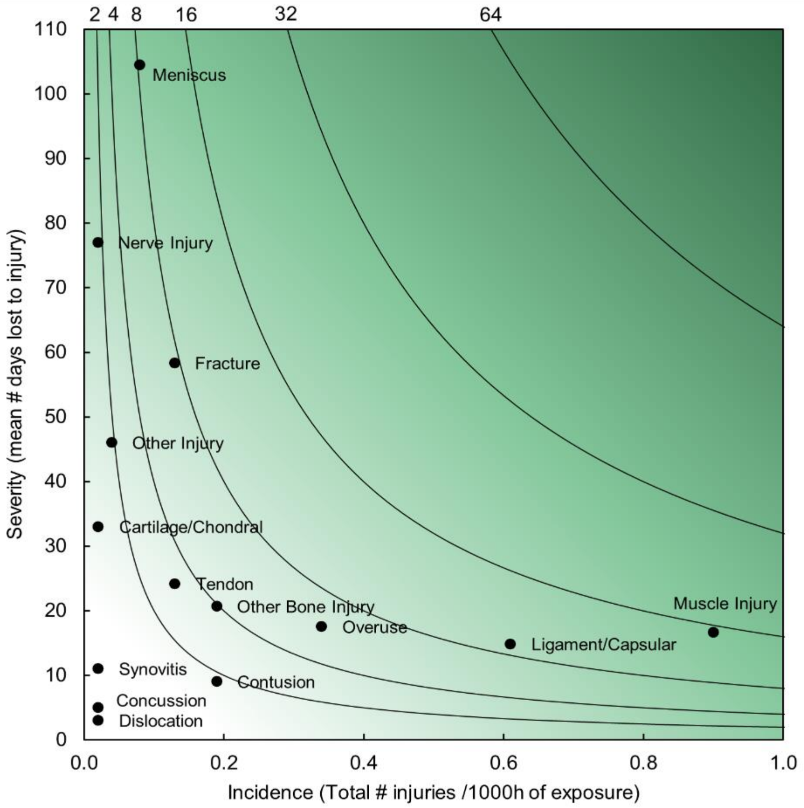


Figure 5 - Injury burden matrix illustrating the incidence and severity (mean days lost) per injury type. The isoquant curves (curved lines) represent points of equal burden. A darker shade represents a greater burden.

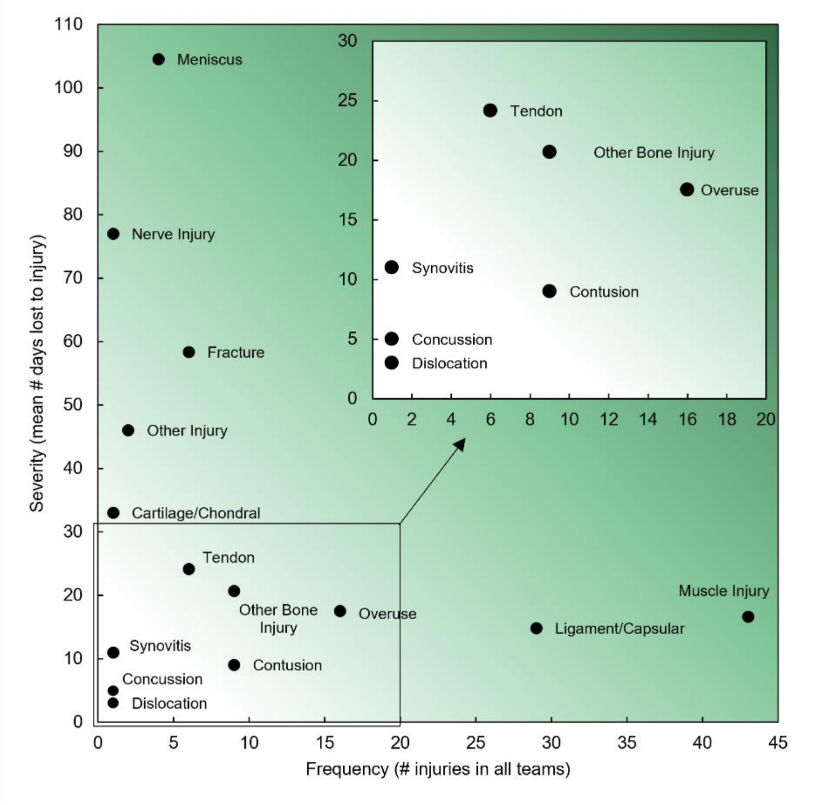


Figure 6 – Distribution of severity (mean days lost) and frequency of each specific injury type. A darker shade represents a greater burden.

Part B1 – Musculoskeletal and workload variables analysis for lower body non-contact soft tissue injuries

From all the variables tested, ASQZ/BW$_{ratio}$ was the only test that was significantly different between groups (p=0.025). Non-injured players showed higher values (0.64±0.11) compared with injured players (0.59±0.11, with a *small* effect size (d=0.401). Table 11 describes all the studied parameters.

Part B2 - Musculoskeletal and workload variables analysis for non-contact groin located and muscular type injuries.

Groin Injuries

We have found significant differences between groups in the ASQZ/BW$_{ratio}$. Specifically, non-injured players exhibited higher values (0.64±0.08) than injured players (0.54±0.11; p=0.007), with these differences being associated with a *large* effect size (d=1.107). No other variable showed significant differences between groups (Table 13).

Muscle Injuries

We have found no differences between injured and non-injured groups, in all the studied parameters (Table 12).

Table 11 - Differences between lower body non-contact soft tissue injured and non-injured groups for musculoskeletal and workload variables

	Non-injured (N=56)		*Injured (N=56)*		*Statistical Significance*		
	Mean ±SD	**95% CI [Lower; Upper]**	**Mean ±SD**	**95% CI [Lower; Upper]**	***t***	***p***	***Cohen's d***
ASQZ (kg)	40.98±10.5	[38.14; 43.82]	39.37±8.9	[36.98; 41.75]	0.999	0.320	0.166
ASQZ/BW_{ratio}	0.64±0.11	[0.61; 0.67]	0.59±0.11	[0.56; 0.62]	2.266	**0.025***	**0.401**
SL-CMJ_{diff} (cm)	-0.31±2.42	[-0.97; 0.34]	-0.21±2.52	[-0.89; 0.46]	-0.208	0.835	-0.040
SL-CMJ_{ratio}	1±0.14	[0.96; 1.03]	1±0.14	[0.96; 1.04]	-0.085	0.933	-0.016
$PKFO_{diff}$ (cm)	0.69±4.08	[-0.41; 1.79]	0.77±3.67	[-0.22; 1.75]	-0.104	0.917	-0.020
$PKFO_{ratio}$	1.05±0.19	[1; 1.1]	1.05±0.14	[1.01; 1.09]	0.159	0.874	0.030
DLT_{diff} (cm)	0.24±1.51	[-0.17; 0.64]	0.15±1.56	[-0.27; 0.57]	0.278	0.781	0.055
DLT_{ratio}	1.07±0.24	[1; 1.13]	1.06±0.33	[0.97; 1.14]	0.147	0.883	0.032
Sum sRPE W -5 (AU)	10987.07±3172.19	[10129.51; 11844.64]	11528.84±3361.71	[10628.57; 12429.12]	-0.833	0.407	-0.166
Sum sRPE W -4 (AU)	8829.34±2428.84	[8172.73; 9485.94]	9270.1±2587.42	[8577.18; 9963.01]	-0.875	0.384	-0.176
Sum sRPE W -3 (AU)	6669.5±1789.93	[6185.61; 7153.39]	7048.08±2135.66	[6476.15; 7620.02]	-0.968	0.335	-0.192
Sum sRPE W -2 (AU)	4493.7±1197.26	[4170.04; 4817.37]	4792.57±1554.7	[4376.22; 5208.92]	-1.135	0.259	-0.215
Sum sRPE W -1 (AU)	2305.84±723.2	[2110.33; 2501.35]	2432.21±811.83	[2214.8; 2649.62]	-0.831	0.408	-0.164
$RA_{uncoupled}$ 7:28 ACWR	1.29±1.16	[0.97; 1.6]	1.27±1.1	[0.98; 1.57]	0.046	0.964	0.012
$RA_{coupled}$ 7:28 ACWR	1.09±0.41	[0.98; 1.2]	1.08±0.41	[0.97; 1.19]	0.077	0.939	0.017
$EWMA_{uncoupled}$ 7:28 ACWR	4.39±15.9	[0.09; 8.69]	3.06±12.19	[-0.2; 6.33]	0.478	0.634	0.094
$EWMA_{coupled}$ 7:28 ACWR	1.48±1.92	[0.97; 2]	1.33±1.4	[0.95; 1.7]	0.473	0.637	0.093
Monotony W -4	1.53±1.16	[1.21; 1.84]	1.61±1.16	[1.26; 1.96]	-0.317	0.752	-0.072
Monotony W -3	1.42±0.9	[1.18; 1.66]	1.49±0.93	[1.24; 1.74]	-0.381	0.704	-0.082
Monotony W -2	1.39±0.63	[1.22; 1.56]	1.38±0.63	[1.21; 1.55]	0.041	0.968	0.006
Monotony W -1	1.47±0.78	[1.26; 1.68]	1.51±0.7	[1.32; 1.69]	-0.269	0.788	-0.043
Strain W -4	4069.2±4004.67	[2986.58; 5151.81]	4377.62±4268.17	[3234.6; 5520.65]	-0.37	0.712	-0.075
Strain W -3	3715.48±2984.7	[2908.61; 4522.36]	3960.2±3148.54	[3117.02; 4803.38]	-0.381	0.704	-0.080
Strain W -2	3535.28±2175.89	[2947.06; 4123.51]	3732±2460.53	[3073.07; 4390.93]	-0.438	0.662	-0.085
Strain W -1	3342.6±2275.02	[2727.58; 3957.63]	3619.88±2387.32	[2980.55; 4259.2]	-0.668	0.505	-0.119
W -5 to W -4 change (%)	0.28±0.27	[0.21; 0.36]	0.28±0.28	[0.21; 0.36]	-0.05	0.960	0.000
W -4 to W -3 change (%)	0.29±0.31	[0.21; 0.38]	0.33±0.29	[0.26; 0.41]	-0.801	0.425	-0.143
W -3 to W -2 change (%)	0.3±0.26	[0.23; 0.37]	0.3±0.3	[0.22; 0.38]	0.055	0.956	0.006
W -2 to W -1 change (%)	0.31±0.25	[0.24; 0.37]	0.28±0.28	[0.2; 0.36]	0.504	0.615	0.098

