An Investigation into the Relationship Between Physical Fitness Parameters and Injury in Male Academy Football Players

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Abstract

Injuries are a constant issue in football at any level, however the players in the Performance Development Phase (players aged 16-19) are potentially at a high level of injury risk due to the psychological, physiological and cultural changes they experience in the transition from the Youth Development Phase (YDP) to senior sport. PDP players are at high risk of injury having recently finished Peak Height Velocity (PHV), and experiencing higher levels of training load and exposure. This study aims to investigate the influence of physical fitness parameters on injury burden in the PDP in a non-league football academy, where there is minimal funding to explore this relationship. Eccentric Hamstring Strength (EHS), Countermovement Jump Height (CMJH), 20m Sprint Times and Anaerobic Speed Reserve (ASR) were assessed as parameters of physical fitness. Also observed was the influence of these variables on injury incidence, injury burden, training availability and match availability in the PDP. This study was a prospective cohort study, following 20 male footballers (aged 16-19) across a full playing season, inclusive of pre-season, in a non-league academy. Injury incidence was found to be lower than found in previous literature, whilst burden matched current findings. Only change in ASR from pre-season to mid-season was found to significantly influence injury severity, with no other significant effects found related to change in physical factors. Availability was not influenced by any variables tested. Hamstring injuries were the most common, due to large between limb dissymmetry which formed across the season, despite EHS being higher than found previously. Physical fitness factors decreased across a playing season due to potential increases in load and exposure, needing further research and examination in a wider population.

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Introduction

For a prospective professional footballer, an injury can end a career before it has begun (Bahr and Krosshaug 2005; Light et al. 2021). Catastrophic injuries such as ACL tears, bone fractures and repetitive strains can significantly reduce an athlete's chances of signing a professional contract, due to reduction in match exposure lowering the chances of being seen by scouts, improving one's performance, and decreasing ranking within a team (Gabbett 2016; Light et al. 2021). Additionally, injury will lower their psychological and overall physiological health(Light et al. 2021; Bishop et al. 2022; Tears, Chesteron and Wijnbergen 2018; Van Der Horst et al. 2017), with only 65% of athletes who had complete ACL reconstruction returning to their pre-injury levels of performance (Waldén et al. 2016) and athletes often experiencing low self-motivation and poor mental health when experiencing long term injuries (Beech et al. 2022). In men's professional football, £45million is lost per season per club in the English Premier League, going towards medical costs, insurance, rehabilitation and paying the players despite them not playing in matches for the club (Pulici et al. 2022).

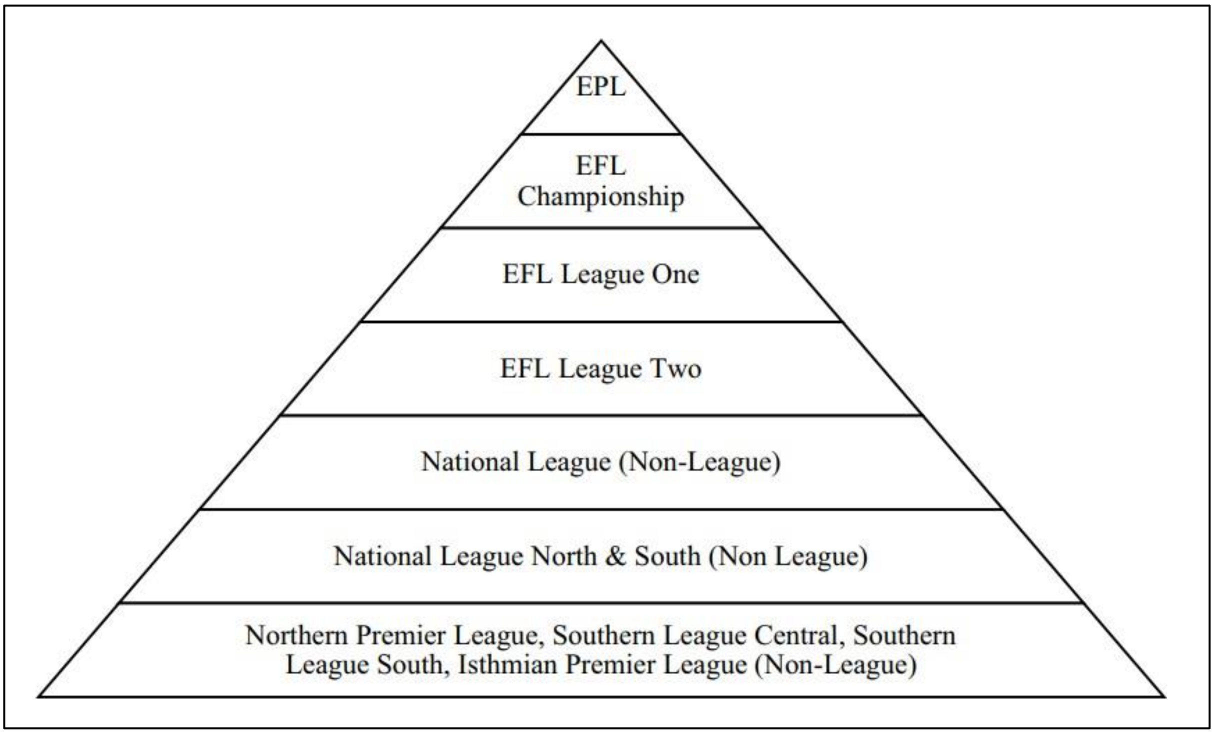
Furthermore, clubs are less keen to take on injured youth players as they do not want to spend the time and resources rehabilitating them when there are more successful, established players in the team, and a large pool of prospective youth players who are fully fit and ready to jump into the training (Salter et al. 2022). It has been found that there are correlations between levels of physical fitness and injury incidence, including sprint speeds, muscular strength and neuromuscular function, which can potentially be utilised to inform injury prediction and prevention in youth football (Deeley et al. 2022; Saward et al. 2020; Markovic et al. 2020).

Context of Non-league Football Academies

Professional English football follows a tiered system approach, with the highest level being the Premier League, Stage 1, with 20 teams. Stage 2 is the English Football League Championship, with 24 teams, regressing to the English Football League 1 and English Football Team 2 as Stage 3 and 4 respectively (The FA 2018). The National League is Stage 5, and also referred to as "Step 1", with non-league football referring to the National League and lower (The FA 2018). Football academies consist of young players usually aged from Under 9's through to Under 23's, however some clubs only have youth teams up to the U19's or U23's age groups, depending on funding and numbers of players available (Tears, Chesterton and Wijnbergen 2018). Graduates from Stage 1 Youth Teams will often have a direct route down to Stage 5 clubs, either gaining experience over a season or half a season on loan, or through gaining a professional contract with the first team there after being unsuccessful at their home club. Across English Football, youth team athletes often spend time at a lower league club with the first team, and subsequently may end up signing a contract with that club (The FA 2018; Mattia and Gavin 2022). Because of this, players can often be "dual-registered" with their home club and their loan club, which can affect exposure, training and match availability alongside other things such as injury risk, rehabilitation time and plans and training programmes.

Figure 1, taken from Prendergast and Gibson (2022) shows the current structure of English Football, with the English Premier league at the top (Stage 1), and National League, the start of non-league football, in the middle as Stage 5, Step 1.

Figure 1 - The Structure of English Football (Prendergast and Gibson 2022)



Background to the Professional Development Pathway (PDP)

Tears, Chesteron and Wijnbergen (2018) explored the implementation of the Elite Player Performance Plan (EPPP), which was developed in 2012 by the English Premier League and Football Leagues with the intention of increasing "home grown" players within senior, elite English football. The Football Association (FA) (2018) defines footballers aged 17-21 as being within the "Professional Development Phase" (PDP), which follows the "Youth Development Phase" (YDP) (12-16) and precedes the progression to elite senior football (Rago et al. 2020; Mattia and Gavin 2022). Due to variations in biological and physiological development, adolescent athletes may respond differently to their adult counterparts regarding training stimuli such as load and exposure, subsequently creating different outcomes surrounding injury and fatigue, with injury incidence in adult (over 21 years old) men's football being 11.5% higher than Under 21's (Injury incidence 7.45/1000 hours and 6.59/1000 hours respectively) (Bult, Barendrecht and Tak 2018; Hägglund et al. 2013; López-Valenciano et al. 2020;Gabbett et al. 2014). Hypotheses also state that there may be variance between YDP and PDP athlete responses to load due to their biological maturity, physiological development and psychological changes and pressures (Gabbett et al. 2014).

In the Professional Development Phase (PDP), there is a significant increase in football exposure for this age group compared to prior to the EPPP implementation, with average exposure increasing by 126% from 3760 hours per season to 8500 hours (Tears, Chesterton and Wijnbergen 2018; Mattia and Gavin 2022). When transitioning from the YDP to the PDP, athletes are often post-Peak Height Velocity (PHV), also referred to as the "growth spurt" (Tears, Chesterton and Wijnbergen 2018). PHV defines the moment of largest increase in body height, with the variance in velocity of growth sometimes creating biological differences within teams, however, in most cases as athletes reach 16 and progress to the PDP they are post-PHV(Tears, Chesterton and Wijnbergen 2018). For those who experience PHV later, the transition to PDP may increase injury risk, with Bult, Barendrecht and Tak (2018) highlighting the 6 months before and after PHV as a time for high injury risk. During this phase, preparation for senior football is often associated with increased injury risk due to higher chronic workload (Gabbett 2016; Bannister et al. 1975), which could contribute to increased injury risk for those who experienced PHV later (Bult, Barendrecht and Tak 2018). Therefore, there is potential for there to be differentiation in both injury statistics and physical fitness levels of the participants of this study, depending on when the experienced PHV.

Unfortunately, the chances of a PDP academy player becoming a professional are low. In 2015, the English Premier League (EPL) statistics revealed that only 0.5% of all academy football players, at any level, and 3% of those from “elite” academies (Stages 1 &2) would ever play in the EPL(Røyhesdal, Toering and Gustafsson 2018). With over 200 football clubs in England, each with academies containing hundreds of prospective players, these statistics show the competition to secure a professional contract is high, with failure ending aspirations, careers and sometimes entire identities (Røyhesdal, Toering and Gustafsson 2018).

Recently, there has been more focus on these athletes, with the FA creating the Professional Development Pathway, for athletes aged 17-21, to encompass the transition from junior (Youth Development Phase (YDP)) to senior, professional football (Tears, Chesterton and Wijnbergen 2018). In this period, injury rates are highest for age group football (Light et al. 2021), despite growth-related injury-risk factors being reduced. This raises questions surrounding the cause of injury, and whether it is possible to predict such occurrences and thus reduce them, subsequently allowing more players the opportunity to progress to professional careers.

Biological Maturity and Growth in Youth Team Footballers

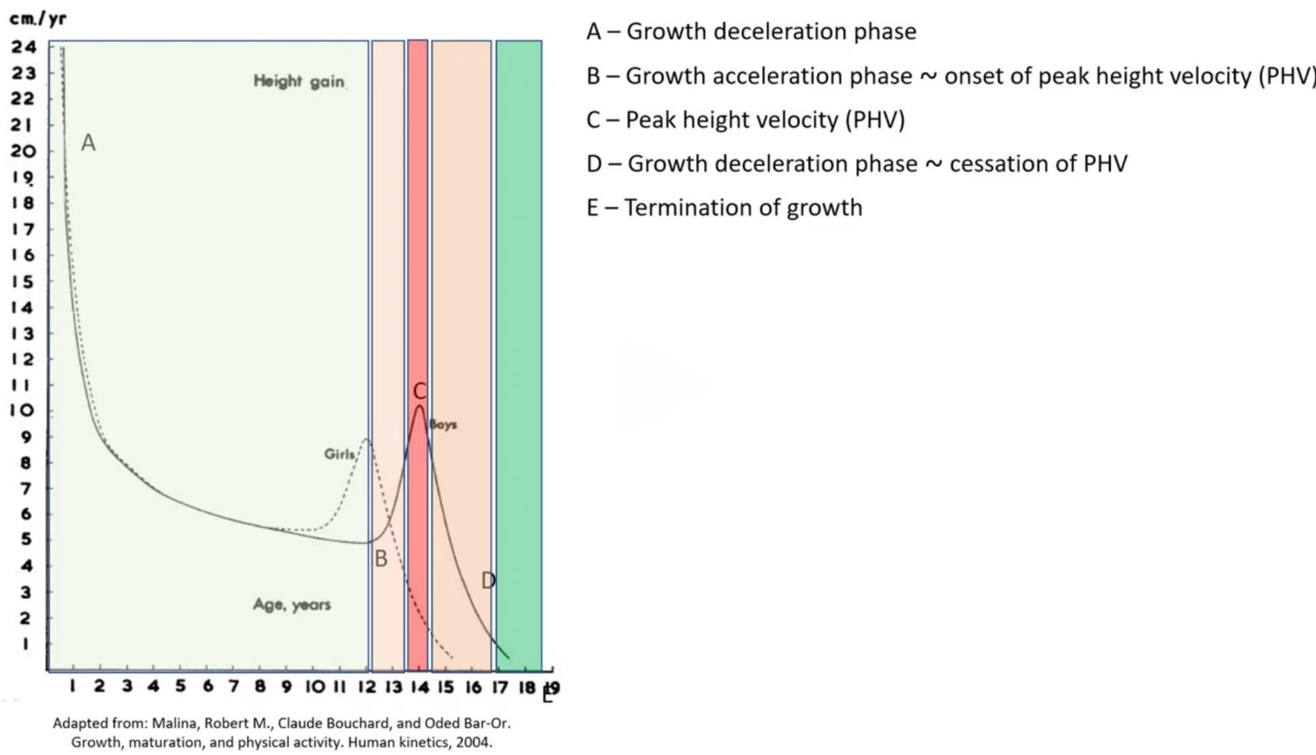
During the YDP, athletes experience a shift towards biological maturity, characterised by accelerated musculoskeletal growth, physiological changes and alterations to neuroendocrine function (Gabbett et al. 2014).

Biological maturity occurs in all bodily tissues, organs and systems, and refers to the body's maturity, rather than the chronological age of the individual (Malina et al. 2015). To assess this, underlying process outcomes are measured to provide an indication towards maturity (Malina et al. 2015; Mirwald et al. 2002). Maturity is assessed through the athletes' status (chronological age) and timing (the chronological age at which maturation milestones are reached), often showing large differences between biological and somatic age (Malina et al. 2015; Mirwald et al. 2002). Biological maturity is often associated with a sudden increase in height, weight and overall size and power of a player (Van der Sluis et al. 2015; Mirwald et al. 2002)

Research has identified one of the most commonly used indicators of maturity in adolescence to be Peak Height Velocity (PHV) (Malina et al. 2015; Van der Sluis et al. 2015). This refers to the highest rate of musculoskeletal growth, where the maximum growth rate occurs, and allows comparison of growth and maturation between athletes (Mirwald et al. 2002; Malina et al. 2015; Van der Sluis et al. 2015). This is often identified by a sudden, rapid increase in growth of height, referred to as the "take-off" phase (Malina et al. 2015). PHV has been shown to be effective at informing practitioners of injury risk, and thus influencing training load implementation (Salter et al. 2022). Whilst many studies have used this method to predict biological age, several more recent studies have collated data from literature to identify the fact that PHV can have a large margin for error in comparison to other methods (Salter et al. 2022).

In the PDP, athletes are expected to be post-PHV, however may still experience weaknesses in certain structures if they reached biological maturity later (Malina et al. 2015). Therefore, participants in this study are confirmed to be post-PHV, assessed by the club medical team at the start of the season prior to this study occurring, but consideration must be in place for those who may have lower physical fitness levels than their counterparts who have been biologically mature for longer. Figure 2 shows a model of PHV from the work of Towlson et al. (2021), originally adapted from the work of Malina, Bouchard and Bar-Or (2004), wherein PHV is identified [c] for boys and girls, alongside the age ranges where this may occur (from 12-17), and the points where PHV ceases, and growth terminates (approximately ages 17 and 19 respectively). Through this model, the variances in PHV occurrence can be seen, and subsequently the age(s) at which biological maturity achieved predicted. It is possible to interpret this to show that not all athletes entering the PDP will have finished growing, and so may experience some weaknesses compared with their biologically mature counterparts (Towlson et al. 2021).

Figure 2: A model of PHV and the associaed ages and stages (Towlson et al. 2021), originally adapted from the work of Malina, Bouchard and Bar-Or (2004),



Psychological Considerations in the PDP

It has been highlighted in recent literature that there has been an increase in the emphasis of “winning” and competitive behaviour within the PDP, as athletes are prepared for transitioning to elite senior football. In this phase, conforming to the sport ethic is considered “essential” for a professional contract (Tears, Chesterton and Wijnbergen 2018; Røynesdal, Toering and Gustafsson 2018) The sport ethic refers to four conditions that create a “real athlete”, and recent research, whilst not referring to it by the same name, confirms that the attitudes surrounding it still exist in sport today (Hughes and Coakley 1991; Røyhesdal, Toering and Gustafsson 2018) In their study, Hughes and Coakley (1991) identified these conditions as being: 1. *Making sacrifices for the game*, 2. *Striving for distinction*, 3. *Accepting risks and playing through pain*,

4. *Refusing to accept limits*. With the Olympic motto being Citius, Altius, Fortius (Swifter,

Higher, Stronger) and the understanding that success establishes distinction and reconfirms identity, this creates a desire for success at all costs (Hughes and Coakley 1991). This creates pressure for athletes, with the knowledge that only those who put sport before all else will succeed, and therefore increases the possibility of athletes taking risks, increasing the likelihood of injury, and of playing whilst injured (Hughes and Coakley 1991; Tears, Chesterton and Wijnbergen 2018).

Building on this, current literature states that a large part of an athlete's identity is focused on success and acceptance, with Røyhesdal, Toering and Gustafsson (2018 p.28) discovering that many professional football coaches share the opinion that "talent will only get you so far, but the way you conduct yourself when you are in the group will count as well". Further in the study, Røyhesdal, Toering and Gustafsson (2018) found that 51% of former academy players who were released suffered from clinical levels of psychological distress, with 97% of former elite academy players never playing in Premier League Football (Mattia and Gavin 2022). For their love of the sport, pressure from their clubs or desire to succeed, young football players will put their bodies on the line to conform, or even overconform, to the norms (Fournier, Parent and Paradis 2022). Over conformity to the sport ethic is characterised by overtraining, excessive weight loss, managing chronic pain and using banned substances, all of which put an athlete at a higher risk of injury (Fournier, Parent and Paradis 2022). Despite there being limited research in this area, it has been found that young men are at a higher risk of overtraining and over conformity, therefore increasing their risk of injury even more (Fournier, Parent and Paradis 2022).

Injury

Injuries have been found to cause damage at physiological, psychological and career levels, causing individual and team loss, and reducing overall success of the athlete (Røyndesdal, Toering and Gustafsson 2018; Silver 2021; Bittencourt et al. 2018; Bahr and Krosshaug 2005). From a team perspective, Gabbett (2016) found that successful sports teams, who win more matches and gain more points, have higher player availability and lower injury rates. Having injured athletes can result in reduced performance for the team, for example where squads are missing key players, or where there are multiple injuries at the same time reducing the number of substitutions, and therefore requiring players to play for longer, with reduced recovery (Røyndesdal, Toering and Gustafsson 2018). Individually, injured players will experience lowered exposure as they return from injury, and may experience reduced performance, as indicated by Waldén et al. (2016), with only 65% of athletes who had complete ACL reconstruction returning to their pre-injury levels of performance. Therefore, as individuals and as a collective, a team with numerous injuries such as this will experience reduced performance, and potentially lowered results (Waldén et al. 2016).

The Football Specific Extension of the IOC Consensus Statement (FSE-IOCCS) was published in 2023, following an update on the IOC consensus statement (IOCCS) from its 2006 publication. The football specific version has been published to align with recent sport and research developments, and thus encourage more consistent study designs, data collection and understanding within the field of football medicine. The authors tailored the IOCCS definitions to football, and are as follows:

A health problem:

"*Any condition that reduces a player's normal state of complete physical, mental and social well-being, irrespective of its consequences on the player's football participation or performance, or whether the player sought medical attention*" (Waldén et al. 2023 p.3).

Health problems can be divided into three categories: resulting directly from football; resulting indirectly from participation in football; not related to football participation. Furthermore, health problems can be broken down to injury and illness.

Injury has been defined as

"*Tissue damage or other derangement of normal physical function, resulting from rapid or repetitive transfer of kinetic energy*" (Waldén et al. 2023, p.3).

Illness has been defined as

"a health complaint or disorder experienced by a player not considered as an injury" (Waldén et al. 2023, p.3).

For the purpose of this study, an injury can be defined as any injury occurring from football training or match play, which results in the athlete being unable to participate in future training or match play, sometimes referred to as a "Time-Loss Injury" (Light et al. 2021).

Injuries can be classified by their type (traumatic or overuse), severity (minimal, mild, moderate or severe), location (body part) and mechanism (non-contact, indirect contact or direct contact) (Waldén et al. 2023; Light et al. 2021; Tears, Chesterton and Wijnbergen 2018).

A reinjury occurs following

"*An injury of the same type and same site as an index injury, occurring no more than two months after a player's return to full participation following the injury"* (Light et al. 2021 p. 1326)

Injury incidence has been defined as "the number of injuries per 1000 player hours (hours of training and match exposure" (Light et al. 2021; Hägglund et al. 2013). Exposure can be separated into training exposure and match exposure, with training exposure consisting of the number of training weeks multiplied by the number of players exposed multiplied by the match duration, and match exposure being the number of matches multiplied by the number of players exposed multiplied by match duration (Light et al. 2021) Total exposure is the sum of training and match exposure, in hours.

The severity of an injury is determined by the time lost through how many days the player was absent from training and match play (Light et al. 2021; Waldén et al. 2023). The FSEIOCC recommended the following categories for time loss:

0 days

1-3 days

4-7 days

8-28 days

28-90 days

90-180 days

>180 days

These detailed categories were created to allow improved communication of injury consequence with stakeholders such as coaches, managers and media, especially severe injuries (Waldén et al. 2023). It is worth noting that in the rare instance that an injury or illness causes retirement, permanent disability or death, this is excluded from any calculations regarding days lost and will not be categorised (Waldén et al. 2023). Whilst allowing more detailed communication and information about injury severity and consequence, using so many categories can create confusion with nomenclature, therefore, following the above recommendation and that of previous research, for this study the following categories have been selected to define injury severity:

Minimal Injury:

"Injury causing absence of 1-3 days from training and match play"

Mild Injury:

"*Injury causing absence of 4-7 days from training and match play"*

Moderate Injury:

"Injury causing absence of 8-28 days from training and match play"

Severe Injury:

"Injury causing absence of over 28 days from training and match play"

(Light et al. 2021 p.1236; Tears, Chesterton and Wijnbergen 2018; Hägglund et al. 2005).

Injuries can occur one of two ways. Traumatic injuries occur suddenly and with a known cause, and make up 75% of all football injuries, such as fractures and sudden ligament tears, whereas overuse injuries have no known trauma and a more subtle onset, representing the remaining 25%, and (Light et al. 2021; Tears, Chesterton and Wijnbergen 2018).

The Burden of Injury in Football

In 2010, Bowen (2017) found that football had a higher injury rate than other team sports, with injury being responsible for the largest amount of match absences (Hägglund et al. 2013). As identified by Tears, Chesterton and Wijnbergen (2018), desire to succeed and conformity to the Sport Ethic are considered essential for a professional football contract, with the culture surrounding football often glorifying those who play through pain and overcome injury

(Røyndesdal, Toering and Gustafsson 2018; Silver 2021). Performance of both the individual and team can be impacted by injuries, causing players to play at a lower standard or miss matches entirely, altering team dynamic and playing strategy (Hägglund et al. 2013). Performance can be maximised by having appropriate training loads, as injury can often be caused by inadequate or excessive training loads resulting in over or under training, with the "sweet spot" between the two improving both player and team performance and reducing injury risk (Hägglund et al. 2013; Gabbett 2016). Gabbett (2016) identified two ways an athlete can respond to training: Positive function, which results in fitness adaptations through an appropriate training load being prescribed, or negative function resulting in fatigue, often from over training, which can cause increased injury risk and reduced performance.

Risk factors of Injury

Research by Haxhiu et al. (2015) confirmed through their study that history of previous injury is the most important risk factor for predicting injuries in football. Kucera et al. (YEAR) found that footballers with a history of previous injury had an injury rate 2.56 times higher than those who had not been injured before. Haxhiu et al. (2015) attributed this to inadequate rehabilitation, or incomplete healing, resulting in reduced musculoskeletal strength, and potential between-limb and between-muscle imbalances. Other research has found that increased age and years playing football to indicate a higher risk of injury. Haxhiu et al. (2015), consistent with older research by Ekstrand et al. (1983) found that players with higher levels of experience playing football have lower levels of injury, however Turbeville et al. (2003) found these athletes to experience higher levels of injury. Unfortunately, it is difficult to isolate whether years' experience is a standalone risk factor, or if age contributes alongside this.

Injury incidence in the study by Haxhiu et al. (2015) is consistent with current injury rates in literature, focusing on elite, adult men's football. This prospective cohort study had a sample of over 200 elite male footballers, and examined injury across a playing season. The results support those found in other studies, and are found to be reliable (Haxhiu et al. 2015).

López-Valenciano et al. (2020) found that the incidence of injuries in football matches was increased by players having higher physical demands, such as increased exposure, increased load and reduced in-game recovery, alongside an increased number of contacts in the game, and higher levels of match fatigue. Match fatigue can be accentuated by reduced in game-recovery, caused by higher intensity matches, or reduced opportunity for substitutions; alternatively, match fatigue can come from reduced between-game recovery, where games are scheduled closely together, alongside training sessions, and lowered squad numbers (due to injury, finances or other reasons) resulting in players having higher match exposure, and insufficient recovery (López-Valenciano et al. 2020). Subsequently, players will experience higher levels of muscle fatigue, increased physiological strain, and higher levels of psychological stress.

Ekstrand, Hägglund and Waldén (2011) identified that a typical 25-man squad of adult males (over age 21) experienced an average of 50 injuries over a season, equating to two injuries per player. In a systematic review and meta-analysis, reviewing over 56 cohorts, López-Valenciano et al. (2020) found overall injury incidence over 21s professional football to be 8.1/1000 hours, with training incidence being 3.7/1000 hours, and match incidence being 36/1000 hours. However, exploration of other papers suggests that the average injury incidence in elite male football is lower, at 6.8/1000 hours, with training incidence being 7.7/1000 hours, and match incidence 29.1/1000 hours (Bult, Barendrecht and Tak 2018;

Hägglund et al. 2013).The increased match incidence from training incidence has been attested to factors such as higher physical demand, increased number of contacts and collisions, and increased fatigue during matches, resulting in higher injury risk (López-Valenciano et al. 2020). Van Beijsterveldt et al. (2014) similarly found that injury incidence in football was higher in matches than training in both amateur and professional football (Overall= 8.05/ 100 hours; Match = 26.1/1000 hours; Training = 3/1000 hours), however also found that professional football had a lower overall training incidence, yet a higher match incidence than amateur football. This was attributed to the fact that the support systems in place for professional sport significantly outweigh those in amateur sport, with set recovery, warm up and injury rehabilitation plans in place for each individual, whereas matches are faster paced with increased risk for injury (Van Beijsterveldt et al. 2014).

In senior football, López-Valenciano et al. (2020) identified minimal injuries as being most prevalent (3.1/1000 hours), whereas the earlier study by Van Beijsterveldt et al. (2014) found that minimal injury incidence was 1.1/1000 hours, with moderate injuries being of highest incidence at 2.1/1000 hours, followed by mild, minimal and severe respectively (2.0/100 hours, 1.1/1000 hours, 1/1000 hours respectively). López-Valenciano et al. (2020) also found severe injuries to be of lowest incidence (0.8/1000 hours) and moderate injuries to fall in the middle with 2/1000 hours. This study also used the classification of "minor" injuries as opposed to "mild" injuries used in other papers, including the FSEIOCC (Waldén et al. 2023). In amateur football, moderate injuries were of the highest incidence at 4.2/1000 hours, 2 times higher than found in professional football in the same study, attributed to reduced injury prevention and rehabilitations in amateur sport (Van Beijsterveldt et al. 2014). Few studies fully examine injury severity in senior football now, with recent research leaning more towards the examination of injury burden, and research regarding severity is often conflicting, as seen here.

Injury burden follows on from injury incidence, accounting for incidence (frequency) and severity (time lost) of injuries. It allows insight into the consequences of injuries on sports teams relating to absence, and thus accounts for changes in exposure (Hägglund et al. 2013; Waldén et al. 2023; Bult, Barendrecht and Tak 2018). Following the FSE-IOCCS, the definition for injury burden is confirmed as the number of days lost per 1000 hours player exposure (Waldén et al. 2023; Beech et al. 2022).

Hägglund et al. (2013) found reduced injury burden within a team coupled with an increase in player match availability to contribute to a higher end of season ranking for the team. Additionally, the same study found decreased injury incidence and burden significantly increased the number of points gained per match in the Champions' League (Hägglund et al. 2013). At this high level of professional football, Hägglund et al. (2013) found injury burden to be 130 days lost per 1000 hours exposure.

Neither study by López-Valenciano et al. (2020) or Van Beijsterveldt et al. (2014) identified injury burden exclusively in their findings, and the presented results do not allow for interpretation of this.

The Burden of Injury in the PDP

Data from senior football cannot always be applied to academy players due to variations in training load, exposure and physiological state (Silva 2021). Several studies have examined injury in youth football, but few focus solely on incidence and burden in the PDP, highlighting the need for further studies to isolate this age group.