ASQZ (kg) – Adductor squeeze; ASQZ/BWratio – Adductor squeeze/ bodyweight ratio; DLTdiff - DLT Absolute Difference (cm); DLTratio - DTL Dominant/Non-Dominant Ratio; PKFOdiff – PKFO absolute Dominant/Non-Dominant difference; PKFOratio - PKFO Dominant/Non-Dominant Ratio; SL-CMJdiff - SL CMJ absolute Difference (cm); SL-CMJratio - SL CMJ Dominant/Non-Dominant Ratio; sRPE sum - Cumulative sRPE week sum (AU); W -5, -4, -3, -2, -1 - Week prior to injury -5, -4, -3, -2, -1; Significance level (p-value, 0.05)

Table 12 - Differences between muscular type injured and non-injured groups for musculoskeletal and workload variables

	Non-injured (N=27)		*Injured (N=27)*		*Statistical Significance*				
	Mean ±SD	**95% CI [Lower; Upper]**	**Mean ±SD**	**95% CI [Lower; Upper]**	**t**	**U**	**p**	**Cohen’s d**	**r**
ASQZ (kg)	40.86±10.32	[36.78; 44.94]	41.26±9.26	[37.59; 44.92]	-0.149		0.882	-0.040	
ASQZ/BW$_{ratio}$	0.61±0.11	[0.56; 0.65]	0.6±0.11	[0.55; 0.64]	0.388		0.700	0.105	
SL-CMJ$_{diff}$ (cm)	-0.89±2.38	[-1.83; 0.05]	0.07±2.69	[-1; 1.13]	-1.389		0.171	-0.378	
SL-CMJ$_{ratio}$	0.97±0.13	[0.91; 1.02]	1.01±0.15	[0.95; 1.07]	-1.167		0.248	-0.318	
PKFO$_{diff}$ (cm)	0.57±4.03	[-1.02; 2.17]	0.69±3.32	[-0.63; 2]	-0.111		0.912	-0.030	
PKFO$_{ratio}$	1.04±0.18	[0.96; 1.11]	1.04±0.13	[0.99; 1.09]	-0.134		0.894	-0.036	
DLT$_{diff}$ (cm)	0.35±1.67	[-0.31; 1.01]	0.09±1.65	[-0.56; 0.75]		329	0.536		0.084
DLT$_{ratio}$	1.06±0.24	[0.97; 1.16]	1.09±0.38	[0.95; 1.24]		328	0.527		0.086
Sum sRPE W -5 (AU)	10370.55±3438.71	[9010.25; 11730.86]	11370.62±3654.3	[9925.02; 12816.21]	-1.036		0.305	-0.282	
Sum sRPE W -4 (AU)	8397.25±2594.95	[7370.72; 9423.77]	9253.18±2615.84	[8218.39; 10287.98]	-1.207		0.233	-0.329	
Sum sRPE W -3 (AU)	6532.43±1781.99	[5827.5; 7237.37]	7208.55±2103.49	[6376.44; 8040.67]	-1.274		0.208	-0.347	
Sum sRPE W -2 (AU)	4478.22±1235.83	[3989.34; 4967.1]	4929.9±1550.86	[4316.41; 5543.4]	-1.184		0.242	-0.322	
Sum sRPE W -1 (AU)	2339.1±745.99	[2043.99; 2634.2]	2518.68±734.63	[2228.08; 2809.29]		314.5	0.387		0.118
RA$_{uncoupled}$ 7:28 ACWR	1.53±1.57	[0.91; 2.15]	1.48±1.47	[0.9; 2.06]		330	0.551		0.081
RA$_{coupled}$ 7:28 ACWR	1.16±0.46	[0.98; 1.34]	1.15±0.44	[0.97; 1.32]		350	0.802		0.034
EWMA$_{uncoupled}$ 7:28 ACWR	7.71±22.41	[-1.16; 16.57]	5.11±17.45	[-1.79; 12.01]		346	0.749		0.044
EWMA$_{coupled}$ 7:28 ACWR	1.93±2.65	[0.88; 2.97]	1.64±1.87	[0.9; 2.38]		339	0.659		0.060
Monotony W -4	1.21±0.73	[0.93; 1.5]	1.53±1.47	[2.12; 0.28]		329.5	0.545		0.082
Monotony W -3	1.36±1.15	[0.9; 1.81]	1.39±0.94	[1.02; 1.77]		335	0.610		0.069
Monotony W -2	1.23±0.52	[1.02; 1.44]	1.4±0.73	[1.11; 1.68]	-0.965		0.339	-0.263	
Monotony W -1	1.33±0.38	[1.18; 1.48]	1.61±0.83	[1.28; 1.94]		272	0.110		0.218
Strain W -4	2947.49±2437.32	[1983.31; 3911.66]	4288.97±5113.28	[2266.22; 6311.71]		325.5	0.500		0.092
Strain W -3	3501.75±3612.14	[2072.84; 4930.67]	3699.85±3060.2	[2489.28; 4910.43]		336	0.622		0.067
Strain W -2	2975.63±2040.5	[2168.43; 3782.83]	3908.19±2955.86	[2738.89; 5077.49]	-1.349		0.183	-0.367	
Strain W -1	2964.56±1558.41	[2348.07; 3581.04]	3982.01±2939.51	[2819.17; 5144.84]		295	0.229		0.164
W -5 to W -4 change (%)	0.32±0.29	[0.2; 0.43]	0.29±0.31	[0.17; 0.42]		329	0.539		0.084
W -4 to W -3 change (%)	0.29±0.33	[0.16; 0.42]	0.37±0.32	[0.24; 0.5]		341	0.684		0.055
W -3 to W -2 change (%)	0.31±0.24	[0.21; 0.41]	0.32±0.29	[0.21; 0.44]		291	0.203		0.173
W -2 to W -1 change (%)	0.28±0.21	[0.2; 0.37]	0.26±0.25	[0.16; 0.36]		320.5	0.446		0.104

ASQZ (kg) – Adductor squeeze; ASQZ/BWratio – Adductor squeeze/ bodyweight ratio; DLTdiff - DLT Absolute Difference (cm); DLTratio - DTL Dominant/Non-Dominant Ratio; PKFOdiff – PKFO absolute Dominant/Non-Dominant difference; PKFOratio - PKFO Dominant/Non-Dominant Ratio; SL-CMJdiff - SL CMJ absolute Difference (cm); SL-CMJratio - SL CMJ Dominant/Non-Dominant Ratio; sRPE sum - Cumulative sRPE week sum (AU); W -5, -4, -3, -2, -1 - Week prior to injury -5, -4, -3, -2, -1; Significance level (p-value, 0.05)

Table 13 - Differences between groin located injured and non-injured groups for musculoskeletal and workload variables

	Non-injured (N=14)		*Injured (N=14)*		*Statistical Significance*				
	Mean ±SD	**95% CI [Lower; Upper]**	**Mean ±SD**	**95% CI [Lower; Upper]**	**t**	**U**	**p**	**Cohen's d**	**r**
ASQZ (kg)	43.91±10.45	[37.88; 49.94]	36.59±10.15	[30.73; 42.46]	1.879		0.072	0.710	
ASQZ/BW$_{ratio}$	0.64±0.08	[0.6; 0.69]	0.54±0.11	[0.48; 0.6]	2.929		**0.007***	**1.107**	
SL-CMJ$_{diff}$ (cm)	1.18±2.88	[-0.48; 2.84]	-0.31±2.09	[-1.52; 0.9]	1.569		0.129	0.593	
SL-CMJ$_{ratio}$	1.09±0.17	[0.99; 1.19]	0.99±0.1	[0.93; 1.05]		60	0.081		0.330
PKFO$_{diff}$ (cm)	1.25±4.1	[-1.12; 3.62]	0.75±3.85	[-1.47; 2.97]	0.333		0.742	0.126	
PKFO$_{ratio}$	1.1±0.22	[0.97; 1.23]	1.05±0.14	[0.97; 1.13]	0.728		0.473	0.275	
DLT$_{diff}$ (cm)	0.07±1.17	[-0.61; 0.75]	-0.25±1.7	[-1.23; 0.73]	0.583		0.565	0.220	
DLT$_{ratio}$	1.05±0.22	[0.93; 1.18]	1±0.25	[0.86; 1.14]		89	0.678		0.079
Sum sRPE W -5 (AU)	10322.52±3143.57	[8507.48; 12137.56]	11626.56±3412.31	[9656.36; 13596.77]	-1.052		0.303	-0.397	
Sum sRPE W -4 (AU)	8493.05±2157.23	[7247.5; 9738.6]	9284.15±2382.85	[7908.33; 10659.96]		93	0.818		0.043
Sum sRPE W -3 (AU)	6473.36±1496.58	[5609.26; 7337.46]	7062±1701.25	[6079.72; 8044.27]	-0.972		0.340	-0.367	
Sum sRPE W -2 (AU)	4255.44±1174.87	[3577.09; 4933.79]	4732.42±1424.18	[3910.12; 5554.71]	-0.967		0.343	-0.365	
Sum sRPE W -1 (AU)	2093.37±760.84	[1654.07; 2532.67]	2366.81±708.72	[1957.61; 2776.01]	-0.984		0.334	-0.372	
RA$_{uncoupled}$ 7:28 ACWR	1.09±0.39	[0.87; 1.31]	1.13±0.5	[0.83; 1.42]	-0.208		0.837	-0.079	
RA$_{coupled}$ 7:28 ACWR	0.99±0.28	[0.83; 1.15]	1.04±0.3	[0.86; 1.21]	-0.397		0.695	-0.150	
EWMA$_{uncoupled}$ 7:28 ACWR	6.33±18.57	[-4.4; 17.05]	1.77±2.16	[0.52; 3.02]		86	0.581		0.104
EWMA$_{coupled}$ 7:28 ACWR	1.81±2.67	[0.27; 3.35]	1.23±0.87	[0.73; 1.73]		88	0.646		0.087
Monotony W -4	1.33±1.01	[0.75; 1.91]	1.25±0.7	[0.84; 1.66]		94	0.854		0.035
Monotony W -3	1.12±0.48	[0.85; 1.4]	1.21±0.51	[0.91; 1.51]		93	0.818		0.043
Monotony W -2	1.39±0.67	[1; 1.78]	1.37±0.54	[1.06; 1.69]	0.081		0.936	0.031	
Monotony W -1	1.49±1.06	[0.88; 2.1]	1.35±0.44	[1.09; 1.61]		90	0.713		0.069
Strain W -4	3460.51±2903.88	[1783.86; 5137.16]	3636.81±2998.94	[1905.27; 5368.34]	-0.158		0.876	-0.060	
Strain W -3	2817.97±1730.47	[1818.82; 3817.11]	3213.57±1940.75	[2093.01; 4334.12]	-0.569		0.574		0.069
Strain W -2	3482.57±2300.9	[2154.07; 4811.07]	3817.98±2645.5	[2290.52; 5345.45]	-0.358		0.723	-0.135	
Strain W -1	3269.61±2655.88	[1736.15; 4803.07]	3181.87±1467.51	[2334.55; 4029.19]		84	0.520		0.122
W -5 to W -4 change (%)	0.38±0.38	[0.16; 0.59]	0.29±0.34	[0.09; 0.49]		82.5	0.475		0.135
W -4 to W -3 change (%)	0.3±0.31	[0.12; 0.48]	0.37±0.32	[0.18; 0.55]		84	0.520		0.122
W -3 to W -2 change (%)	0.39±0.24	[0.25; 0.52]	0.3±0.22	[0.17; 0.43]		78	0.358		0.174
W -2 to W -1 change (%)	0.27±0.21	[0.15; 0.39]	0.21±0.19	[0.1; 0.32]		81	0.435		0.148