Injury Incidence in the PDP

Light et al. (2021) conducted a prospective cohort study, using footballers aged 12-21, to investigate injury incidence and the relation with maturity in youth footballers. Their study found the Under 21's category (with the next group being U18's) experienced the highest number of injuries over the four-year study period (27.4%). U21's injury incidence was found to be almost 7x higher than the U11's (Light et al. 2021), with the average injury incidence in U21s in current literature being 6.59/1000 hours (Tears, Chesterton and Wijnbergen 2018; Light et al. 2021; Bult, Barendrecht and Tak 2018; Hägglund et al. 2013). Training injury incidence was found to be 2.55 / 1000 hours, with match injury incidence being significantly higher at 30.7/1000 hours, as has been identified in senior, professional football (Bult, Barendrecht and Tak 2018; Tears, Chesteron and Wijnbergen 2018; Van Beijsterveldt et al. 2014). Additionally, traumatic injuries were found to have an incidence of 6.29/1000 hours, whereas overuse injuries were of a lower occurrence, at 2.04/1000 hours (Tears, Chesterton and Wijnbergen 2018; Light et al. 2021; Bult, Barendrecht and Tak 2018; Hägglund et al. 2013).

Interestingly, Light et al. (2021) stated that time-loss injuries peak between the ages of 13 and 16, which corresponds with Peak Height Velocity (Tears, Chesterton and Wijnbergen 2018). Bult, Barendrecht and Tak (2018) found the highest injury burden to be within the U16's age group, with injury burden being at its highest in the six-month period following Peak Height Velocity, 31% higher than pre-PHV. However, in their study Bult, Barendrecht and Tak (2018) did state that first year PDP players could be at the highest risk of injury due to an increase in training load and competition regimes, including increased frequency and intensity of exposure, indicating that this needs empirical evidence to support thus hypothesis. Noticeably, Tears, Chesterton and Wijnbergen (2018) also found that youth football players (age 16-19) had 2x higher injury incidence during training than their senior, professional counterparts, however other papers fail to support this claim.

Tears, Chesterton and Wijnbergen (2018) also stated that 21% of all injuries in youth football are classed as "severe", with large time loss consequences. As with senior football, there have been discrepancies in the research regarding severity, with many studies now opting to explore injury burden as a measure of the impact of injury, with results not often isolating severity for discussion.

In recent studies, Bult, Barendrecht and Tak (2018) found injury burden in footballers aged 12-19 to be 58.37 days per 1000 exposure hours, highlighting a significant increase when players transition to elite football (Hägglund et al. 2013; Bult, Barendrecht and Tak 2018; Tears, Chesterton and Wijnbergen 2018). Røynesdal, Toering and Gustafsson (2018) highlighted the transition from youth to senior football as a key developmental stage for players, with individuals needing to meet a complex set of dynamic demands to succeed. This includes matching a higher training intensity and frequency, which can contribute to increased injury risk (Røynesdal, Toering and Gustafsson 2018).

Most injuries in UK football academies are non-contact, soft tissue injuries, hypothesised to be due to inadequate training load prescription, or growth-related changes (Salter et al. 2021). In academy football, approximately 60% of injuries occur in training, often following periods of relatively high or low exposure in comparison to the average training load, usually during pre-season or a mid-season break (Salter et al. 2021). This phenomenon is consistent with adult populations. Increasing exposure hours can increase the risk of overtraining, and subsequently increase injury risk, and here it is important to note that the EPPP does not consider any training outside of football training, i.e personal gym sessions or runs that players may do (Tears, Chesterton and Wijnbergen 2018).

Injury incidence being so high for young athletes, especially those in the PDP (16-21 years old), can contribute to developmental issues following PHV. Additionally, injuries can cost clubs large amounts of money, through costs such as rehabilitation, use of specialist equipment and getting scans, and time loss costs of having to pay athletes despite them not playing for the team (Haxhiu et al. 2015) . For athletes hoping to gain professional contracts, this can put them at risk of not gaining these, due to clubs wanting to invest in fit players, who are ready to perform, not likely to cause hindrance for the club through repeated, or ongoing injury. This high-risk age group therefore needs further research, and subsequent support regarding strength and conditioning, injury prevention, and social and emotional support through this transition to either senior football, or out of the football entirely (López-Valenciano et al. 2020; Haxhiu et al. 2015).

Pathology of Injury in the PDP

Lower limb injuries were found to be most common in academy football (84.7%), with an incidence of 6.8/1000 hours (López-Valenciano et al. 2020) then the abdomen/ pelvis/ head (9.5%), and finally the upper extremity (5.3%) (Light et al. 2021; Tears, Chesterton and Wijnbergen 2018; Bult, Barendrecht and Tak 2018). The thigh has been determined the most commonly injured location for youth footballers (22%), followed by ankle injuries (19.8%), knee injuries (15%), hip/ groin injuries (12.2%), foot/ toe injuries (9.5%), lower leg/ Achilles (8.6%), and lower back/ pelvis injuries (6.8%) (Light et al. 2021; Tears, Chesterton and Wijnbergen 2018; Bult, Barendrecht and Tak 2018). Other locations were of minimal percentage/ significance i.e face/head and fingers. Injury incidence of the lower limb can be split into the thigh (1.8/1000 hours), the knee (1.2/1000 hours), the ankle (1.1/1000 hours), the hip/ groin (.9/1000 hours), the lower leg/ Achilles tendon (.8/1000 hours) and the foot/ toe (.4/1000 hours) (López-Valenciano et al. 2020).

Muscle and tendon injuries were of highest incidence (4.6/1000 hours), followed by contusions (1.4/ 1000 hours), joint and ligament injuries (excluding bone) (.4/1000 hours), fractures and bone stresses (.2/1000 hours), lacerations and skin lesions (.05/1000 hours) and nervous system injuries (/04/1000 hours) (Lopez-Valnciano et al. 2020).

For footballers in the U21's category, muscular injuries (inclusive of tears, strains, cramps and ruptures) were the most common (30%), followed by ligament injuries (inclusive of sprains and ruptures) (19.5%), then haematomas and bruises (16%), bone injuries (not inclusive of fractures) (8.6%), tendon injuries (inclusive of tears, ruptures and tendinopathies) (8.4%), fractures (6.6%), meniscal and cartilage injuries (3%), concussions (2%), dislocations and subluxations (1%), with other injuries accounting for the remaining 5% (Light et al. 2021; Tears, Chesterton and Wijnbergen 2018; Bult, Barendrecht and Tak 2018).

Traumatic injuries have been identified as being more common than overuse injuries (73% and 27% respectively) (Salter et al. 2021; López-Valenciano et al. 2020; Light et al. 2021). Of traumatic injuries, muscular tears, cramps and strains were the most common (36%), followed by sprains (26%) and haematomas/ contusions (18%) (Light et al. 2021; Tears, Chesterton and Wijnbergen 2018). In contrast, overuse injuries were most frequently non-fracture bone injuries (47%), followed by muscular tears, cramps and strains (16%), and then tendon tears and tendinopathies (13%) (Light et al. 2021; Tears, Chesterton and Wijnbergen 2018). Other overuse injuries in young athletes have been identified as being bone related injuries, including stress fractures of both high and low risk, such as to the patella, pars interarticularis, or femoral neck, or the fibula, ribs or metatarsals (Patel, Yamasaki and Brown 2017). Additionally, growth plate and apophysis type injuries can often occur in youth athletes, along with tendon and bursa irritation which can result in long term removal from sport (Patel, Yamasaki and Brown 2017). The risk of overuse injuries can be increased by consistent factors such as a sudden increase in the intensity, duration and volume of physical activity, often referred to as "load", poor conditioning and insufficient sport-specific training and inappropriate equipment or protective gear. Inconsistent factors such as anatomic variations, hard playing surfaces, stress to growth cartilage and a decrease in musculotendinous flexibility can also contribute to overuse injury (Patel, Yamasaki and Brown 2017).

The Impact of Injury in the PDP

Across a football season, Hägglund et al. (2013) found 77% of male professional football players were available for training, and 86% were available for matches, whereas Wik et al. (2021) found youth players to be available for training 85% of the time, with matches the same as senior players. Availability is often influenced by illness and injury, causing time lost and exposure reduced (Hägglund et al. 2013; Newton et al. 2017). Reduced availability can decrease a footballer's career prospects, as it results in less exposure during games, where scouts and other managers are watching youth players who may potentially be offered professional contracts (Newton et al. 2017). Player development is often at risk when athletes are injured, with those who sustain a severe injury less likely to return to the same level of fitness and performance as they were before, and some not returning to sport at all (Newton et al. 2017).

Injuries can compromise team success, if those who are often starting or deemed to be "better players" by the coaches are injured, performance can drop (Gabbett 2020). Additionally, having numerous injuries in a team will reduce the number of substitutions available, causing players to have to play for longer, therefore increasing injury risk more (Gabbett 2020). Hägglund et al. (2013) found significant association between low injury rates across a season and increased performance for professional sports teams, and it has been hypothesised by the authors that this will be reflected in academy level sport. Decreased injury burden coupled with an increase in match availability was found to result in a higher end of season ranking, with the same study finding decreased injury incidence and burden coupled with increased availability to result in an increase in the number of points gained per match (Hägglund et al. 2013). Ahtiainen (2018) found clubs who win domestic leagues generate $59.2 million greater revenues than other clubs, and that reaching one position higher on the league table generates $1.3million more. This study focused on European football, including the English Premier League, and so whilst these values are averages, the results can be applied to this study with reference to elite English football. With an increased chance of winning leagues, through higher end of season ranking, clubs are more likely to receive financial reward for their team's success; therefore, resources and support can be improved through increase financial provision (Ahtiainen 2018). As a result, clubs can improve injury prevention and rehabilitation provision for all teams, and therefore reduce injury risk and recovery times (Ahtiainen 2018; Haxhiu et al. 2015).

For an individual, injury can have a negative impact which may continue past the rehabilitation process and effect their performance after return to sport (Newton et al. 2017). As noted previously, injury can prevent career progression due to the physical impact it can have, such as reduced physical strength, agility, sporting ability and overall function (Merkel 2013;

McKay, Cumming and Blake 2019). Long term impacts of injury can include decreased technical and physical development, causing reduced chance to progress and hindrance compared with teammates, which ultimately reduces a player's chances of being selected (McKay, Cumming and Blake 2019). Additionally, for players who have experienced a severe injury, there is increased risk of osteoarthritis and other long-term health conditions (Merkel 2013; McKay, Cumming and Blake 2019).

Athletes who experience pain on palpation following hamstring injuries are found to be 4 times more likely to experience a reinjury, however authors noted that this was not solely due to tissue damage, but psychological considerations such as fear of reinjury (Van Der Horst et al. 2017). Reinjury is both a physical and psychological concern for players, with Van Der Horst et al. (2017) finding that fear of reinjury can generate avoidance behaviours in youth footballers and being the largest reason for failure to return to sport (McKay, Cumming and Blake 2019; Rice et al. 2020). Several PDP athletes who have experienced injury have reported feelings of social isolation following time-loss injuries, and difficulty reintegrating into the team upon return (Newton et al. 2017; Merkel 2013; McKay, Cumming and Blake 2019; Rice et al. 2020).

Therefore, current research recommends incorporating both psychological and physical testing strategies into rehabilitation, with athletes needing to be cleared as "psychologically ready to return to sport" as well as passing physical criteria (Van Der Horst et al. 2017). Specific assessments have been created for major injuries, such as the Knee Self Efficacy Scale (Van Melik et al. 2016), as have more generic assessments of overall psychological wellbeing such as the Athlete Psychological Strain Questionnaire (Rice et al. 2020).

Injury Risk Factors

Multiple studies have identified injury risk factors in football, including inappropriate warm up, overtraining, undertraining and emotional stress (Gabbett 2020; Light et al. 2021; Gabbett et al. 2016; Impellizzeri et al. 2020). Risk factors can be split into internal and external factors, with internal risk factors including sleep, age, career duration, previous injury, sex and psychological factors such as perfectionism and fear of reinjury, and external factors including load, days between games and weather conditions (Pulici et al. 2022; Gabbett 2016; Gabbett 2020).

Theoretical Underpinning to Injuries in Football

Injury prevention research and implementation from grassroots through to elite sport has been increasing rapidly in recent years, however the concept of injury prediction is still being explored, trialed and researched (Gabbett 2020; Impellizzeri et al. 2020). Several different methods have been applied to attempt to predict injury, with one more recent method being the use of Artificial Intelligence (AI) (Van Eetvelde et al. 2021). AI uses machine learning to analyse large data sets across a variety of sports, research methods and languages to analyse and understand correlations and trends in data sets, through which it can predict future patterns (Van Eetvelde et al. 2021). The use of AI is a relatively new concept, however, despite its infancy and need for further research and testing, Van Eetvelde et al. (2021) found AI to be capable of predicting injury in youth sport with 85% accuracy, alongside identifying key factors which predict injury. The study by Van Eetvelde et al. (2021) identified previous injury, higher training load and higher body size (mass and height) as being "twice as important" when predicating injury, also indicating that low training load after injury may indicate an injury that is not fully healed, and thus at risk of reinjury. This field is still being explored, however it is important to be aware of the increase in technological input in injury prediction and prevention research.

Injury occurrence is a multifactorial, non-linear phenomenon that will not occur through one risk factor alone (Bahr and Krosshaugh 2005; Bittencourt et al. 2018). Previous research has explored injury mechanisms from a single lens, such as work by Meeuwisse et al. (1994), who developed a model for risk and cause of injury from an epidemiological perspective, and that by McIntosh (2005), which was biomechanically focused, both of which has been determined to be insufficient by recent research (Bittencourt et al. 2016).

Two reliable and valid models of injury causation and the underlying factors associated with injury risk have been formed through research, both giving unique perspectives of the multifactorial nature of injury (Bittencourt et al. 2016; Bahr and Krosshaugh 2005).

Bahr and Krosshaug (2005) – A Multifactorial Approach to Injury

Bahr and Krosshaug (2005) emphasised the knowledge that injury occurs through a transfer of energy through a tissue(s), with an injury mechanism being the fundamental process through which a given reaction or result will occur (Whiting and Zemicke 2008). The mechanical properties of tissues will determine the response to this mechanism, with this differing in each tissue dependent on the nature, type and rate of load, the frequency of load repetition, the magnitude of energy transfer, and intrinsic factors such as age, sex and physical condition, as discussed previously (Bahr and Krosshaug 2005; Gabbett 2020; Van der Sluis et al. 2015; Impellizzeri et al. 2020). The phrase "injury mechanism" can be used to describe an inciting event, which could be one of many things such as specific aspects of a sports situation, athlete and/or opponent behaviour, whole body biomechanics, or tissue/ joint biomechanics (Bahr and Krosshaug 2005). A key statement from the research by Bahr and Krosshaug (2005) is that the relationship between load and load tolerance is what determines the injury outcome of an event, and it is important to examine this when exploring the phenomenon of sports injury. For overuse injuries, the inciting event may be distant from the outcome, but it can still be examined in the same way (Bahr and Krosshaug 2005).

Bahr and Krosshaug (2005) created a comprehensive injury causation model based on previous work exploring injury from a single lens (Meeuwisse 1994; McIntosh 2005). This model can be used to assess the interaction between both internal and external risk factors, and the effect this has on load tolerance, and how interactions between different factors can cause injury (figure 3) (Bahr and Krosshaug 2005). It has also been found to address potential prevention strategies for injuries (Bahr and Krosshaug 2005).