ASQZ (kg) – Adductor squeeze; ASQZ/BWratio – Adductor squeeze/ bodyweight ratio; DLTdiff - DLT Absolute Difference (cm); DLTratio - DTL Dominant/Non-Dominant Ratio; PKFOdiff – PKFO absolute Dominant/Non-Dominant difference; PKFOratio - PKFO Dominant/Non-Dominant Ratio; SL-CMJdiff - SL CMJ absolute Difference (cm); SL-CMJratio - SL CMJ Dominant/Non-Dominant Ratio; sRPE sum - Cumulative sRPE week sum (AU); W -5, -4, -3, -2, -1 - Week prior to injury -5, -4, -3, -2, -1; Significance level (p-value, 0.05)

5. Discussion

This aim of this research study was three-fold. First, it investigated the characteristics of injury incidence and patterns in an elite youth male football academy. This one season length study, with 184 players found 129 time-loss injuries, with 56 lower body non-contact soft tissue injuries, with muscle injuries as the most common injury type. Secondly, it investigated the differences between injured and non-injured players for workload and musculoskeletal tests in lower body non-contact soft tissue injuries. Against to what was hypothesized for part B1, *small* differences between injured and non-injured players for $ASQZ/BW_{ratio}$ were found. Lastly, in part B2, the differences between injured and non-injured players for workload and musculoskeletal tests in groin located and muscular type injuries was studied. *Large* differences between groups were found for $ASQZ/BW_{ratio}$ in groin located injuries, leading us to accept part B2 hypothesis.

Part A – Injury characteristics

Injuries were found to occur most frequently in training, while injuries occurring in match context presented higher incidence and burden. The lower body was the most frequently injured location, with non-contact injuries (74.4%), particularly muscular injuries, more prevalent. Moderate (7-28 days lost) injuries were more frequent. Midfielders were the most affected position. U17's players were the most affected.

The academy overall injury incidence was 2.7 injuries per 1000h. Incidence was low in contrast to others (Bowen et al., 2017), where 137 injuries were reported with an incidence of 21.1, with 7.9 and 33.5 in training and match, respectively. This data was tracked with only 32 players (U18-U21), which contrast with the present study, with 184 players. The large sample used contributed to a more diluted analysis, with teams contributing with different competition and training demands according to age. The low incidence was similar to another one-season length study (1.28-4.33 /1000h) (Bianco et al., 2016; Read et al., 2018; Renshaw et al., 2016), in contrast with other multiple season work which appears to have a higher incidence (8.31-12.1 /1000h) (Bacon et al., 2017; Ergün et al., 2013; Larruskain et al., 2018). The length of injury surveillance can be an important factor to consider, especially when the sample size is small.

The players missed an average of 21.9 days to injury, which is consistent with previous findings (Read et al., 2018). Moderate injuries category ranges from 7 to 28 days lost to injury. In the present population, moderate injuries had the highest prevalence in the academy (55.8%), which could help explain the mean value found.

Relative to age, this study findings are in line with Le Gall et al. (2006), which found younger age groups to suffer more injuries in training, while older players were more often injured in matches. This can be explained by the increase in competitiveness and the exposure to a more demanding workload (Price et al., 2004). Younger players are less resilient coping with injury and pain. This could contribute to longer periods of rehabilitation (Von Rosen et al., 2018). Also, when looking only at U19 and U23 squads, where competition demands are greater (Oliva-Lozano et al., 2020), overall incidence (3.0 and 2.5) was much lower than the previous authors reported (Bacon et al., 2017; Bowen et al., 2017; Delecroix, Delaval, et al., 2019). The different styles of play and competition demands are dependent on the country and culture, thus making it difficult to compare incidence values with this study findings.

For the IB_{rate}, the average player was expected to miss 59.3 days per 1000h of exposure. The U17 presented the highest IB rate, with a high number of severe injuries that represented one-third of all injuries in this team, meaning that more serious injuries occurred with longer periods of absence. Also, U17 had the highest frequency of total injuries (n=30), and incidence for non-contact injuries, with a total sum of 837 days lost to injury, a 1.63-fold increase compared to the second-highest team. The U14 to U17 teams had more severe injuries than older age groups (U19 and U23). The literature supports these findings. Pfirrmann et al. (2016) found that more severe injuries occurred in youth soccer players aged 14 to 16 years than in older players. This was also backed by Renshaw et al. (2016), which reported that U16 players sustained the highest number of severe injuries. In this age groups, with maturational offset and the different body transformations, players are especially prone to injury (Le Gall et al., 2007; Read et al., 2018). Peak height velocity usually occurs in players from U15, U16 and U17 age groups, where an higher injury burden is usually found, in line with this study's findings (Bult et al., 2018). The higher severity in younger players highlights the impact that injuries have on their athletic development. Other factors, such as early specialisation, has been associated with higher injury rates in young players (Shelbourne et al., 2012) with the lack of exposure to movement variability, essential for the balanced development of movement-related skills, proposed by the long term athletic development model (Lloyd et al., 2012).

Non-contact injuries represented 74.4% of total injuries with a total burden of 48 days lost /1000h. While the most severe type of injury was the meniscus, it only represented 3.1% of total injuries with mean days lost of 104.5 ±74.9. The wide variability of severity in meniscus injuries can be explained as some more severe injuries may require surgical procedures, which usually lead to longer absence periods.

The lower extremity was the most common injury location, with the thigh being the most injured body part, as consensually reported in the literature (Brink et al., 2010; Larruskain et al., 2018; Nilsson et al., 2016). This can be explained by the fact that muscle injuries were the most frequent type of injury. Previous authors (Bowen et al., 2017; Larruskain et al., 2018) have suggested that posterior thigh muscle strains were the most common football injuries. Similarly to Read et al. (2018), this investigation found the most common injury to be anterior thigh injuries, being mostly injured during both sprinting and shooting mechanisms, while hamstrings were mostly injured during sprinting actions only.

Recent epidemiological studies (Materne et al., 2020; Wik, Lolli, et al., 2020) have highlighted the deceiving picture of risk that injury incidence alone could give. Bahr et al. (2018) suggested that it should be used in adjunction with severity, giving a cross-product (incidence x severity), the injury burden matrix, representing the true impact of an injury on a team player's availability.

This is highlighted in the present study, as the U16 group presented the highest incidence (3.4 /1000h), while the U15 the highest mean severity (mean of 29.9 days lost). Nevertheless, relative to the cross-product incidence x severity, the U17 was the most affected team with a high discrepancy to the other teams, as represented in Figure 4. This is in line with one of the few authors that used this injury burden matrix analysis (Wik, Lolli, et al., 2020). Although with different incidence and severity, the burden for the U16 team and the academy overall was the same, as shown by the isoquant curved lines representing the injury burden.

The overall two most burdensome type of injuries were muscle (Mean time-loss: 16.6 days, incidence: 0.9 injuries /1000h) and ligament injuries (Mean time-loss: 14.8 days; incidence: 0.61 injuries /1000h). Meniscus and fracture type of injuries had similar but slightly lower burden comparing to ligament injuries, in line with the findings of an Asian academy, where ligament and muscular injuries were the most affected (Materne et al., 2020).

The overall higher frequency and burden of muscle injuries in this elite youth academy in comparison to the literature might reflect an increase in weekly football practice participation and higher intensity (Materne et al., 2020). The few authors that used the injury burden matrix (Materne et al., 2020; Wik, Lolli, et al., 2020) did not use exposure time to calculate incidence, making it difficult to compare with our results.

The disparity between research may be related to injury definition, different injury assessment techniques and differences in the quality of rehabilitation treatment provided to the samples of players examined. Injury definition is one of the most important decisions, as different injury definitions may lead to different conclusions, being non-comparable to others (Eirale et al., 2017). Reporting injuries retrospectively is commonly done using a self-questionnaire (Junge et al., 2000). This approach relies on the individual's ability to recall their own injury history and may lead to bias (Engebretsen et al., 2008; Read et al., 2016). One of the strengths of the present study is the consistency of prospectively reporting injury through a careful process as described above.

Part B – Musculoskeletal and workload differences between groups

For part B1, the aim was to study the differences between injured and non-injured players for workload and musculoskeletal tests in lower body non-contact soft tissue injuries. It was hypothesized that injured and non-injured athletes would not exhibit differences in musculoskeletal and internal workload variables in lower body non-contact soft tissue injuries. This hypothesis was not verified as non-injured players presented higher ASQZ/BW$_{ratio}$ than injured players (0.64±0.11 vs 0.59±0.11, *p*= 0.025, *d*=0.401).

For part B2, the aim was to study the differences between injured and non-injured players for workload and musculoskeletal tests in groin located and muscular type injuries. It was hypothesized that for groin located injuries, groups would exhibit differences in some local musculoskeletal tests (ASQZ or ASQZ/BW$_{ratio}$) but not for internal workload variables; and this was observed. Non-injured athletes exhibited greater values on ASQZ/BW$_{ratio}$ compared to injured peers. For muscular injuries, it was hypothesized that injured and non-injured players would not differ in internal workload nor in the musculoskeletal tests, which was also observed.

Among musculoskeletal variables, only ASQZ/BW$_{ratio}$ was significant to differ between injured and non-injured players in non-contact lower body soft tissue injuries. As shown in part B2, the *large* difference found in groin located injuries could help explain this finding in Part B1 as groin injuries accounted for 25% of the sample analysed. Adductor-related injuries are among the most common injuries in football (Bianco et al., 2016; Werner et al., 2019). Reductions in pre-season adductor absolute peak force were previously associated with in-season injury (Bourne et al., 2019). Absolute ASZQ value differences were not significant. Absolute peak force values do not account for the anthropometric characteristics, i.e., an absolute value of 40kg in ASZQ will have different implications in players with different body mass. To address this, ASZQ was normalized to body mass (ASZQ/BW$_{ratio}$). The differences found for groin located injuries were expected as the ASQZ/BW$_{ratio}$ specifically assesses the common structures involved in these injuries, including adductor strength, a well-identified factor for groin injuries. When normalized to body mass, a value lower than 6.971 N/kg has been found to increase the probability of suffering a groin injury by 83% (Moreno-Pérez et al., 2019). Cut-off values were not estimated, neither injury risk was studied. Although, for the groin injured players, the CI 95% upper limit was 0.6, the same as the lower limit for the non-injured group. This means that an ASQZ/BW_{ratio} of 60% shows promising value as a cut off value to differ between groin injured players. Additionally, unilateral ADD/ABD ratio was not included, commonly associated with injury (Harøy et al., 2019; Engebretsen et al., 2010). It would be of interest to take into consideration in future research.

Curiously, PKFO was reliable to assess hip ROM and was associated with groin injuries in the past (Malliaras et al., 2009; Mosler et al., 2015). Although in the present population, differences were not significant. Other authors have previously highlighted internal rotation, as a prominent risk factor for groin injuries (Tak et al., 2017). The PKFO screen essentially for adductor muscular group length. Thus, other hip ROM tests more specific for internal rotation, as in prone or supine position, could reflect a better approach to use in the future (Ibrahim et al., 2007; Tak et al., 2017). Moreover, hip ROM tests using weight bearing positions in closed kinetic chain could have represent a more valid option as they assess the joint ROM under the same conditions (under load) as during the sport (Gulgin et al., 2010).

For SL-CMJ, the results can be explained by the wide age spectrum of this study population, which likely reflects different levels of experience performing this test. Being a multiarticular test, there is a higher probability of error. Less experienced athletes could present higher movement variability and different strategies, despite familiarization and detailed instruction were given prior to the tests. Moreover, in this study, a contact mat was used to measure contact time. According to Bosco's equation, this device calculates jump height using an indirect method based on flight time (Pueo et al., 2020). A force plate system is commonly used as the gold standard, and allow to investigate other metrics rather than jump height, such as peak ground reaction landing forces that are less prone to error (Read et al., 2018). Moreover, jump height is an outcome that can be influenced by the preceding jumping phases (Tenelsen et al., 2019). For example, two athletes with a CMJ height of 30 cm could have different contributions from the eccentric and concentric phase, with the first being more dependent on the ability to produce eccentric strength rapidly. Also, this test cannot reproduce the reaction times that are present in injury mechanisms. For example, ACL injuries are reported to occur in approximately 40 milliseconds (ms) after ground contact (Koga et al., 2010) while the CMJ test duration is approximately 500 ms (Laffaye et al., 2013). A higher reactive strength index (RSI) has been found to reflect the ability to rapidly produce force

(Flanagan et al., 2008), which is important as most game actions occur with rapid movements below 250 ms (Mooses et al., 2018). This highlights the importance to produce high amounts of force during shorter contact times. To assess fast SSC and RSI, tests as the drop jump test (Ball et al., 2012) or the 10/5 maximal rebound jump test (Comyns et al., 2019) would be of interest to use in the future.

Most of the musculoskeletal tests used are specific to some anatomical structures. For example, the dorsiflexion lunge test only screens the ankle joint. Due to the multifaceted battery of tests used, the probability of finding significant differences in injured groups was diluted in Part B1, as general lower body injuries were considered. Although, to address this limitation, in part B2, clusters of specific locations and injury types were used. The *large* effect found for ASQZ/BW$_{ratio}$ in groin located injuries could reinforce the authors' point of view.

Interestingly, none of the ROM musculoskeletal exhibited statistical differences between groups. The DLT test position used could have influenced the results. Other authors have used a weight-bearing position that is more sensitive to calf-length restrictions (Konor et al., 2012). In this study, ankle dorsiflexion was screened in a half-kneeling position, which is more stable and easier to control. However, the axial load in the weighted bearing position could influence ROM. The DLT test is more specific for articular restrictions in ankle joint, indirectly affecting other structures. Ankle dorsiflexion asymmetry was previously associated with acute traumatic injuries for hamstring (Van Dyk et al., 2018), and ACL injuries (Amraee et al., 2017), chronic overuse injuries in ankle instability (Hoch et al., 2015), along with patellar and Achilles tendinopathy (Malliaras et al., 2006; Whitting et al., 2011). Ankle, ACL, and tendon injuries had a lower prevalence in this population, contributing to these findings.

Moreover, in this study approach, unilateral tests to assess asymmetries were used. The literature presents conflicted opinions regarding asymmetries; some considering those as normal adaptations to the surrounding context (Hoch et al., 2015). Additionally, the formula to calculate asymmetry can influence the results (Bishop et al., 2018). The value of a true asymmetry for injury risk should only be considered when in the presence of a true difference. Additionally, the tests were performed in a real-world scenario, where several professionals collected data during different days, and tests were pre-established according to their value to rehabilitation purposes and ecological use. Nonetheless, this will allow practitioners to compare their data with this population normative values.

For muscular type injuries no differences between groups for musculoskeletal tests were found. The literature is ambiguous regarding muscular injuries, as conflicting findings are reported for ROM and strength risk factors (Van Dyk et al., 2018).

Moreover, for groin located injuries, no differences for other musculoskeletal tests were found, except for $ASQZ/BW_{ratio}$. Individual's characteristics, musculoskeletal tests used, and the normal variability of the test scores could have influenced results. Another important factor is that this assessment only reflects one specific moment of the season, not accounting for individual responses to the work stimulus and its effects on the players' musculoskeletal system. The aim was not to study the risk or association of these variables with injury, as this methodological approach is faulted for injury prediction models. Nonetheless, these variables are of value when establishing baseline values for future rehabilitation purposes, identifying current physical deficits that threaten safe participation, and ultimately helping establish injury prevention plans to mitigate modifiable risk factors (Hughes et al., 2018; Van Dyk et al., 2017).

Workloads have been recently highlighted as an important factor in the injury aetiology model (Windt et al., 2017). Workload monitoring and management is a topic that has gained interest, to examine the relationship between fitness, fatigue and injury (Impellizzeri et al., 2019). Most authors investigated the relationship between injury risk/odds and internal workload using cumulative loads and derived metrics as the ACWR (Schwellnus et al., 2016; Soligard et al., 2016). This is usually used for predictive purposes, which have shown to be flawed and inadequate for injury prediction (Bahr, 2016; Hughes et al., 2020; Van Dyk et al., 2017). ACWR theoretical model states that when an acute load exceeds the chronic load that the player is used, he or she is at higher risk of injury. Differences between groups were investigated, making it difficult to compare with other authors findings. None of the workload variables had significant differences in weeks -4, -3, -2, -1 before injury, between injured and non-injured players. This was somehow expected, as described within the hypotheses, given the matched-pair approach used in the present study. By matching the injured athletes with non-injured athletes that belong to the same squad, it reduced the probability of a major difference in the workload as the participate in the same training sessions. Regardless, although not significant, there were generally higher values in injured players for cumulative sum and within week change (MON and STR), not for ACWR and between weeks changes. For cumulative load, most of the players had weekly values higher than some thresholds reported (≥1500 to - ≤2120 AU) (Malone et al., 2017), nonetheless, not able to differentiate between injury. In part B1, ACWRs could not differentiate groups, and except for $EWMA_{uncoupled}$ 7:28, the ratios presented were within the low-risk range previously claimed by Gabbett (2016). Also, the type of ratio and coupling option used was irrelevant. An unusual high $EWMA_{uncoupled}$ 7:28 value was found, which may be explained by the data analysis, as the workload was normalized to the day of injury. This is important when dealing with different age groups, as the teams' schedules are very different. Younger age groups had holidays breaks that could had influenced these ratios. As with low chronic loads, when exposed to higher acute loads, greater ratios are expected. The match paired cases approach allowed for comparison among athletes.