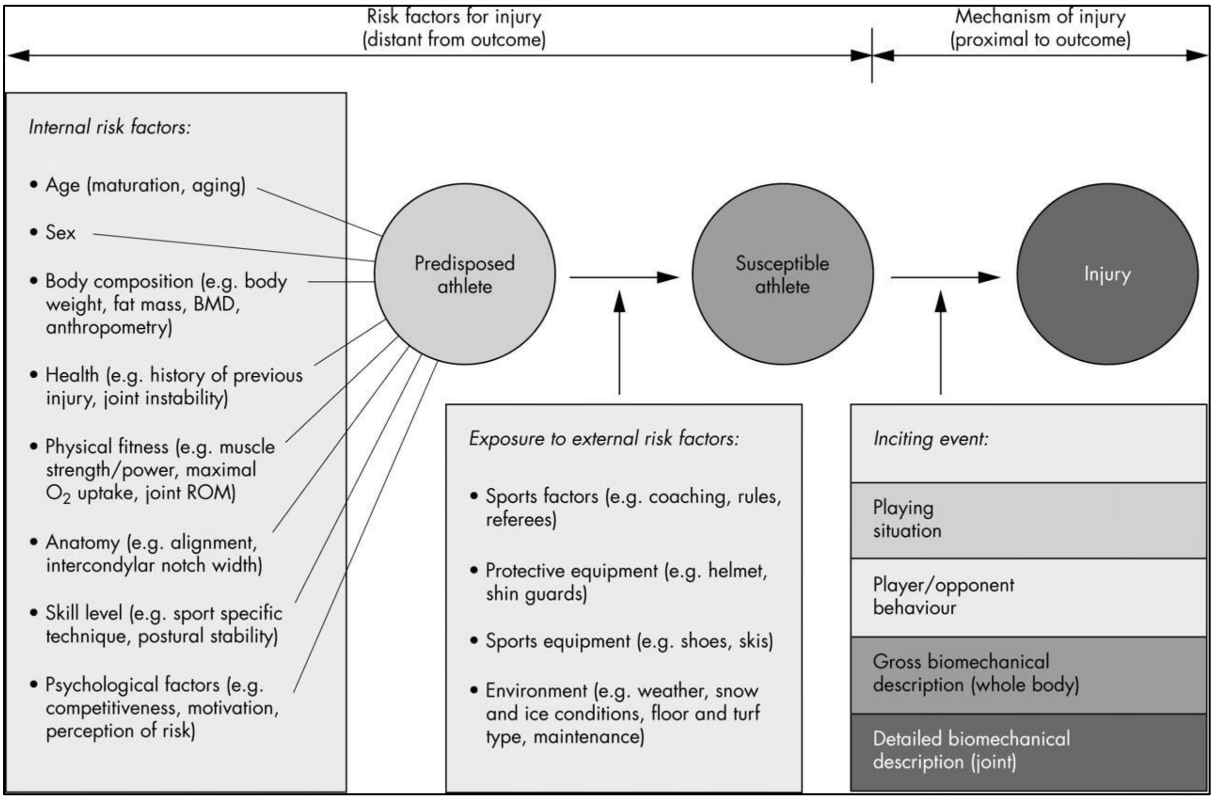


Figure 3 - A Multifactorial Approach to Injury (Bahr and Krosshaug 2005)

The model by Bahr and Krosshaug (2005) has taken inspiration from the work by McIntosh (2005) and Meeuwisse (1994) to give a holistic approach inclusive of epidemiological and biomechanical factors, and the characteristics of each sport. The authors hypothesised the use of this model for examination of the interaction between various injury risk factors and mechanisms, using an example of an ankle sprain in football and volleyball to highlight this; in both sports, injury risk is high if there is history of previous injury to the same site, due to decrease neuromuscular control. However, in football ankle sprains occur mainly due to laterally directed force, whereas in volleyball they mainly occur due to landing mechanics, with both having a different direction of force and therefore different mechanism (Bahr and Krosshaug 2005). This identifies that certain preventative strategies would not be effective, and also allows investigation into what can cause a predisposed athlete.

The model by Bahr and Krosshaug (2005) takes into consideration numerous internal risk factors that can create a predisposed athlete, such as age, sex, physical fitness, skill level and psychological factors, such as fear or (re)injury, or competitiveness (Bahr and Krosshaug 2005; Impellizzeri et al. 2020). For example, an older player with reduced muscle strength and VO_2 Max due to previous injury, and a fear of reinjury to that site and reduced skill through lack of training is already predisposed to injury (Impellizzeri et al. 2020). Once a predisposed athlete is identified, the addition of exposure to external risk factors can increase the risk of injury by creating a susceptible athlete, such as poor footwear not supporting the ankle, a wet pitch reducing grip and a coach demanding intense work from the sidelines. With just internal and external risk factors alone, an athlete is not necessarily certain to be injured, there is the requirement of an inciting event, or mechanism, as highlighted before, which could be contact, sudden change of direction or a change in biomechanical function to cause injury (Bahr and Krosshaug 2005; Impellizzeri et al. 2020; Silver 2021).

The positives of the model include the ease of accessibility; it is clear to see what creates a predisposed athlete, and what might then make them susceptible following introduction of external risk factors. However, it does not allow the practitioner to see how much of an impact each risk factor has, if any, and how these contribute to injury risk. Additionally, this model can make it difficult to determine which risk factors have a relationship and potentially cause each other, such as anatomical abnormalities affecting physiological ability. Despite this, having a clear model that allows the clear understanding of each risk factor categories' influence on injury risk, alongside its ease of understanding, must not be overlooked. Some models, such as that by Bittencourt, may overcomplicate the process, and therefore not be accessible to all (Impellizzeri et al. 2020).

Bittencourt et al. (2016) – A Complex Systems Approach

Bittencourt et al. (2016) introduced a "complex systems approach" for sports injury prediction and risk factor identification, used to address the complexity of injury incidence in sport. This model is formed through a web of determinants, made of interrelating determinants which interact in unpredictable and unplanned ways. In a system, these complex interactions form from the history of the system, creating patterns and observable regularities, which over time creates a global pattern, resulting in injury or adaptation.

Bittencourt et al. (2016) formed a model through the research process which can be seen in figure 2, based on the knowledge that sports injuries need to be explored through a complex lens, meaning features present in these complex systems must be identified (Bittencourt et al. 2016). Bittencourt et al. (2016) indicate three main features that need to be examined:

1. The pattern of interactions between determinants
2. Regularities that characterise and constrain performance.
3. Emerging patterns from the web of determinants.

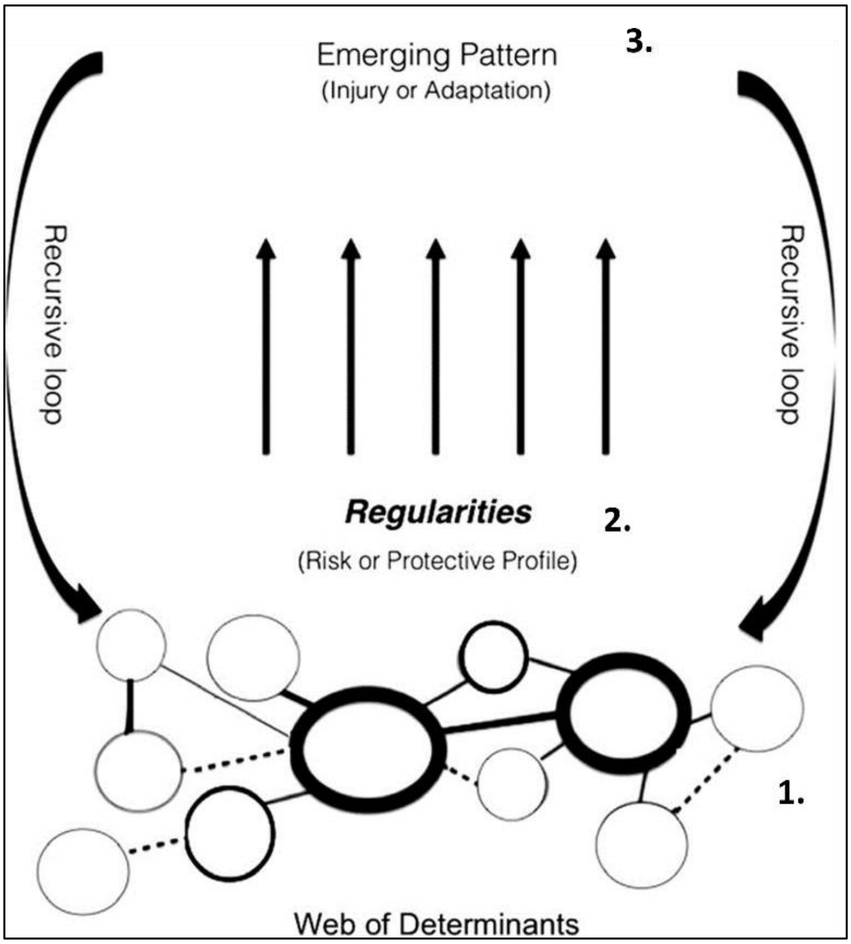


Figure4 - Web of Determinants Concept (Bittencourt et al. 2016)

A single risk factor will not cause injury, several factors must interact with each other to create injury risk, following research by Bittencourt et al. (2016).

Several determinants, or risk factors, of varying size and strength interact with each other to form a risk or protective profile (regularities), which then leads to the emerging pattern or injury or adaptation. Following this, feedback will influence the web of determinants through the recursive loop, and the system repeats (Bittencourt et al. 2016). A completed example of this model is used in the study by Bittencourt et al. (2016), and is used to explain the risk factors behind an ACL injury in basketball and ballet, displaying the difference in risk factors between sports for the same injury (figure 5).

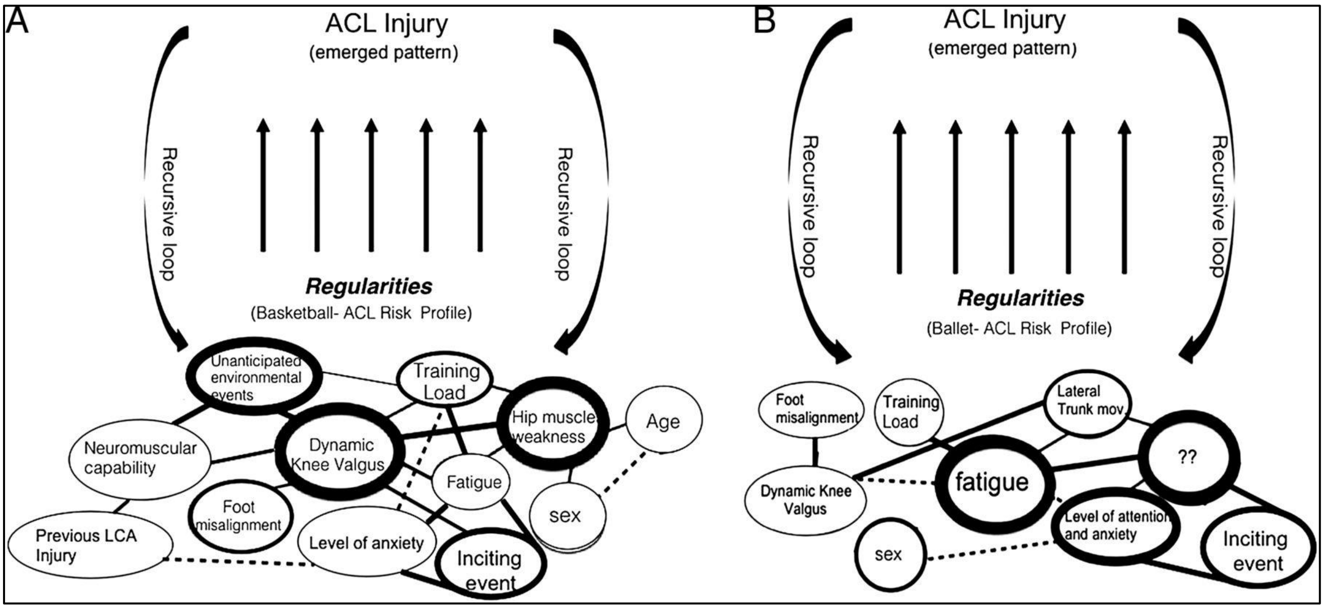


Figure 5 - Completed Examples of the Web of Determinants Theory (Bittencourt et al. 2016)

Through this model, it can be identified that ACL injuries are influenced by dynamic knee valgus, which in turn is affected by fatigue, hip muscle weakness, neuromuscular control, foot alignment and training load. These factors are influenced by other variables, such as sex and age, and in turn also influence other factors such as attention level and anxiety (Bittencourt et al. 2016). The way in which these interactions occur and how they influence ACL incidence creates a risk profile, through which the level of injury risk can be interpreted (Bittencourt et al. 2016).

Complex systems such as this have been used to predict complicated problems universally, in domains such as medicine, biology, economics and social sciences (Bittencourt et al. 2016). However, the use of such a model is less successful at predicting overall injury risk, it is rather tailored to predict a type of injury in a select situation, such as ACL risk in ballet dancers (Bittencourt et al. 2016).

This area has developed over recent years, with models being revised and created based on previous research, such as that by Bahr and Krosshaug (2005) and Bittencourt et al. (2016). It is clear that the model by Bittencourt et al. (2016) has taken some inspiration from Bahr and Krosshaug (2005), however the complex systems approach now allows the focus to be on complexity rather than reductionism (Bittencourt et al. 2016). Positives of this model include the ability to include ordered variables, wherein one can assess the impact of each risk factor, and how much it will influence injury risk. However, this model is complex, and may not be accessible to all due to this. Compared to the model by Bahr and Krosshaug (2005), this model shows that all risk factors influence injury risk at the same time, with no differentiation in types of risk factor.

In comparison to the model by Bittencourt et al. (2016), Bahr and Krosshaug (2005) have created a model that allows the early identification of at-risk athletes, and thus allows early intervention to reduce internal risk factors, and thus decrease risk. Therefore, the presence of external risk factors is not as concerning, and risk can be controlled. Using the web of determinants model, there is no separation between internal and external risk factors, nor the inciting event, which reduces the ability of the practitioner to address early risk factors. Therefore, for this study, the model by Bahr and Krosshaug (2005) will be employed to examine injury risk and prediction.

External Risk Factors

External risk factors can include the specific demands of each league, and each game, match and training exposure, days between matches, exposure and inadequate or excessive training load (Pulici et al. 2022; Gabbett 2020; Hägglund et al. 2013; Light et al. 2021).

Recent research has identified load, and the internal responses to it, to significantly influence injury risk, especially when coupled with other factors such as physiological fitness (Light et al. 2021; Gabbett 2016; Gabbett 2020). The term “Training Load” has been widely discussed in modern literature, with Staunton et al. (2022) highlighting the difficulty of accurately defining this term, given all that it can encapsulate. Impellizzeri et al. (2020) defined training load as being the input variable utilised to induce a training outcome, inclusive of all exercise sessions which may elicit such a response. Training load refers to the volume and intensity of training, inclusive of both external and internal domains.