Different methodological approaches, as the EWMA, were suggested to reflect a better approach for ACWRs (Lolli et al., 2019; Williams et al., 2017). However, the same statistical artefacts have been found with both ratios (RA vs EWMA) (Gabbett et al., 2019; Windt et al., 2019). Some limitations of the ACWR methodology could help explain the results found. As ACWRs are a proportion, making them sensitive to the denominator, and players with low chronic or high acute load tend to have higher ratios. Also, the values depend on the direction of the comparison, which are linear (e.g. 100 / 80 = 20 % VS 80 / 100 = 25%) as highlighted by Impellizzeri et al., (2020).

Regarding within week changes, monotony and strain did not reflect significant differences, which conflicted with the literature. In academy football players (Brink et al., 2010), high monotony and strain were associated with increased injuries rates. Also in professional football players (Delecroix, Mccall, et al., 2019), 4 weeks of monotony and strain were associated with increased injuries. The congested periods in older teams could have a great impact on the workload monotony and strain, and as teams were not differentiated in part B analysis is a limitation for this study.

This study results and methodology do not allow for accurate comparison with other authors investigating workload and injury. In literature different methodological approaches are used. To address ACWR methodological flaws, one investigation with a cluster randomised controlled trial among elite youth footballers (Dalen-Lorentsen et al., 2020) found no between-group difference in health problems prevalence, suggesting that load management intervention was not successfully reducing injuries. This highlights that not only study design, but the ratio itself could be inadequate. Although this study results being in accordance, it does not allow to make these assumptions. Indeed, no differences were found between groups, suggesting that workload alone cannot predict or explain injury. Regardless, we, as many other authors believe workload management is an important piece of the injury prevention puzzle that cannot be ignore nor dismissed.

More work should be done in clarifying which ACWR methodology to use, or even to discard it in workload analysis as some authors (Impellizzeri et al., 2020; Lolli et al.,

2020) recently suggested. In this study, only the internal workload (sRPE) was used. Despite previously shown to be reliable and ecological, it is a subjective metric, making it susceptible to error, especially with younger players (Coutts et al., 2003; Impellizzeri et al., 2004). It would be of interest to study the potential of external workload as it could reflect the impact of specific actions (e.g. high speed running) on soft tissue injuries (e.g. hamstrings) (Malone et al., 2018).

The underlying relationship between load and injury is still unknown, but it appears to be influenced by mechanisms as overtraining affecting tissue resilience, with greater risk of injury and illness (Halson, 2014). In football, the never-ending quest to find the solution to injury occurrence has precipitated the emergence of workload preliminary research with questionable methods and findings. To this day, such findings still guide the professionals on the field, as no accurate method for workload monitoring is consensual. Practitioners should evaluate other, more sensitive, measures of load monitoring. Using variance for estimation of the within-player variability might represent a valuable alternative to facilitating longitudinal tracking workloads over time and differentiate loading approaches prescription for each (Esmaeili, Hopkins, et al., 2018; Robertson et al., 2017).

Individual factors in a multifactorial context as football, have a very low ability as injury prediction factors. Therefore, the predictive ability of workload and musculoskeletal variables were not assessed. Given the multifactorial nature of injury, it is not surprising that workload data alone cannot accurately predict injury. Moderators such as fitness, previous injuries, fatigue, and psychological factors, which have also been linked to injury, were not considered (Arnason et al., 2004; Hägglund et al., 2006; Hägglund et al., 2013; Henderson et al., 2010). An injury is a multifactorial event with multiple confounding factors, making it complex to study (Bittencourt et al., 2016). A match paired approach was used to minimize the individual characteristics' influence, accounting for age, team, and position. Risk factors studies usually use a reductionist approach, however, the ability to recognize the non-linear interactions between them should be done using complex approaches in future research (Bittencourt et al., 2016; Ruddy et al., 2019).

This study is not without limitations. With different coaching styles and high interchangeability of players per different age groups teams, incidence, burden, and workload could have been influenced by the different contexts. It would be of interest to investigate the absolute and relative workload metrics to study if the training and coaching methodology could help explain the differences found. Multiple staff were used to track exposure data, possibly introducing a source of bias. Using fewer staff to monitor and record exposure data in the future would reduce this. Data from musculoskeletal tests were analysed during the season and so prevention plans to minimise injury were made, but as only preseason musculoskeletal tests were included, results were not influenced. A time-loss definition was used in conformity with the injury surveillance consensus (Fuller et al., 2006), although this definition is considered reliable to capture injuries affecting participation, it likely underestimates the incidence of gradual onset injuries and complaints that only require medical attention without withdrawing from participation (Wik, Lolli, et al., 2020). A source of bias could come from injury diagnostic, as the diagnosis was made according to the physical and clinical evaluation that is based on the athlete's perception of injury, pain experienced, and experience of the clinician. Moreover, the screening test battery was originally designed for periodic health examination. Thus, other tests to describe lower extremity characteristics and function, that could be more appropriate have not been studied. Additionally, previous injury was not considered as that were no official records from previous seasons. This would involve the individual’s ability to recall their injury history as a retrospective analysis, leading to recall bias. Due to the pandemic that emerged during March 2020 in Portugal, the rest of the season was cancelled. As a result, the study only included the data until the last official training session until March. The homogeneity of this study population, with young male football players, limits these findings to adult players, female gender, or other sports. Only chronological age was considered, this method does not account for the phase of maturation of an athlete with different body sizes and growth that influences the risk of injury (Rommers et al., 2020; Wik et al., 2020). Furthermore, as commonly recommended in elite sport research, future work involving multiple clubs and/or multiple seasons would enhance the ability to generalise these findings and detect *small* to moderate associations when using more than 200 injuries, as suggested before (Bahr et al., 2003).

Although several previous researchers explored injury epidemiology in elite youth footballers, only three other studies (Esmaeili, Hopkins, et al., 2018; Esmaeili, Stewart, et al., 2018; Møller et al., 2017) concurrently assessed injury with musculoskeletal and workload metrics. However, none of these investigations was conducted in a football context. Additionally, no differences between injured groups were reported, neither use similar methodological approaches as the match paired cases. To our knowledge, this is the first study using a match paired case approach when comparing athletes to minimize confounding anthropometric characteristics effects, thus reducing analysis bias. Also, the first study of this kind conducted in Portugal, and one of the few in the literature, to use an injury burden matrix with isoquant curves (point of equal burden) to facilitate an easier and relevant approach to interpret the burden of incidence and severity.

6. Conclusion

This study investigated 1) the characteristics of injury incidence and patterns and 2) the differences between injured and non-injured players for workload metrics and musculoskeletal tests in an elite youth male football academy.

In Portugal, there is a lack of research regarding epidemiological research in football. This study aimed to fill this gap between applied practice and research, answering the first two steps of the Van Mechelen, Hlobil, & Kemper (1992) injury prevention model, as previously mentioned. To our knowledge, this was the first study to concurrently investigate injury epidemiology with musculoskeletal and workload absolute and derived metrics in elite youth footballers. Additionally, this is the first study using a match paired case approach minimizing confounding anthropometric characteristics effects. Moreover, one of the few uses the injury burden matrix with isoquant curves to interpret the incidence and severity burden.

Overall injury incidence was low, with injuries occurring more frequently in training, but with higher incidence and burden rate in match context. Lower body injuries had greater incidence with the thigh as the most frequent location. Non-contact injuries, particularly muscular injuries, were more prevalent. Quadriceps was the most injured muscle group, mainly by sprinting and shooting mechanisms. Moderate injuries were more frequent, with an overall mean of 22 days lost to injury. U17 team was the most affected, with the highest burden cross-product (incidence x severity).

Different characteristics of injury incidence, burden, and patterns are present in elite youth football. Despite the low overall incidence of injury, the preventable non-contact injuries remain frequent, representing a threat to the young football player's safe development. The higher incidence and burden of injuries in pre-adolescent players makes this population the focus for injury prevention measures. Greater non-contact injury during training in younger players emphasises the importance of a cautious approach towards training intensity, technical and tactical abilities, which can be moderated by physical qualities development and intrinsic factors.

Moreover, to understand which monitoring strategies to use, the exploratory analysis found some preliminary evidence that could support $ASQZ/BW_{ratio}$ as a future factor differentiating players for lower body non-contact and groin injuries. For muscular injuries, no relevant musculoskeletal or workload factor was found. While this study methodology limits the generalizability of the results, except $ASQZ/BW_{ratio}$, musculoskeletal tests and workload absolute and derived metrics monitored were unable to differentiate between injured and non-injured athletes in the studied population.

Although these findings could not clarify which variables are worth monitoring to reduce injury, they can help practitioners make informed decisions to identify physical problems and serve as a baseline for rehabilitation purposes. Moreover, the use of workload monitoring metrics such as the ACWR to predict injury is questionable. Instead, these monitoring metrics should help plan, adjust, and inform about the training process to understand how the athlete copes with the load. The complex relationship between factors should be considered and used as a part of the injury prevention process along with individual differences.

Based on these conclusions, a more observations of the studied athletes throughout the season would be of interest to better characterize injury epidemiology in younger players and investigate which musculoskeletal and workload factors are relevant to injury. For example, pre-season tests can hardly infer or predict an injury that occurs 6 months later. Therefore, having a seasonal picture of the athletes would allow to establish a more robust relationship between the musculoskeletal and workload parameters and the occurrence of injuries. Moreover, future research should further investigate $ASQZ/BW_{ratio}$ to confirm its value as a risk factor, possibly defining cut off values and risk of injury, especially in groin injuries. Given the multifactorial nature of injury, we should also focus on the complex relationship between risk factors and their relevance for injury occurrence.

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8. Appendices

Appendix I - Workload methodology supplementary chapter

Appendix II – Musculoskeletal tests procedures

Appendix III – Injury report form

Appendix IV – Ethics approval

8.1 **Appendix I -** Workload methodology supplementary chapter

a) Responses to Training

The general adaptation theory also called the supercompensation principle, refers to the process of the body adapting to the training stress, which temporally has negative effects (fatigue). The body compensates adjusting itself to a higher level of fitness, leading to positive training adaptations (Selye, 1952).

One of the training principles is progressive overload, thus, to have physical adaptations, training must involve overload, with adequate time to recover. Physical performance can be expressed as the difference between fitness (positive adaptations to training) and fatigue (negative effects of training) (Schwellnus et al., 2016; Soligard et al., 2016). Depending on this relationship, athletes can experience short-term performance decrement without severe negative symptoms, called functional overreaching (Bell et al., 2020). When athletes do not respect the balance between training and recovery, non-functional overreaching or overtraining can occur (Meeusen et al., 2013), resulting in a long-term decrement in performance taking several weeks or months to recover (Cunanan et al., 2018).

Thus, monitoring the workload is important to determine whether an athlete is adapting to the training process and to minimize the risk of negative consequences leading to injury and illness (Halson, 2014).

b) Workload quantification

Internal load measures can be measured subjectively using the rating of perceived exertion (RPE) and session rating of perceived exertion (sRPE). It can be also measured, using objective variables as heart rate variability, blood lactate, oxygen consumption and creatine kinase (Bourdon et al., 2017). The training impulse (TRIMP) is also often used. It is calculated using training duration and heart rate (HR) during exercise, with five arbitrary HR zones (Halson, 2014).

In football, the internal load is usually used for the on-field training session, but it can also be reported regarding gym sessions, both independently or/and in conjunction (Bourdon et al., 2017; Impellizzeri et al., 2019; Lockie et al., 2012).

External load refers to the amount of work performed, it can be represented by the total moved external weight (tonnage) or the number of impacts in different contexts.

When referring to team sports, can be represented by the on-field training actions as speed, acceleration, and distance covered in different speed zones (Bowen et al., 2019; Stevens et al., 2017). To objectively measure these actions, global positioning systems (GPS) accelerometers are commonly used (Kupperman et al., 2020; Scott et al., 2013). Video tracking systems (VTS), and local positioning systems (LPS/radar) can be also used (Halson, 2014).

Global navigation satellite systems (GNSS) or GPS (Kupperman et al., 2020) are commonly used to track external load. Nowadays, different sensors as three-dimensional gyroscope, accelerometer, magnetometer and heart rate monitor allow the professional to assess different information (Beato et al., 2018; Colby et al., 2014; Coutts et al., 2010; Rampinini et al., 2015). GPS depend on different characteristics as the rate of sampling frequency (Hz), sensors incorporated, number of satellites connected, movement speed, software of raw data analysis and interchangeability of units (Coutts et al., 2010).

GPS are used to monitor sport-specific metrics, that differ widely. Total distance covered (TD), high-speed running (HSR), sprinting distance, accelerations and decelerations (ACC/DCC), high metabolic load distance (HMLD), and intensity using meters per minutes (m/min) are some of the most commonly used (Beato et al., 2018; Colby et al., 2014; Coutts et al., 2010; Kupperman et al., 2020; Rampinini et al., 2015).

A combination of both internal and external workload monitoring may provide a better approach to inform and manage training stimulus (Griffin et al., 2020; Meeusen et al., 2013).

c) Workload Methodology and inferenced metrics (Acute chronic workload ratio - ACWR)

To monitor physical workloads and responses to physical imposed stress, Hulin et al., (2014) and Gabbett, (2016), hypothesized and described a useful tool the acute: chronic workload ratio (ACWR), based on the first model proposed by Banister et al., (1975). ACWR compares workload in a recent week, with workload performed in the past two, three or four weeks, creating a ratio. It can be used with internal or external load monitoring data, and it can be calculated using different mathematical approaches (Hulin et al., 2016; Murray et al., 2017).

This interest in workload has led to a two-part joint consensus in 2016, (Schwellnus et al., 2016; Soligard et al., 2016), defining load as a stimulus that is applied to a human biological system over different periods and magnitude (Soligard et al., 2016). Internal load represents the physiological responses to exposure to an external load. (Griffin et al., 2020; Schwellnus et al., 2016; Soligard et al., 2016).

Absolute load refers to combined workload during a given period, as the cumulative sum of previous weeks (1-, 2-, 3-, or 4-week loads). Relative load refers to the comparison of workload accounting for time (e.g. ACWR) (Bourdon et al., 2017; Schwellnus et al., 2016; Soligard et al., 2016).

For ACWR**,** an acute load can be considered as the average sum of the recent workload, usually a 7-day workload, but it can differ (3, 5, 6, or 7-days) (Andrade et al., 2020). The chronic load is the average sum of the work accumulated during several weeks, with different time windows (14, 21 or 28 days), commonly 28 days (Andrade et al., 2020).

ACWR is not without conflict findings among literature. A recent review of Wang et al., (2020), discourages the use of the ACWR metric in injury prediction but highlights the value of monitoring load, which remains supported. Some authors suggest that different methodological considerations need to be considered. Different mathematical formulas, time windows of acute and chronic load, type of coupling, type of load, injury lag or reference values (Jones et al., 2017; Wang et al., 2020).

Cumulative absolute high or low loads have been reported to be associated with injury (Gabbett, 2010; Gabbett, Kennelly, et al., 2016). Different thresholds for injury risk have been identified, between ≥1500 to - ≤2120 AU, or higher than 3000 AU (Malone et al., 2017).

ACWR ratio highlights that not only high or low absolute values of training but the interaction between them could help explain injury (Gabbett et al., 2016). Spikes or week to week increases in training loads were found to be likely responsible for most soft-tissue injuries, both in the week the workload is applied and the subsequent week (Bowen et al., 2017; Gabbett, 2016; Gabbett, Hulin, et al., 2016). Malone et al., (2017) found that changes in load (550–1000 AU) were experienced in injured players, but for players with greater fitness, the load experienced did not increase in injury risk (Malone et al., 2017).

ACWR in some investigations has been stratified by categories/range, from very low (≤0.49) low (0.50–0.99), moderate (1.0–1.49) high (1.50–1.99) and very high,(≥2) (Murray et al., 2017).

Regarding thresholds values, Gabbett, (2016) stated that the lowest injury risk would fall between 0.80 and 1.30, which was intituled the ‘Sweet spot’ of training load. This range was calculated for rolling average (RA) coupled ACWR method. For the uncoupled method (1 week:4 week) ACWR, these thresholds would correspond to different ratios (0.75–1.45) (Windt et al., 2019). This ‘Sweet Spot’ was recently studied on football players, (Sedeaud et al., 2020) and despite association, there was no relationship between the sweet spot interval and protection against injury (Sedeaud et al., 2020). In professional football, players were at lower risk of injury when ACWR was between 1.00 and 1.25 (Jaspers et al., 2018). This finding did not support the previous sweet spot range, which was supported by more recent work (Enright et al., 2020) with 54% of injuries occurring in the ‘sweet spot’ range.

Players with a high chronic workload were found to be more resistant to injury with moderate ACWR (0.85–1.35) ACWR, and less resilient when ACWR and spikes in acute workload were very high (ACWR >1,5) (Hulin et al., 2016). ACWR should be used to enhance performance in players through developing high chronic workloads to adequately prepare players for competition demands reducing injury risk (Murray et al., 2017). If the chronic load is safely and progressively increased, the athlete can be better suited for its context demands.

The impact of load can be moderated with well-developed physical characteristics and fitness (Malone et al., 2017). One author (Lolli et al., 2020), highlighted the importance to distinguish the specific nature of an event, either acute or overuse injuries. The lack of clear differentiation between injury types implied that the load-injury relationship is the same for acute or overuse injuries, not considering its onset.

d) ACWR Models (Rolling Average (RA) VS Exponentially weighted moving averages (EWMA))

There are two mathematical methods to calculate the ratio, rolling average (RA) and exponentially weighted moving average (EWMA). The rolling averages ACWR can be calculated by dividing the average sum of acute workload by the average chronic workload (Hulin et al., 2014).

More recently, the validity of the ACWR has been questioned, as the rolling average fails to account for the decaying nature of a training stimulus over time, and it may not accurately represent the athlete’s responses to training. For example, the chronic load using a RA considers equally a session realized the day before the analysis and a session occurring 28 days before (Murray et al., 2017; Williams et al., 2017).

To answer this problem, the EWMA proposed by Williams et al., (2017), has shown to be more sensitive to detect increases in injury risk at higher ACWR ranges, using the following formula:

$$EWMA\ today = Load\ today \times \lambda a + ((1 - \lambda a) \times EWMA\ yesterday)$$

The λa is a value between 0 and 1 that represents the degree of decay, with higher values discounting older observations: $\lambda a = 2/(N + 1)$. N is the chosen acute or chronic time decay constant. This method accounts for the decaying effect of load (Murray et al., 2017; Williams et al., 2017).

e) Acute chronic (A:C) Windows (3:21 Vs 7:28), coupling (Coupled VS uncoupled)

The ACWR, as previously described, is a ratio that uses an acute load as numerator and chronic as denominator. In the literature, several time windows can be found (Andrade et al., 2020; Carey et al., 2017; Delecroix, Delaval, et al., 2019; Gabbett et al., 2019; Windt et al., 2019). These time windows are based on the first study published that laid the foundations for this ratio (Banister, et al., 1975). Acute load can be found with 1, 3, 6 or 7 days, and chronic load 7, 14, 21 or 28 days (Andrade et al., 2020; Carey et al., 2017). The most commonly cited and used ratio is the 1:4 ratio (7:28 days), although the 1:3 ratio (7:21 days) has also been found to be related to injury risk (Bowen et al., 2019, 2017; Delecroix, Delaval, et al., 2019; Delecroix et al., 2018; Delecroix, Mccall, et al., 2019; Fanchini et al., 2018; McCall et al., 2018). The choice of this ratio should be based on the sport and week microcycle. Teams with match congestion should use a ratio with shorter acute days, reflecting the days of training and match. In a weekly normal microcycle, a 1:3 or 1:4 ratio should be used (Andrade et al., 2020; Carey et al., 2017). As an example, an author (Malone et al., 2018) has found an association between a 3:21 ratio with injury risk, due to a more congested schedule.