External load is defined as being “The total amount of mechanical or locomotive stress generated by an athlete during exercise” such as distance covered or weight lifted (Staunton et al. 2022, p.440). The former example is commonly measured through Global Positioning Systems (GPS), which allows data acquisition in real time, thus allowing concurrent adaptations to training sessions in line with session aims (Gabbett 2016). External training load encapsulates all physical training completed by an individual, including volume, intensity and duration (Gabbett 2020). Internal load can be defined as “the psychological and physiological stress imposed on an athlete in response to external training load” (Staunton et al. 2022, p.440).

Internal load is sometimes referred to as perceived load, and can be measured through heart rate (HR) monitoring, or the Rate of Perceived Exertion of a session (sRPE) (Gabbett et al. 2014; Gabbett 2016; Staunton et al. 2022; Impellizzeri et al. 2020; Foster et al. 2001).

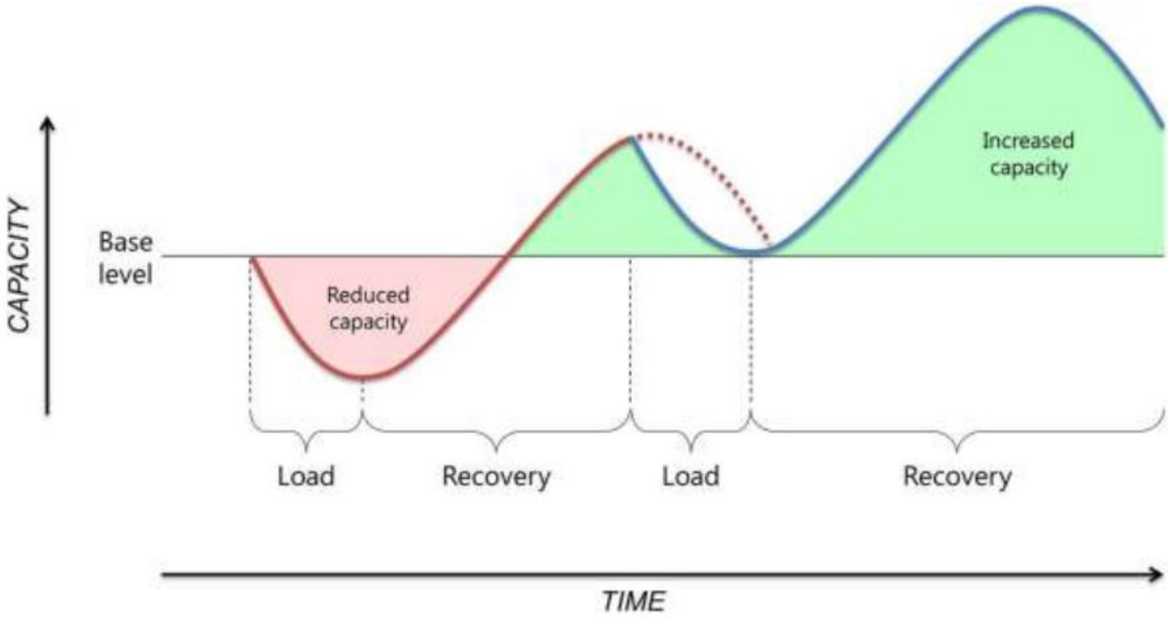
External load, created through the implementation of exercise quality, quantity and organisation, creates internal load, which, through the subsequent adaptations, elicits a training outcome (Impellizzeri et al. 2020; Soligard et al. 2016). It is noted that both internal load and the subsequent adaptations are influenced by a number of factors such as one’s individual characteristics, which encompasses age, gender and muscle fibre type, which are factors which also influence injury risk (Impellizzeri et al. 2020; Bahr and Krosshaug 2005). Training and psychological statuses, alongside health, nutrition, genetics and the athlete environment also play a part influencing these variables (Impellizzeri et al. 2020). Internal load, the psychophysiological response experienced during training, is the stimulus for training outcomes including biological and physical adaptations (Impezzerilli et al. 2020).

Across a season, footballers participating in the U12s to U18s category were exposed an average of 640.85 +/- 83.25 hours per player, per year in training, and 29.53 +/- 9.19 hours per player per year in matches (Tears, Chesterton and Wijnbergen 2018). Transitioning from YDP to PDP sees increased exposure, which can contribute to athlete load and thus can contribute towards injury risk and incidence in youth teams (Tears, Chesterton and Wijnbergen 2018). Increasing exposure can increase the risk of overtraining, as the EPPP does not consider physical activity exposure outside of structured training, such as personal gym or fitness sessions, which athletes may undertake to enhance their training (Tears, Chesterton and Wijnbergen 2018).

Soligard et al. (2016) created an adapted model which shows biological adaptation through cycles of loading and recovery (figure 6) demonstrating how biological adaptations can be used to increase fitness levels, and subsequently performance (Soligard et al. 2016). Through using progressive overload and adequate recovery, athletes will experience increased overall physiological capacity, and ability to withstand higher loads. The model indicates that to begin with, athletes will experience acute fatigue, however will then see improved performance (Soligard et al. 2016). Soligard et al. (2016) stated that progressive overload is the basis of most training programmes, however, can be transformed into excessive overload, wherein load is too high and acute fatigue becomes chronic, creating higher injury risk and reduced recovery ability. Therefore, it is important for practitioners to be aware of the load that athletes can tolerate, and how to successfully implement progressive overload to elicit the desired responses (Bowen et al. 2020; Soligard et al. 2016).

Research by Bowen et al. (2020) examined the load, and progressive overload, with reference to injury risk in the EPL, and found similar results to that of Soligard et al. (2016), wherein progressive overload elicits a physiological response to increase biological adaptations and tolerance of load.

Figure 6 - Biological adaptation through cycles of loading and recovery (Soligard et al. 2016)



Training for over 18 weeks prior to an injury has been found to decrease the risk of subsequent injury, and an increase in training load prior to progression from junior to senior football has been found to reduce injury significantly when embedding into senior teams (Gabbett 2016). An increase in training load coupled with higher physical capabilities reduces injury risk, however only when training load and recovery is balance appropriately (Impellizzeri et al. 2020; Gabbett et al. 2014; Gabbett 2016; Soligard et al. 2016). For example, decreased training load and increased recovery can result in a decrease in overall exposure, and therefore an increase in injury risk, however, the same outcome can occur through a higher load and decreased recovery, causing increased exposure and reduced recovery, meaning reduced time for adaptations (Gabbett 2016).

Soligard et al. (2016) stated that the relationship between load and health can be seen as a “wellbeing continuum”, where load and recovery have equal input, and load from both sport and personal lives impose stress on athletes, therefore shifting their overall physical and psychological wellbeing back and forth along a continuum. The International Olympic

Committee created a consensus statement regarding the relationship between load and health outcomes, wherein load was defined and its relationship with health on the wellbeing continuum clarified (Soligard et al. 2016). Competition has been identified as placing higher levels of stress and load on athletes than training, with Soligard (2016) discussing the potential for this rapid load increase to lead to more injuries in competition than in training.

Training load can be monitored to help predict and prevent injury risk, by assessing the Acute Chronic Workload Ration (ACWR) (Bannister et al. 1975; Bannister and Calvert 1980; Gabbett 2016). Acute workload refers to the absolute workload performed in all training sessions over a week-long period, creating the outcome of "fatigue" (Gabbett 2016; Gabbett et al. 2016; Bannister et al. 1975; Bannister and Calvert 1980). Across a week, lower workload reduces fatigue, and subsequently reduces injury risk (Gabbett 2020; Gabbett 2016; Hulin et al. 2015). Chronic workload is the average workload completed over a 3-6 week period, usually 4 weeks, which creates an outcome of "fitness" (Hulin et al. 2015; Gabbett 2020; Gabbett et al. 2016; Gabbett 2016; Bannister et al. 1975; Bannister and Calvert 1980). With high chronic load, it can be expected that an athlete will experience higher levels of fitness, which is associated with decreased injury risk in some studies, although it must be noted that overtraining may occur and increase injury risk in certain circumstances (Hulin et al. 2015; Gabbett 2020; Gabbett et al. 2016; Gabbett 2016; Bannister et al. 1975; Bannister and Calvert 1980). The Acute Chronic Workload Ratio allows a comparison between work done over a previous chronic work period

(4 weeks), and current acute workload (1 week), indicating whether acute workload was above, below, or equal to the chronic period (Hulin et al. 2015). Through this, it can be determined if workload will have positive (fitness) or negative (fatigue) outcomes, creating either well-prepared or fatigued athletes, and therefore inform practitioners about the risk of injury athletes are exposed to (Hulin et al. 2015; Gabbett 2020; Gabbett 2016).

ACWR between .8 and 1.3 has been described as the "sweet spot", where positive training adaptations occur such as increased aerobic capacity and prolonged high intensity running ability, done through increasing fitness (Hulin et al. 2015). This is achieved via progressive overload, gradually increasing both acute and chronic workloads over a period of time (Hulin et al. 2015; Gabbett 2016; Gabbett 2020). An ACWR over 1.5 has been identified in literature as being a "danger zone", increasing injury risk through either suddenly loading the athlete in an unprepared state (suddenly increasing acute load after low levels of chronic load), or overtraining (continuous high chronic load with small or no recovery period), which can result in injury or maladaptive training outcomes such as poor technique, reduced sleep or increased stress (Gabbett et al. 2016; Gabbett 2020; Gabbett 2016). Impellizzeri et al. (2020) confirmed that whilst overload and progression are key fundamentals of training, progressing load too quickly can cause overtraining. However, more recent research indicates that whilst some athletes are injured when ACWR supersedes 1.5, not all athletes experience this, leading Gabbett (2020) to highlight that injury risk does not equal injury rate, and later discusses the possibility that if athletes can train safely at these high ratios, it may improve injury risk and performance (Soligard et al. 2016; Hulin et al. 2015).

It has been found that small changes to training load can have large effects on injury risk (Gabbett 2016). Gabbett (2016) stated that it may not be all instances of high training load that increase injury risk, but the type of load and its implementation alongside intrinsic risk factors as identified above (Bahr and Krosshaug 2005). Gabbett (2016) identified decreased high-speed running decreased injury risk; however, with a lower high-speed running load comes reduced readiness for that load when required during match scenarios, showing the need to monitor both training load and athlete response.

Bowen et al. (2020) found that athletes who have low exposure to deceleration coupled with high (>2.0) ACWR are at the highest risk of non-contact injury, with high ACWR being referred to as "spikes" in workload. Furthermore, athletes who experience higher levels of exposure experience lower levels of injury risk, supporting work by Soligard et al. (2016) with reference to progressive overload (Bowen et al. 2020). With current literature exploring the impact ACWR has on injury risk in adult football, it is also important to consider this effect on youth football.

Tears, Chesterton and Wijnbergen (2018) hypothesised that whilst high chronic workload has been shown to have a positive effect reducing injuries in team sports, athletes in the PHV phase, especially aged 13-16, are more at risk of injury with higher training loads. These athletes are seen as being vulnerable due to PHV and the associated musculoskeletal developments, therefore practitioners may reduce the load they are exposed to and manage load cautiously to reduce injury risk. Whilst this reduces exposure to high chronic loads, it can cause undertraining and thus leave young athletes underprepared to experience high load during match-scenarios (Tears, Chesterton and Wijnbergen 2018; Soligard et al. 2016).

Gabbett (2016) investigated the training-injury paradox, and explored the relationship between training load, training phase (preseason, mid competition or late competition), and the likelihood of injury. This study found that athletes were at high risk (50-80%) of injury during pre-season, when load was increasingly significantly from the off-season, yet as the season progressed, load changes were less likely to result in injury due to positive adaptation (Gabbett 2016; Gabbett 2020).

From these findings, Gabbett (2016) hypothesised that if athletes could safely train through “high risk” portions of the training load – injury curve using the ACWR, they may develop greater resilience and training tolerance. Therefore, this would allow for an increase in training adaptations, and subsequently improved performance (Gabbett 2016; Gabbett et al. 2014). Gabbett (2020) indicated that practitioners should consider changes in training load in relation to chronic load. When acute training load decreases, this will create a decrease in chronic load for that chronic period, therefore delaying progression; similarly, an increase in chronic load will create an increased tolerance to higher acute training loads (Gabbett et al. 2020). Injuries are multifactorial, and it is important to ensure athletes have appropriate recovery and preparation support alongside appropriate load monitoring (Gabbett 2020). Performance is also multifaceted, often affected by a combination of biomechanical, emotional and lifestyle stressors, alongside environmental and internal fluctuations (Gabbett 2016).

There is minimal current literature exploring the influence of training load on injury risk and performance in adolescents, however results are extensive for senior sport, specifically football (Gabbett et al. 2014). Training load is often not monitored in academy settings due to barriers such as resource limitation, staff numbers, financial budges and limited opportunities for intervention (Salter et al. 2020). This is of concern, given the findings of Salter et al. (2020), emphasising that monitoring training load is of the highest importance when it comes to precenting injury in youth athletes.

Internal Risk Factors

As athletes age, they experience biological growth, such as increases in height and weight. This results in larger forces created when athletes collide with each other, and increased stress and load on skeletal structures (Patel, Yamasaki and Brown 2017). Older athletes were found to be at higher risk of injury in football, associated with decreased recovery rates (Pulici et al. 2022; Gabbett 2016). Additionally, Mendez-Villanueva et al. (2021) found younger athletes in the same age category are able to sustain high-intensity running for longer periods of time, and therefore fatigue slower. Musculotendinous flexibility is found to decrease during the adolescent growth period, and is associated with increased injury risk, especially in males, who have lower flexibility rates than their female counterparts (Patel, Yamasaki and Brown 2017; Bahr and Krosshaug 2005). Additionally, Gabbett (2016) identified age as being a key factor influencing training adaptations, highlighting the need for training programmes to be adapted for each age group. Therefore, academy athletes who are older, or those who are in the PDP, could be seen as being higher risk of injury than those in the YDP, thus requiring further support and research.

Psychological maturity and developmental factors are important aspects influencing the perception of sports participation by young athletes, which has direct implications for adherence to both training and treatment recommendations, and injury coping strategies (Patel, Yamasaki and Brown 2017). Gabbett (2020) also identified other risk factors for young athletes, such as social and emotional stress, academic concerns, personality traits such as perfectionism and self-blame, and training load (Gabbett 2016; Gabbett et al. 2016; Light et al. 2021).

Van der Sluis et al. (2015) identified that with differences in biological maturity comes variations in the power and size of players, therefore creating a discrepancy in the performance levels within an age group. It has been indicated in literature that players who mature earlier score higher on agility assessments, therefore indicating a reduction in injury risk from rapid change of direction compared to those who mature later (Van der Sluis et al. 2015). Additionally, those who mature at a later time are deemed to be at a disadvantage due to a temporary decrease in motor skills associated with PHV occurring at the same time those who experienced maturation earlier finish their PHV period (Van der Sluis et al. 2015).