Not only the time windows need to be considered. It is important to consider coupling options. When the acute load is present in both the numerator and denominator (Wang et al., 2020) it is a called a coupled ratio. Previously, this mathematical coupling has been demonstrated to lead to spuriously correlations (Lolli et al., 2019). To solve this problem, some authors (Bowen et al., 2020, 2017) used different approaches of coupling for ACWR, using an uncoupled approach, as suggested by Lolli et al., (2019). The uncoupled ratio excludes the acute workload from the chronic workloads, thus also altering, the ACWR itself (Andrade et al., 2020). An author (Gabbett et al., 2019) investigated the differences between coupled and uncoupled ratios, there were no significant differences found between coupled and uncoupled approaches, with both increasing the likelihood of injury. This is consistent with other research that compared both methods for 4-week workload distributions (Windt et al., 2019).

f) Workload Monotony and Strain

Not only week-to-week changes have been associated with injury, but within week change association was also reported (Delecroix, Mccall, et al., 2019). Monotony and strain are used to quantify this within week variation (Delecroix, Mccall, et al., 2019), and have first been proposed by Foster, (1998). Training monotony was described as the week RA workload divided by the standard deviation of daily loads of the past week. Strain was then calculated by multiplying the sum of daily loads of the past week with the training monotony (Foster, 1998).

In an investigation with academy football players (Brink et al., 2010), it was found that increases in monotony (OR = 2.59) and strain (OR = 1,01) were associated with increased injuries rates. However, only in traumatic type of injuries. Also in professional football players (Delecroix, Mccall, et al., 2019), it was founded that 4 weeks workload monotony and strain were associated with an increase in incidence. Authors highlighted that these two metrics should be monitored in combination with other factors to reduce the injury (Delecroix, Mccall, et al., 2019). Therefore, not only acute spikes in workload but also the lack of workload variation is a factor worth considering for injury reduction.

8.2 **Appendix II –** Musculoskeletal tests procedures

a) Passive Knee Fall Out (PKFO)

To access the hip mobility, the passive knee fall out is performed. The players are instructed to lay supine on the floor, with 45º hip and 90º knee flexion. While the examiner holds the player's feet together, the player is instructed to let both knees fall out to the side. The examiner then exerts light pressure on both knees, to ensure the player is at the end of their range. The vertical distance from the inferior edge of the fibula head to the floor is then measured on each side. Measurements are made using a ruler to the nearest 0.5 cm. The PKFO test demonstrated excellent inter-tester reliability, with ICC values (0.91-0.92), with MDC (0.75-0.95cm), suggesting that the change of ~1cm reflect true changes (O'Brien et al., 2018).

Figure 7 - Passive Knee Fall Out Test Position

b) Single-Leg Countermovement Jump (SL-CMJ)

Single leg countermovement jump was measured using a contact mat, that derivates jump height from flight time (*Chronojump Boscosystem*, *Barcelona, Spain*) (Moreno-Pérez et al., 2017). This system has shown to be reliable and accurate before (Pueo et al., 2018). Subjects stood in an upright position, hands on hips, with feet positioned hip-width apart. To begin the test, one leg was lifted off the floor to approximately mid-shin height of the standing leg. Subjects then performed a countermovement to a self-selected depth followed by a quick upward vertical movement triple, with maximal intention. Players are instructed, "to reach for the ceiling, landing with the toes on the mat". Three alternated repetitions are made on each side, with 30s rest between them. The highest jump height value is used for analysis.

Figure 8 - Single Leg Counter-Movement Jump Test Position

c) Dorsiflexion Lunge Test (DLT)

To measure ankle dorsiflexion, a permanent tape measure was fixed on the floor with a 0 cm mark at a wall junction. Players were asked to place the big toe and heel of the testing leg above the tape. Athletes were then instructed to lunge forward until the knee touches the wall, looking to stay as far as possible from the wall while keeping the heel in contact with the floor. The observer held the participant's heel to prevent it from lifting off the floor and manually locked the subtalar joint, so it remained in a neutral position throughout the test. The maximum distance from the tip of the big toe to the wall was recorded to the nearest 0.5 cm. The test has shown previously to have good inter- and intra-clinician reliability of the DLT to assess dorsiflexion range of motion (Powden et al., 2015).

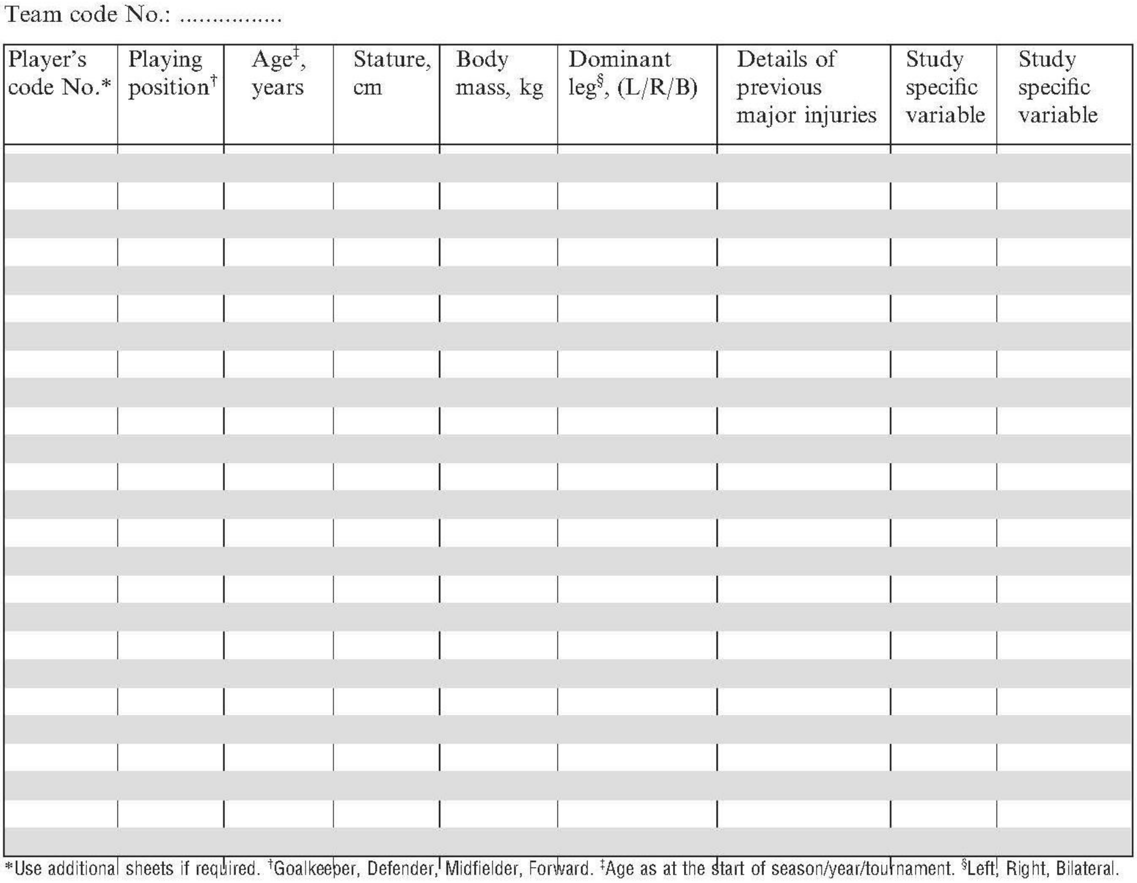
Figure 9 - Dorsiflexion Lunge Test Position

d) Adductor (Groin) Squeeze Test

To measure maximal isometric hip adductor strength, each participant lay supine on the treatment table with hips positioned in a 45º flexion with knees flexed to 90º and hips in neutral rotation. The squeeze test was quantified using a handheld dynamometer (*Smart Groin Trainer, Neuro Excellence, Portugal*). It is placed between the knees near the femoral condyles. Players are instructed to squeeze the device maximally for 3 contractions, during 5s each, with 1 minute of rest between them. The maximal squeeze value is recorded during each of the three test trials, and the best is used for analysis. The portable dynamometer is reliable and with low values of error (ICC = 0.94 (0.86-0.97) (Mesquita et al., 2018) and (ICC = 0.77–0.98) (Correia et al., 2021), with minimal detectable change (MDC) = 25.3 N (Mesquita et al., 2018).