When athletes reach the PDP, they are generally expected to have reached biological maturity, however there are occasions when this is not the case. For athletes who have reached biological maturity at a later age than their peers, whilst they are no longer at a high level of risk, they will still experience certain weaknesses and imbalances from their delayed growth, which can increase vulnerability (Gabbett 2020; Van der Sluis et al. 2015). Therefore, it is important to consider the effects of delayed growth in youth athletes who are biologically mature, and use this information to inform load implementation and acceptance. From these findings, and the aforementioned subconscious over-conformity to the sport ethic (i.e win no matter what and play through pain for success), it has been found that athletes who mature later are at a higher risk of overall injury, specifically overuse injuries (Van der Sluis et al. 2015).

Physical Fitness Factors

Newton et al. (2017) highlighted poor movement and reduced strength as being contributing factors to the incidence of non-contact injuries, such as ACL and hamstring tears, however evidence is conflicting. In the 2017 study by Newton et al., no difference was found for Functional Movement Screening (FMS) scores between injured and non-injured athletes, and with injuries that were non-contact, severe or overuse. However, it has been found that FMS has poor predictive abilities and is not a reliable tool for measuring physical fitness parameters (Newton et al. 2017). Following training and match play, decreased maximal voluntary force production, perceived fatigue, altered neuromuscular function and muscle soreness can last for several days (Deeley et al. 2022). When exploring this, it is important to include factors relating to common injuries in youth football, such as non-contact, traumatic injuries, as well as the mechanism of injury. For the purpose of this study, the following factors have been chosen to assess physical fitness in relation to the demands of the sport and common injuries:

1. Eccentric Hamstring Strength
2. Sprint Speed
3. Anaerobic Speed Reserve and subcategories -
    a. Maximal Aerobic Speed
    b. Maximal Sprint Speed
4. Neuromuscular Power (NP)

Eccentric Hamstring Strength

The hamstring muscles have been identified as being one of the most common time loss injuries in football, resulting in significant absence and often financial detriment at all levels (Suarez-Arrones et al. 2019; Bautista et al. 2021; Bishop et al. 2022). Bishop et al. (2022) identified footballers as commonly experiencing reinjury, especially to the hamstring, which represent 37% of all injuries in a football season. For athletes under twenty, this percentage is somewhat lower, however in this demographic hamstring injuries still represent a large proportion of injuries (Ribeiro-Alvares et al. 2020). On average, hamstring injuries result in a three-match absence, reducing availability and exposure for football players (Bishop et al. 2022).

Low eccentric hamstring strength (EHS) can indicate risk of reinjury, or future injury, to the hamstrings, and to other structures such as the ACL (Bautista et al. 2021; Suarez-Arrones et al. 2019), with 30% of footballers who sustain a hamstring injury being found to have history of injuries to that muscle group (Ribeiro-Alvares et al. 2020). Due to the biomechanical and physiological requirements of football, namely sprinting, participants often become "quad-dominant", with players developing a high quadriceps: hamstrings ratio (Ribeiro-Alvares et al. 2020). Bishop et al. (2022) highlighted the importance of measuring and improving EHS in footballers due to the incidence and risk associated with the injury. Markovic et al. (2020) found EHS in the PDP to be significantly lower than in senior football, with the average for the stronger leg being 287±50 N for youth players, and 336±58 for senior players. For players in the YDP, there was minimal difference between scores there and PDP scores, with the U16s age group scoring higher than the U18s (300±64 for stronger legs).

Often a between limb asymmetry of over 15% can indicate risk of a hamstring injury in professional football (Bishop et al. 2022; Ribeiro-Alvares et al. 2022). In the research by Markovic et al. (2020), bilateral asymmetry was 11.4% ±3.6 for PDP players, whereas senior footballers had a lower asymmetry of 8.1% ±8, indicating a decrease in injury risk from this perspective. This risk can be reduced through isolating the hamstrings in eccentric exercises such as the Nordic Hamstring Exercise, commonly used as a method of injury prevention in both senior and academy football, often highlighted for use in youth football (Bishop et al. 2022). The Nordic Hamstring Exercise (NHE), often referred to as the Nordic Hamstring Curl, is valid and reliable method of increasing hamstring strength, reducing risk of injury, and of measuring EHS at both a bilateral and unilateral level (Bishop et al. 2022; Markovic et al. 2020). Increasing eccentric hamstring strength has been found to reduce the incidence of hamstring injury through lengthening the biceps femoris fascicles by up to 2cm and causing further muscle structure adaptations (Suarez-Arrones et al. 2019; Pasanen et al. 2015; Ribeiro-Alvares et al. 2020; Bishop et al. 2022).

Maximal Sprint Speed

The sport of football has an intermittent structure, with athletes completing repeated high-intensity efforts interspersed with periods of lower intensity activity (Grgic, Lazinica and Pedisic 2021). Therefore, players need to be able to accelerate quickly and maintain high sprint speeds for short bursts, whilst decelerating regularly and managing at a steady aerobic state (Grgic, Lazinica and Pedisic 2021).

Maximal sprint speed is the point where an athlete no longer accelerates and has reached their peak running speed (Sandford et al. 2019). Reaching maximal sprint speed in training sessions has been shown to reduce injury for footballers, and determine the efficacy of training sessions (Massard, Eggers and Lovell 2018). If the implementation of maximal speed sprinting is done appropriately in training sessions, being employed in conjunction with the application of other load types, such as acceleration, aerobic work and explosive training, (i.e shooting), positive function can occur over time (fitness) (Gabbett et al. 2016; Hulin et al. 2015; Massard, Eggers and Lovell 2018). This relies on practitioners being able to monitor and apply load appropriately for the athletes they are working with, as discussed previously.

Maximal sprint speed (MSS) is usually reached between 20m and 40m of a sprint episode, with the first 5-10m often being the acceleration phase (Al Haddad et al. 2015). Generally, in youth football older players are expected to achieve higher sprint speeds due to biological maturity levels, strength, psychology and overall physical fitness (Al Haddad et al. 2015). MSS in youth footballers (U19s) has been found to be $8.71 m/s^2$ (Al Haddad et al. 2015; Buchheit 2010), and found to be between 8.31m/s and $8.56\ m/s^2$ in senior football (Massard, Eggers and Lovell

2018; Ortiz et al. 2018). Brocherie et al. (2015) found a slight decrease in MSS following repeated sprint training, from 8.61m /s to 8.52 m/s, however the significance of this change

Maximal sprint speed can be assessed through various methods, with the gold standard being radar guns, often used to measure the speed of cars (Talukdar, Harrison and McGuigan 2021). Dual-beamed electronic timing gates have been found to give similar levels of reliability and validity as radar guns, used to measure sprint speeds over a set distance, with a beam being broken at the start and end of the sprint by the athlete running through (Al Haddad et al. 2015).

Maximal Aerobic Speed

Maximum Aerobic Speed (MAS) occurs when an athlete reaches maximal oxygen uptake and is unable to take any more oxygen onboard – referred to as VO_2 Max – and reaches their maximum speed before anaerobic speed reserve is employed (See Anaerobic Speed Reserve) (Buchheit 2010; Grgic, Lazinica and Pedisic 2021). Analysis of MAS has been found to correlate with 20m flying sprint times, agility and repeated sprint times (Grgic, Lazinica and Pedisic 2021),

Anaerobic speed reserve (ASR) represents the variation between maximal aerobic speed (MAS) and maximal sprint speed (MSS), or "the speed zone ranging from velocity at maximal oxygen uptake (VO_2 Max) to the maximal sprint speed (MSS) (Sandford et al. 2019; Ortiz et al. 2018) Whilst there may be similarity between athletes' MSS scores, MAS variation can trigger discrepancies in exercise tolerance, and thus alter injury risk (Ortiz et al. 2018). Buchheit (2010 p.3) produced a diagram which explains ASR, and the affect increased maximal sprint speed can have on this (figure 7)

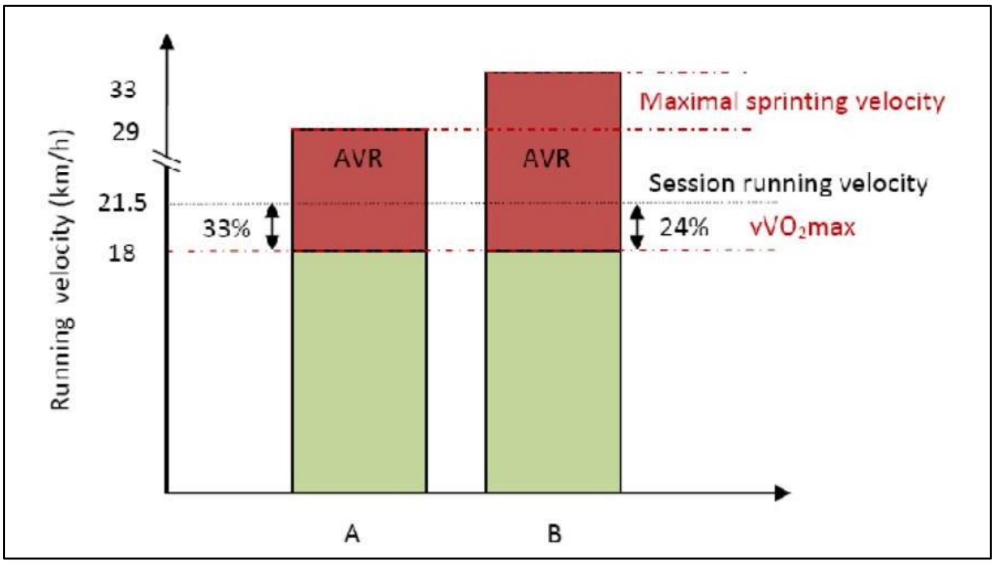


Figure 7 Athletes have similar MAS scores, but one has higher MSS. During high intensity sprint training, player B will work at a lower % of their ASR (in this figure AVR - Anaerobic Velocity Reserve)

Anaerobic speed reserve was found to indirectly correlate with anaerobic capacity and neuromuscular qualities such as CMJH and change of direction (Buchheit 2010). Buchheit (2010) identified that players with poor COD skills will have poor running economy, and therefore have lower VO_2 Max and lower maximal sprint speeds.

Laux et al. (2015) identified an association between recovery rates and risk of injury, finding that higher levels of injury risk are caused by decreased heart rate recovery rate, which in turn has ASR negatively (Reinhardt et al. 2020). Increased sprint speeds are associated with decreased ASR, which in turn has an inverse relationship with recovery rate, therefore reducing injury risk (Laux et al. 2015; Reindhart et al. 2020; Buchheit 2010; Del Rosso, Nakamura and Boullosa 2017).

Neuromuscular Power

High intensity intermittent sprints (or shuttle runs) put strain on the neuromuscular system through repetitive acceleration, deceleration and change of direction, and can be associated with increased energy cost (Buchheit 2010). This can result in fatigue, which reduces the function of the neuromuscular system and perceptions of muscle soreness (Deeley et al. 2022). Additionally, common injuries in football such as hamstring or ACL injuries are multifactorial, due to anatomical, biomechanical, and neuromuscular factors (Pasanen et al. 2015; Bahr and Krosshaug 2005). Lower extremity strength and neuromuscular control can counterbalance poor biomechanical patterns and joint stability, which otherwise would leave an athlete susceptible to injury (Pasanen et al. 2015) When an athlete is in a fatigued state due to a high ACWR, they will experience decreased peak force sand eccentric function across all structures, reducing eccentric muscle and neuromuscular function, indicating higher risk of injury (Rago et al. 2018). Therefore, it is important for athletes to have high neuromuscular function to reduce injury risk (Pasanen et al. 2015; Buchheit 2010), with Arnason et al. (2004) and Deeley et al. (2022) highlighted those with lower scores for jump height have higher injury incidence. In previous studies, jump height has been identified countermovement jump as a way of measuring jump height and, although Rago et al. (2018) and Deeley et al. (2022) indicate that it is not appropriate to use jump height as a standalone measure, and that a battery of tests should be used to assess physical fitness from a neuromuscular perspective. 24 hours after a training session, jump height was found to still be 5% lower than baseline scores, with muscle impairment still present up to 72 hours post-training (Deeley et al. 2022). This indicates that the fatiguing effects of training sessions are still present when an athlete has another training session or match, and therefore are more likely to experience injury.

Statement of the Problem

Previous literature has explored injury burden in depth in senior, professional football, finding the above-discussed physical fitness parameters to be contributors to injury risk (Pulici et al.

2022; Van Beijsterveldt et al. 2014), with more recent studies beginning to examine the variances found in youth football (Light et al. 2021; Tears, Chesterton and Wijnbergen 2018; Bult, Barendrecht and Tak 2018; Patel, Yamasaki and Brown 2017; Gabbett et al. 2014). Under 21's footballers experience the highest levels of injury, when compared to other YDP and PDP ages, and over 21's (men's) football, with 84.7% of these injuries being lower limb injuries, however these findings were in elite academy football. Non-league football is often overlooked, with Gabbett et al. (2014) highlighting a lack of consistency in the prescription, duration and evaluation of sprint and strength and conditioning programmes in adolescent football. This contributes to the increased difficulty to research the effects of physical fitness parameters across an entire population, as each club's athletes will be exposed to a different programme, and therefore different training loads, thus meaning results are not always able to be applied to the entire population (Gabbett 2014). Despite this, due to the increased incidence and severity of injuries, training exposure and load in the PDP compared with the YDP, more research needs to be done to ensure players transitioning from academy to senior football have the support they require (Light et al. 2021).

Aside from the increase in training load, athletes in the PDP are also expected to change psychologically to prepare for the leap to senior football, (Røyhesdal, Toering and Gustafsson 2018). Often players are expected to conform to the norms of senior football, including subconscious over-conformity to the sport ethic, specifically playing through pain (Røyhesdal, Toering and Gustafsson 2018). Røyhesdal, Toering and Gustafsson (2018) highlighted the cultural gap between youth and senior football may be a cause for anxieties for players, and with stress being a risk factor for injury, these athletes are put at risk once more. Therefore, the chosen population for this study is youth team players, aged 16-19.

The Present Study

The current study is using a prospective cohort study design to assess the change in physical fitness levels across a season at different time points, and to determine whether these changes influence injury burden and availability for players. Longitudinal study designs such as this one allow assessment over several time points of the same sample to explore the change at an individual level, whereas cross-sectional studies only take snapshots of data using different samples, giving the results of change at a group level, such as the study by Chan, Wong and Wang (2020). A cross-sectional study could be employed, however this would not allow for the collection of data at multiple time points using the same sample and would limit the findings of the study, whereas a prospective cohort study will allow change in the independent variables to be examined and the effect of this change explored in the context of the dependent variables. (Bult, Barendrecht and Tak 2018; Chan, Wong and Wang 2020).

Study Aims & Hypotheses

The aims of the present study are:

i) To investigate and examine injury incidence in male, non-league, youth footballers

ii) To examine the relationship between physical fitness factors and injury burden in male youth footballers in a non-league football club from pre-season to the mid-season.