Figure 10 - Adductor Groin Squeeze Test Position

8.3 **Appendix III –** Injury report form

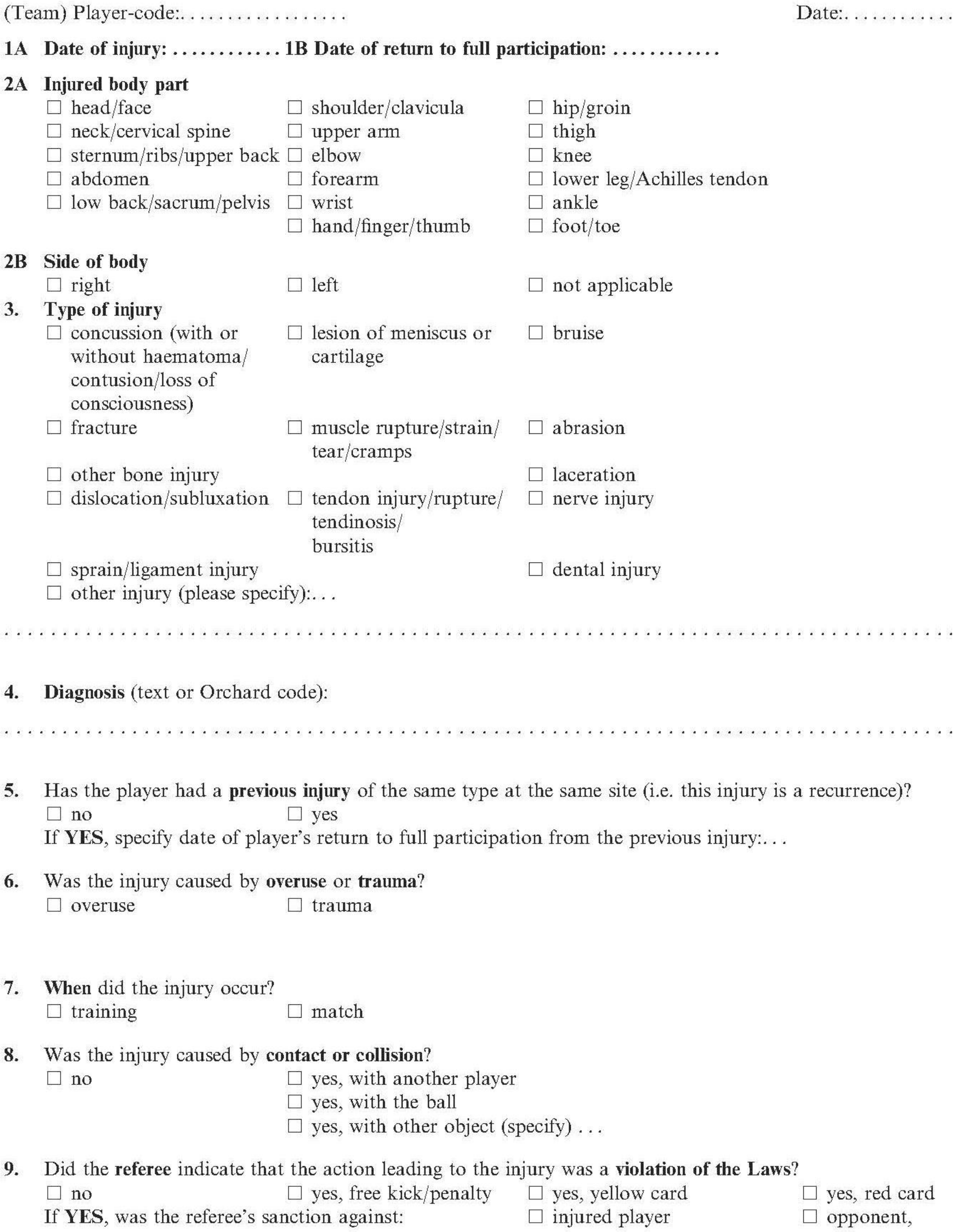


Team code No.: ....

Player's code No.*	Playing position†	Age‡, years	Stature, cm	Body mass, kg	Dominant leg§, (L/R/B)	Details of previous major injuries	Study specific variable	Study specific variable

*Use additional sheets if required. †Goalkeeper, Defender, Midfielder, Forward. ‡Age as at the start of season/year/tournament. §Left, Right, Bilateral.

Figure 11 - Player's Baseline Information Form



(Team) Player-code:. . . . . Date:. . . . .

1A **Date of injury:** . . . . **1B Date of return to full participation:** . . . .

2A **Injured body part**

☐ head/face
☐ neck/cervical spine
☐ sternum/ribs/upper back
☐ abdomen
☐ low back/sacrum/pelvis
☐ shoulder/clavicula
☐ upper arm
☐ elbow
☐ forearm
☐ wrist
☐ hand/finger/thumb
☐ hip/groin
☐ thigh
☐ knee
☐ lower leg/Achilles tendon
☐ ankle
☐ foot/toe

2B **Side of body**

☐ right ☐ left ☐ not applicable

3. **Type of injury**

☐ concussion (with or without haematoma/ contusion/loss of consciousness)
☐ fracture
☐ other bone injury
☐ dislocation/subluxation
☐ sprain/ligament injury
☐ other injury (please specify):. . .
☐ lesion of meniscus or cartilage
☐ muscle rupture/strain/ tear/cramps
☐ tendon injury/rupture/ tendinosis/ bursitis
☐ bruise
☐ abrasion
☐ laceration
☐ nerve injury
☐ dental injury

. . . .

4. **Diagnosis** (text or Orchard code):

. . . .

5. Has the player had a **previous injury** of the same type at the same site (i.e. this injury is a recurrence)?

☐ no ☐ yes

If **YES**, specify date of player's return to full participation from the previous injury:. . .

6. Was the injury caused by **overuse** or **trauma**?

☐ overuse ☐ trauma

7. **When** did the injury occur?

☐ training ☐ match

8. Was the injury caused by **contact or collision**?

☐ no
☐ yes, with another player
☐ yes, with the ball
☐ yes, with other object (specify) . . .

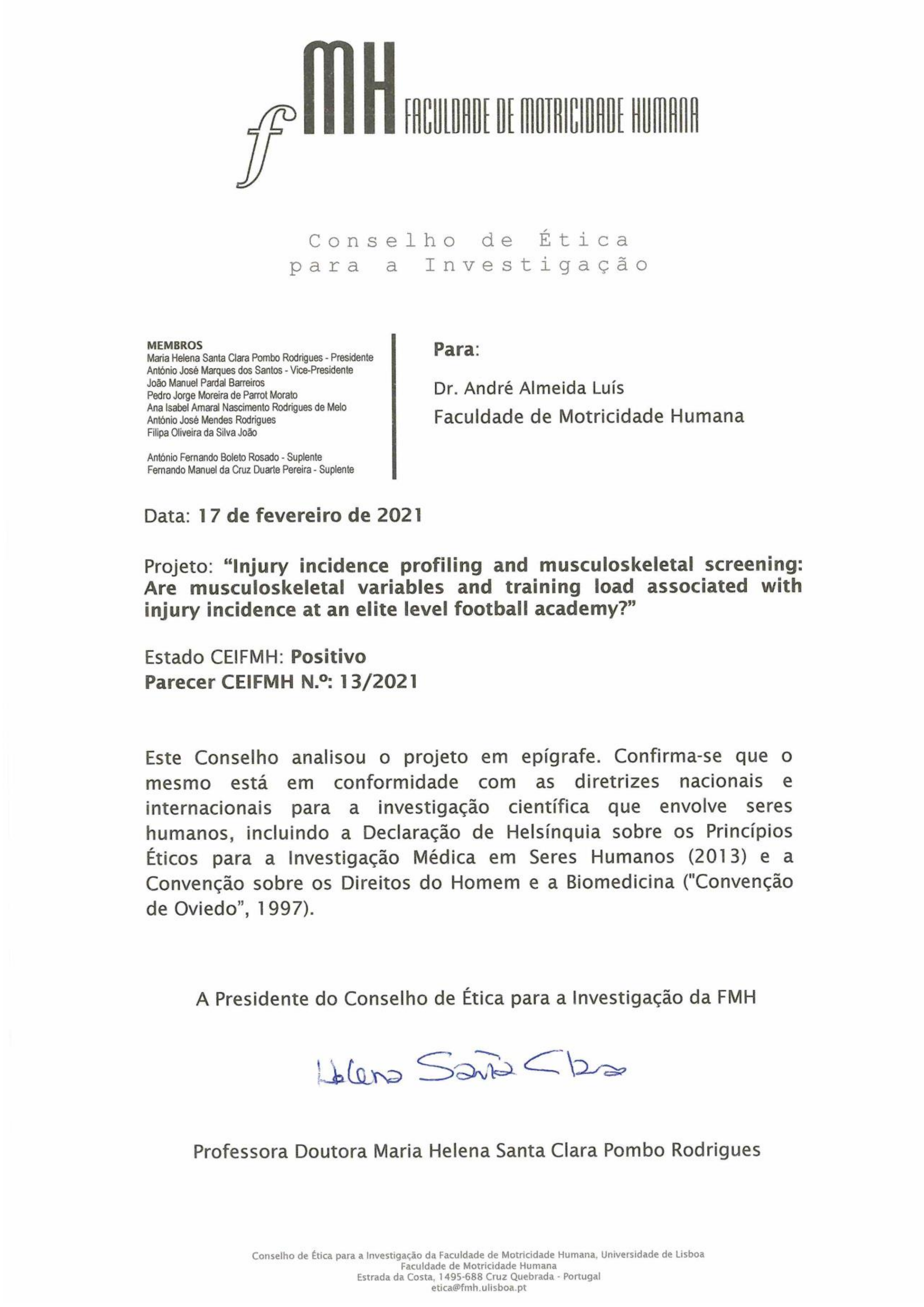
9. Did the **referee** indicate that the action leading to the injury was a **violation of the Laws**?

☐ no ☐ yes, free kick/penalty ☐ yes, yellow card ☐ yes, red card

If **YES**, was the referee's sanction against: ☐ injured player ☐ opponent,

Figure 12 - Injury Report Form

8.4 **Appendix IV –** Ethics approval



fMH FACULDADE DE MOTRICIDADE HUMANA

Conselho de Ética
para a Investigação

Para:

Dr. André Almeida Luís
Faculdade de Motricidade Humana

Data: **17 de fevereiro de 2021**

Projeto: **"Injury incidence profiling and musculoskeletal screening: Are musculoskeletal variables and training load associated with injury incidence at an elite level football academy?"**

Estado CEIFMH: **Positivo**
Parecer CEIFMH N.º: 13/2021

Este Conselho analisou o projeto em epígrafe. Confirma-se que o mesmo está em conformidade com as diretrizes nacionais e internacionais para a investigação científica que envolve seres humanos, incluindo a Declaração de Helsínquia sobre os Princípios Éticos para a Investigação Médica em Seres Humanos (2013) e a Convenção sobre os Direitos do Homem e a Biomedicina ("Convenção de Oviedo", 1997).

A Presidente do Conselho de Ética para a Investigação da FMH

Helena Santa Clara

Professora Doutora Maria Helena Santa Clara Pombo Rodrigues

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