The hypotheses for this study are:

1. Physical fitness levels influence injury burden negatively in male youth

football players in a non-league football club (as physical fitness increases, injury burden decreases)

2. There will be significant decrease in physical fitness levels over a playing season for male, youth football players in a non-league football club, measured through decreased neuromuscular power, eccentric hamstring strength, and anaerobic speed reserve and the associated subcategories.

Methods

Study Design

This study followed a prospective cohort study design, following the participants across a season of non-league, youth football, inclusive of pre-season, being longitudinal in nature (Bult, Barendrecht and Tak 2018). Pre-season was included as injuries sustained in this time period can be a) carried into the start of the season and b) injuries sustained here can be indicative of future injuries (reinjuries) during the season. Pre-season lasted from the 10th of July 2022 to the end of August 2022, with the first pre-season game being on the 16th July. The season started on the 1st of September 2022, with the first game being played on the 13th September 2022. The Christmas break lasted for 2 weeks, with players returning on the 3rd of January 2023. Due to match cancellations and rescheduling, the season lasted a month longer than anticipated, with the expected finish being in April, and the actual end of season being in May. Testing took place in July 2022 to collect baseline data, in line with regular club testing and in March 2023 to assess late season data. A final testing data was initially scheduled at the end of the season, however due to the longevity of the season resulting in players being released almost immediately at the end, this was not possible to complete and acquire substantial data for the study. Therefore, only two fitness testing dates were completed, one in the preseason, and one mid-season.

Ethical Permissions

Ethical permission was granted in line with the Declaration of Helsinki through York St. John University, via the School of Science, Technology and Health Research Ethics Committee. The ethics reference number for this study is: STHEC0065, and ethical permission to carry out this study was granted in August 2022, following the start of preseason. At this time, injury reporting had already begun in line with the club's structure, and this was subsequently added to the study.

Every participant gave informed consent following a discussion about the study and its implications. Participants were aware that data could inform their training development and collection would coincide with their regular training schedule, however was not to negatively impact their playing experience.

When working with participants under 18 it is important to ensure informed consent comes from both participant and parents/ carers, and that the health and wellbeing of the participant comes first. Therefore, if players were experiencing injury or illness at the time of testing, they were excluded from this to ensure their health was protected. All data collected was collected and stored in line with GDPR guidelines and the club's policy, being stored on a password protected laptop, and any physical reports of data being stored in a locked filing cabinet in a locked medical room. All involved in the research and club practitioners were required to have a DBS certificate and safeguarding certificate to comply with legal safeguarding requirements.

Participants

24 male U19 youth team football-scholars (Age 17± 0.91; Height: 181.22 ± 6.7cm; Weight: 73.51 ± 6.9kg) were selected for this cohort sample. Due to the nature of non-league academy football, some players may be on loan to other clubs and subsequently not available for every training session or match. Consequently, numbers reduced to 20 participants at the end of the season.

As scholars, participants are required to attend college classes twice per week. The team played in the National League U19 Alliance, the National League Academy Cup, and the FA Youth Cup. Four participants had contracts signed with the first team, and so were exposed to other training and match loads through a) first team appearances and training and b) loan club appearances and training. These appearances (games and training for the first team or other clubs) occurred instead of the players' regular training with the youth team, and therefore were included in calculations for exposure. All participants were post-PHV at the time of first data collection (July 2022).

Club Structure

The youth team had access to a part-time sports therapist who worked exclusively with the team, the club head Sports Therapist who worked mainly with the first team but was available for the entire club, and the head of medical, who was on hand to see players when needed, working at multiple clubs. Additionally, participants had access to strength and conditioning facilities, including trained strength and conditioning staff external to the club. They were coached by the youth team manager with input from other club staff such as the head of youth development, goalkeeper coach and other support staff.

Reporting Injury

All injuries and complaints were required to be reported to the club medical team on the day of incidence, or next training session via text or in person. Cross et al. (2018) found that use of a 24-hour time loss definition increases the number of reports of injury in a team, and therefore increases reliability of reporting. Players were all asked about injury at the start of the training session, with half an hour allocated for injury assessment prior to training for players who could potentially train after assessment. At the start of the season, all players were educated on the injury reporting system, which at the time included a health monitoring survey completed every week on the Monday before training about injuries or issues the previous week, in line with the Orchard Sports Injury and Illness Classification System (OSIICS) (Orchard et al. 2020).

However, compliance with this was low and following the attempted implementation of this until December, it was removed as a reporting variable due to underuse; it was found that players were more likely to report injury in person or via text to the medical team than via a survey. Compliance became as low as one participant completing each week, with the entire sample completing both surveys for only a 3 week period at the start of the season. When a player was diagnosed with an injury, the medical team passed the information onto the coaching team alongside an estimated time loss and any recommendations. The player would then remain in rehab for the necessary time, with return to sport criteria to be met and assessments completed prior to integration back into the training structure. Players were required to complete both physical and psychological assessments at various stages of the rehabilitation process, dependent on the injury. Injuries were classified by their body part, tissue type and pathology type, and successively their severity. Additionally, injury mechanism (contact or non-contact) and type (overuse or acute) were recorded.

Inclusion and Exclusion Criteria

Players who were a part of the youth team were all eligible for inclusion at the start of the season. Those who were not available for all testing dates, or who were released prior to the end of the season were excluded due to the potential for incomplete data. 4% of players were released in the February, and 13% were unavailable for all testing dates due to illness, injury and commitments to loan clubs, resulting in 83% of the initial sample remaining (n=24-4; n=20).

Exposure

Individual football exposure was monitored through an attendance record. This included information about players absent due to illness or injury or other reason i.e loan. (Ekstrand, Sprecco, Bengtsson and Bahr 2021).

Each participants had potential exposure to three training sessions (240 minutes each) and one game (90 minutes) as part of their pre-determined training. Due to changes in match schedule and cancellations, towards the end of the season there was potential exposure to 2 games a week. Preseason lasted across July and August, with the main season spanning between September and May. Across the season there were 133 training sessions (28 preseason; 105 in-season), and 39 games (5 pre-season, 34 in-season).

Exposure refers to the number of hours athletes had potential to engage with across the season, being calculated as follows:

Training Exposure =

Number of Training Weeks x Number of Players Exposed x Weekly Training Time (mins) Beech et al. (2022)

Match Exposure =

Number of Matches x Number of Players Exposed x Match Duration (Beech et al. 2022)

Training Exposure was calculated to be 66240 hours, and Match Exposure was calculated to be 70200, with overall Exposure being 732600 hours.

Measures

Anthropometric Measures

Standing height was calculated by the participant removing footwear and wearing light training clothing, standing on a flat surface with their heels against a wall, using a body height metre. Participants were stood erect with their feet flat, heels together and head in the Frankfort horizontal plane, and height was measured to the nearest millimetre (mm). Weight was measured on a digital scale (Salter, Manchester, United Kingdom) which was zeroed to calibrate it before measurement, measured to the nearest gram (g). For both heigh and weight, three measurements were taken to ensure accurate data was collected, and if not aggregable a fourth measurement was taken to reduce anomaly. Age was recorded at both testing points, with data from the first session being reported.

Dependent Variables

Definition of Injury

For the purpose of this study, an injury is defined as any injury occurring from football training or match play, which results in the athlete being unable to participate in future training or match play for at least one session (Light et al. 2021).

Injuries were recorded at time of incidence, with diagnosis including location, type (traumatic or overuse), mechanism (contact or non-contact). Severity was recorded when players returned to sport, with estimations of time to be lost recorded at injury diagnosis.

Players were considered "injured" until cleared for full participation by either the head sports therapist, first team sports therapist or youth team sports therapist. Full participation included training and match play without compensation (Ekstrand, Sprecco, Bengtsson and Bahr 2020).

Injury Incidence

Injury incidence refers to the number of injuries and illnesses sustained across a team per 1000 hours of football exposure (Light et al. 2021). The exposure consists of all planned training and match situations, but does not account for any external exercise players may have done, due to the fact that they were not advised to do any extra training outside of their scheduled hours at the club, and so was not measured. . The equation, as discussed prior, is:

((∑ injuries/ ∑ exposure hours) x 1000) (Light et al. 2021; Hägglund et al. 2013)

Injury incidence was calculated across the whole team, and for each individual.

Injury Severity

Injury severity refers to the amount of time lost per injury, determining how detrimental it was. For the purpose of this study, injury severity has been graded using adaptations of the recommendations by the FSE-IOCC, informed by recent research to give four categories of severity:

Minimal Injury: *"Injury causing absence of 1-3 days from training and match play"*

Mild Injury: "*Injury causing absence of 4-7 days from training and match play"*

Moderate Injury: *"Injury causing absence of 8-28 days from training and match play"*

Severe Injury: *"Injury causing absence of over 28 days from training and match play"*

(Light et al. 2021 p.1236; Tears, Chesterton and Wijnbergen 2018; Hägglund et al. 2005).

The day of injury incidence is deemed as the first day lost due to injury, and final day of absence is the day before the athlete fully reengages in training without adaptation or concern (Return to Training/ Return to Sport – RTT/RTS) (Light et al. 2021).

Injury Burden

Injury burden takes injury severity and calculates the strain it can put on a team as a whole. Hägglund et al. (2013) identified injury burden as being the number of injury days lost per 1000 hours of exposure (severity/ exposure), using the equation:

$$((\sum \text{days lost}/ \sum \text{exposure hours})/\text{x}1000)$$

(Ekstrand, Spreco, Bengtsson and Bahr 2020; Haaglund et al. 2013)

Injury burden was calculated for the team, and for each individual.

Availability

Ekstrand, Spreco, Bengtsson and Bahr (2020) identified overall availability as being the average percentage of players available for training and match selection, excluding players who were injured, ill, or away on national team duty or other reason. Match availability across a season was recognized by Hägglund et al. (2013) as being the opportunity for matches minus match absences as a percentage, with the same for training, shown in the following equations:

Match Availability:

$$((\sum \text{player match opportunity}) - (\sum \text{match absences})) \text{ x } 100$$

Training Availability:

$$((\sum \text{player training opportunity}) - (\sum \text{training absences})) \text{ x } 100$$

Independent Variables

Gabbett et al. (2014) conducted a systematic review, investigating physical performance and injury in adolescent male football players, and found several reliable and valid measures to assess physical performance. Key methods included sprints and repeated sprints, countermovement jumps, strength and power tests and sport-specific assessments, which have all been selected as variables for this study, with the appropriate measures (Gabbett et al. 2014).

Warm Up Protocol

Before every training session, match and testing, participants completed an adapted version of the FIFA 11+ warm up (FIFA 2006). Two lines of 5 cones 6m apart (2 x 24m lines) were laid out. Participants completed the heart raising activities to the end of the line, and used a recovery jog back to the start to incorporate mobile stretches. Figure 6 shows the warm up used by participants.

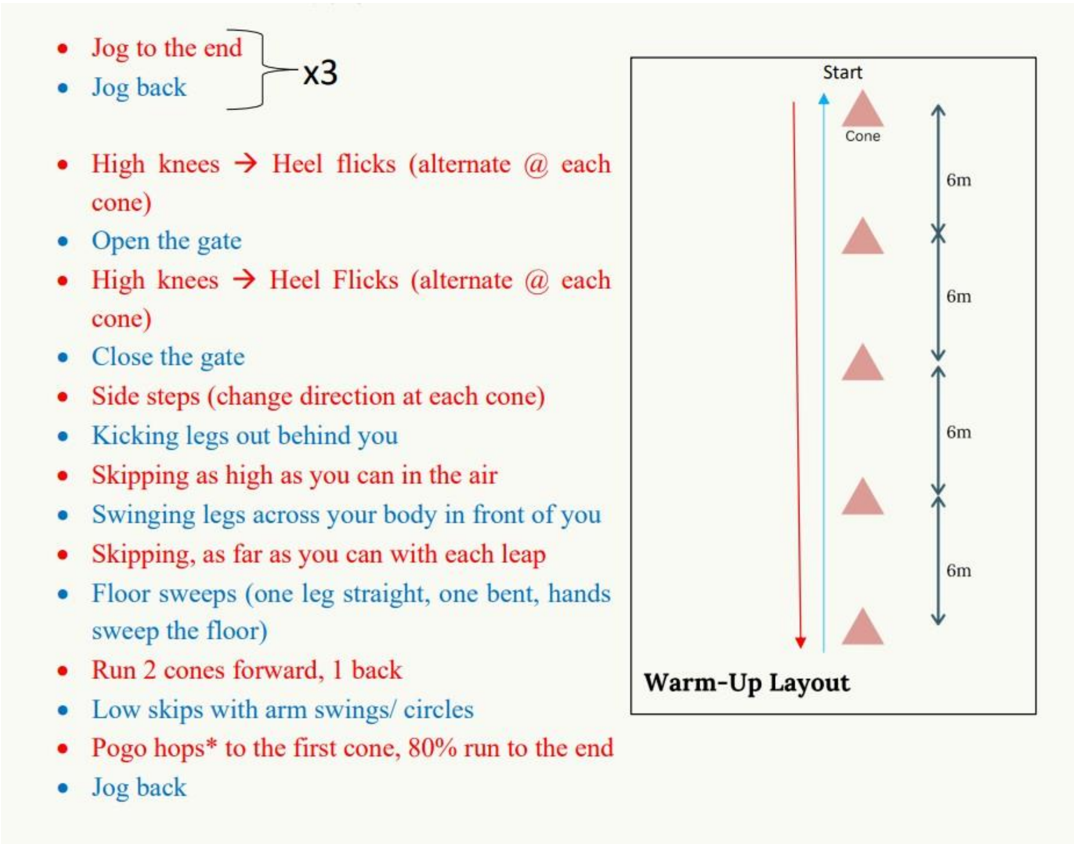


Figure 8 - Warm Up Protocol for Study Participants

Following this, mobility work was incorporated using spinal twists, deep squats, kneeling TFL stretch into a hamstring stretch, calf stretches and Cossack squats. Load acceptance was then completed, consisting of 10 x double leg to double leg 180° jumps, then 10 x 90° hops from double leg to single leg, 5 on each leg, and then 20 lateral hops over a 20cm space, and 20 forward and backward hops of a 20cm space. Finally, players would engage in increasing speed activities, running the line of cones three times to build up to 95% speed.

This warm-up was familiar to participants and was led by the youth team sports therapist at every session to ensure consistency and compliance.

Countermovement Jump

The countermovement jump (CMJ) was selected as a measure of physical fitness, measuring power performance, and variability to that, fatigue and risk of injury (Merrigan, Stone, Hornsby and Hagen 2021). Rago et al. (2018) identified CMJ as being the easiest of jump protocols to perform, both from an athlete and practitioner perspective. CMJ is quantified by jump height (JH) and/ or flight time (FT), which are both indicators of vertical jump performance, and can be used together or separately to measure this. However JH and FT have been deemed not suitable to be used as stand-alone measures of neuromuscular function to indicate physical fitness, hence the use of multiple variables to assess physical fitness in this study, such as EHS and ASR(Rago et al. 2018). Motion capture and force plates are deemed the "Gold standard" of measuring CMJ, however these are not always accessible due to location and financial parameters (Rago et al. 2018). Therefore, the "Optical Equipment with Light-Emitting Diodes" or "Optojump" was used for this study (Optojump, Microgate, Bolzano, Italy). The Optojump consists of two bars, one metre apart, 0.3cm above the ground, and with 33 optical LEDs in each bar, spaced 3.125cm apart (Rago et al. 2018). One bar acts as the transmitter, and the other as the receiver, with any break in the beam automatically activating a digital chronometer, which calculates JH and FT (Rago et al. 2018). Rago et al. (2018) highlighted that whilst JH and FT are both measured by the Optojump, FT is recommended to be used over JH due to its direct measurement, and reduced risk of error from calculation with JH being a calculation of FT squared.

In the study by Rago et al. (2018), which compared transportable methods of measuring CMJ, only the Optojump provided valid and reliable results that matched the gold standard of force plates for FT, with JH also found to be reliable and valid (r =.98). There has been found a .99 correlation coefficient between Optojump and force plates as a means of measuring CMJ, with low error between repetitions for both (Rago et al. 2018).

The countermovement jump was carried out with the participant standing straight, with their feet hip distance apart and toes facing forwards. With hands on their hips to prevent arm swing, participants were told to “jump as high as possible” for one maximal jump, and “try and minimise your contact time on the ground” for a series of 10 maximal repeated jumps to eliminate variability and anomalies from a single jump performance (Rago et al. 2018; Deeley et al. 2022). Prior to the test, a practice jump was conducted where participants mimicked the jump protocol for familiarisation. Any jump where the participant did not comply with the instructions given was disregarded, and repeated after rest to reduce anomalous results. For the purpose of this study, flight time and ground contact time were collected to calculate jump height for use as an independent variable (Rago et al. 2018).

30-15 Intermittent Fitness Test

The 30-15 test was created in 2000 by Martin Buchheit, and first used as an “official” test in 2002, by the Young Women’s French National Handball Team. Its creation came from a need for a more specific test to assess intermittent fitness in sports such as handball, football and futsal (Buchheit 2010). Intermittent exercise is characterised by increases in oxygen consumption, heart rate and blood lactate concentration, with decreased pH in both blood and muscles (Grgic, Lazinica and Pedisic 2021). Additionally, intermittent exercise often sees Change of Direction (COD), and variation of use of anaerobic and aerobic capacity (Buchheit 2010). Including the 30-15, several other tests such as the Yo-Yo Intermittent Recovery Test and 20m Shuttle Run Test can test for intermittent fitness, however blood lactate levels and oxygen consumption need to be measured through more lab-based measures, such as using gas analysers and blood tests. The 30-15 has been developed as a proven highly reliable and valid test, on par with the Yo-Yo test for reliability, however validity has been proven across numerous sports, fitness levels and ages (Buchheit 2010).

Participants complete 30s shuttle runs between two lines, 40m apart, with 15s active recovery (walking) between each run. The starting speed is 8km/h, however can be 10 km/h or 12 km/h for well-trained athletes; speed increases by 0.5 km/h per stage. The speed is dictated by a pre-recorded beep which signals the start of the stage, a warning before the end, and the end of stage (start of active recovery). Participants walk forwards towards the next line to begin the next stage from that point. If participants fail to make the "3m zone" before the line on three successive occasions, or stop due to fatigue, the test is terminated (Buchheit 2010; Grgic, Lazinica and Pedisic 2021).

This test reflects more than straight line and continuous running tests, with aerobic and anaerobic fitness being assessed alongside change in direction and neuromuscular qualities and inter-effort recovery ability (Buchheit 2010). However, it must be noted that for accuracy these factors should be assessed by multiple tests in some cases (Buchheit 2010).

Buchheit (2010) stated during testing VO_2 max is often reached before the end of the test; the lowest speed at which VO_2 Max is reaches is referred to $vV0_2max$, or maximal aerobic speed (velocity), which may result in players using anaerobic reserves to complete the stage. vVO_2 max itself can only be measured through gas analysis, however Maximal Aerobic Speed is measured through the score from the 30-15IFT, as an entire stage is not completed using anaerobic reserves (Buchheit 2010; Grgic, Lazinica and Pedisic 2021).

The highest stage reached by each participant was recorded in km/h, then changed to m/s in line with units for this study, by use of the equation:

Speed (m/s) = Speed (km/h) / 3.6

Sprint Performance Indicators

Maximum Sprint Speed (MSS) was assessed through repeated 40m sprints wherein 20m sprint time was gathered, completed outdoors on a 3G surface in suitable weather conditions (i.e negligible wind and sun). Photoelectric cell timing gates (Witty, Microgate, Bolzano, Italy) were placed at the start point (0m), 5m, 10m, 20m and 40m intervals, following previous studies' procedures (Al Haddad et al. 2015; Massard, Eggers and Lovell 2018; Buchheit et al. 2014; Suarez-Arrones et al. 2019).

Participants began the test from a standing static start, with their front foot 0.5m behind the first timing gate. Time started when the beam between timing gates was broken, meaning participants could start in their own time, reducing error from reaction time. Participants were instructed to sprint at their maximum speed for the full 40m, and repeat the test with sufficient rest time between each trial (2 minutes+).

Maximum Sprint Speed (MSS) was measured using a radar gun (Stalker ATS ProII; Applied Concepts, Plano, TX, USA), and sprint speeds for 20m were measured. The researcher held the trigger for the gun when the participant was past the 20m mark, and held until they passed the next mark, and a top speed was indicated on the screen and recorded to the nearest 0.1m/s. An average of each sprint time (to the nearest 0.1s) and MSS (to the nearest 0.1m/s) was calculated following all three trials. MSS was measured between 20-40m as this has been identified as the area where top speed is achieved, whereas between 5-10m is where maximal acceleration occurs (Al Haddad et al. 2014). Sprint speed and time in the 5-10m area was not recorded, as acceleration was not measured for this study due to the nature of it being determined to different biomechanical and physiological parameters to MSS (Al Haddad et al. 2014).

Use of radar gun and timing gates were selected over GPS due to previous findings of inaccuracy with GPS (Massard, Eggers and Lovell 2018). When compared with the gold standard of radar gun, GPS has been found to measure MSS at a lower, and therefore less accurate speed, than timing gates, which has been proven to be both a reliable and valid way to measure MSS and sprint speeds (Massard, Eggers and Lovell 2018; Talukdar, Harrison and McGuigan 2021; Zabaloy et al. 2021). Previous studies have measured MSS through GPS during match play, however it has been found that during match play MSS achieved is 90% lower than during standardised testing such as 40m sprints, due to the tactical constraints of games never allowing absolute maximal speed to be attained (Massard, Eggers and Lovell 2018; Mendez-Villanueva et al. 2011). Additionally, it is not possible to get an accurate reading of sprint speed from a standing start, due to the requirement of acceleration across the first 10m, requiring an acceleration zone to be added for this purpose (Massard, Eggers and Lovell 2018). Therefore, measuring MSS through 20m sprint times across a 40m distance with timing gates and radar gun is the most reliable and valid method to give accurate results for this study.

Anaerobic speed reserve (ASR) represents the variation between maximal aerobic speed (MAS) and maximal sprint speed (MSS) (Figure 5) (Sandford et al. 2019). ASR can be measured through translating MSS and MAS scores into m/s from their standard units, and then calculating the difference between the scores, displayed in m/s (Sandford et al. 2019). ASR indirectly correlates with heart rate recovery, and also with anaerobic capacity and neuromuscular qualities such as CMJH and change of direction (Buchheit 2010; Del Rosso, Nakamura and Boullosa 2017).

Eccentric Hamstring Strength

Eccentric hamstring strength (EHS) has been found indicative of future injury to the hamstrings themselves and other structures such as the ACL (Bautista et al. 2021; Suarez-Arrones et al. 2019), and was selected as a measure based on previous research. Suarez-Arrones et al. (2019) and Bautista et al. (2021) found EHS to correlate with both injury risk and sprint time, with both studies finding significant improvement in 20m sprint times after the implementation of an eccentric hamstring strengthening program. These programs used the Nordic Hamstring Exercise (NHE) over a period of several weeks in football, an exercise used to measure EHS through use of a “Nordbord”.

The EHS test was completed following protocol from previous research, using the NHE on a

Nordbord (Vald Performance, Newstead, Australia). Participants were positioned in a kneeling position on a padded board, with their ankles secured just superiorly to the lateral malleolus by individual ankle braces (hooks) that were attached to uniaxial load cells with wireless data acquisition capabilities (Suarez-Arrones et al. 2019; Bishop et al. 2022). The Nordbord allows for real-time data collection of both peak and mean force generated by both limbs, and allows comparison between player and limb strength (Bishop et al. 2022).

The "Gold-Standard" for measuring EHS is an isokinetic dynamometer (IKD), however this is not portable, can be time consuming and expensive (Bishop et al. 2022), therefore cannot be accessed by all sports teams, and is thus harder to compare results between studies with different measures being used. For this study an IKD was not available to allow measurements to be completed within the time constraints and to allow comparison between studies. Handheld dynamometers are portable versions of IKDs, however use of these requires both strength and skill, and cannot always be reliable as a result (Bishop et al. 2022). Use of the Nordbord as a measure of EHS has been found to have moderate-high between-session reliability (0.63-0.87), with absolute reliability being high, subject to an appropriate introduction and familiarisation with the testing protocol and exercise (Opar et al. 2013; Bishop et al. 2022).

Data Collection

Data was collected across a full playing season inclusive of pre-season (July-May), with a one-week break at Christmas. Injury data was collected continuously by the sports therapist as outlined above. Physical fitness parameters were measured at two points throughout the season: pre-season and middle season. The second time point was selected to be before players started to be released at the end of the season, and at a point where they did not miss training when the game frequency was high. A third time point would have benefited this study, however due to time constraints from the club, the scheduled end of season time point did not happen.

Data Analysis

There were several steps to analysing data. First, data was entered into an excel spreadsheet during collection, where it was screened for anomalies and missing results following collection. Any incomplete data was removed, and participants excluded from the study following the inclusion criteria.

Second, an injury audit was conducted, wherein all injuries were classified via their:

- Type (Contact or Non-contact)
- Onset (Traumatic or Overuse)
- Location (head/neck, thoracic region, upper limb, thigh/groin, hamstring, knee, calf/Achilles, ankle)
- Severity (Minimal, Mild, Moderate, Severe)

Additional information collected included:

- Time of injury (Pre-Season, Early Season, Mid Season, Late Season)
- Tissue Type (Muscle, ligament, tendon, bone, brain, cartilage)
- Pathology (strains – inclusive of all muscle tears barring ruptures, sprains – inclusive of all ligament tears excluding ruptures, ruptures, contusions, concussions, bone bruises, fractures, tendonitis and lacerations)

Exposure was calculated for both training and matches, at both team and individual levels in line with equations discussed in the “methods” section. Availability was calculated for training and matches, and reported at an individual level, with overall availability for the whole team across all activities, at match level, and at training level.

Following the calculation of injury incidence and burden at both individual and team level, all data was entered into Jasp (2023; Version: 0.17.2.1, Netherlands).

Independent variables were: mean EHS right, mean EHS left, mean EHS average CMJH, 20m sprint times, MSS, 30-15, MAS, ASR. Each variable had data for time point one and two, the average across both time points, and the change from time point one to time point two.

Dependent variables entered were training availability, match availability, total availability, injury incidence and injury burden for each individual. Height and weight were also added to the data set for descriptive statistics.

Descriptive statistics were calculated for all variables, and a correlation matrix ran for all dependant and independent variables. Dependent t-tests were run to assess the change in size of height, weight, EHS average, EHS left and EHS right, 20m sprint times, CMJH , MAS, MSS and ASR from time point one to time point two.

Linear regressions were completed to assess the how the change in EHS, CMJH, 20m sprint speed and ASR affected the dependent variables of injury incidence, injury burden training availability and match availability. R^2 values were evaluated to assess the percentage of variance in the dependent variable(s) that can be explained by the independent variable(s), and how well this first the regression model (goodness of fit).

All data was rounded to 2 decimal places, and significance demonstrated as significant = α <.05*, moderately significant α <.01** or highly significant α <.001***.

Results

The following section explores the results of data collection and analysis. Here, background injury characteristics are described, including the injury audit and injury burden. Descriptive statistics, bivariate correlations and regression analyses are stated here.

Background Injury Characteristics

Injury Burden

Exposure was calculated for training, matches and as a total across both activities. Following previous research (Beech et al. 2022), calculations for exposure were the following:

Training Exposure =

Number of Training Weeks x Number of Players Exposed x Weekly Training Time

Match Exposure =

Number of Matches x Number of Players Exposed x Match Duration

Total Exposure =

[Training Exposure] + [Match Exposure]

Training exposure was 11040 hours across the season, with match exposure being 1170 hours, and total exposure equating to 12210 hours, inclusive of pre-season.

Injury Incidence

Injury incidence is presented as [number of injuries]/ 1000 hours football exposure, inclusive of training and match play. Overall injury incidence was calculated to be 3.44/1000 hours. Injury incidence was also calculated at an individual level, with the input into the exposure calculation being adjusted accordingly, which was calculated to be 0.15/1000 hours exposure per person.

Injury Severity

Injury severity was presented as the total days lost for each injury, classified as shown in table 1. Of all injuries, 36.84% were moderate (8-28 days absent), 34.21% were mild (4-7 days absent). 21.05% were minimal injuries (0-3 days absent), and 18.42% were severe, with over 28 days absent.

Injury Burden

Injury burden was calculated as the ([Total days lost/ Total exposure] x 1000), as identified by Beech et al. (2022). Injury burden was found to be 56.35 days absent per 1000 hours exposure for the entire team. Injury burden per individual was calculated as well, with the mean burden being 2.39 days/ 1000 hours.

Injury Audit

Inclusive of pre-season, there were 38 injuries across the team, or 1.9 per person, with 11 being in pre-season (July-September) (28.95%), 7 early season (September-November) (18.42%), 18 Mid-Season (December – March) (47.37%) and 6 late season (March – May) (15.79%). Injury data is available in table 1.

Table 1 -Overview of Injury Statistics

Location	**Total**	**Onset** Overuse	Traumatic	**Type** Non-contact	Contact	**Severity** Minimal	Mild	Moderate	Severe
Head/ neck	n=4		n=4		n=4		n=3	n=1	
Thoracic	n=6	n=5	n=1	n=5	n=1	n=3		n=2	n=1
Upper limb	n=3		n=3		n=3	n=1			n=2
Thigh/ groin	n=4	n=2	n=2	n=3	n=1	n=1	n=1	n=1	n=1
Knee	n=3	n=2	n=1	n=3			n=2	n=1	
Calf	n=4	n=2	n=2	n=2	n=2		n=2	n=1	n=1
Ankle	n=6	n=1	n=5	n=5	n=1	n=1	n=1	n=4	
Hamstring	n=8	n=5	n=3	n=7	n=1	n=1	n=3	n=3	n=1
	38	**17**	**21**	**18**	**20**	**7**	**14**	**13**	**6**

36.84% (14) of injuries were contact and 73.68% (28) were non-contact, of which 28.57% (8) were of traumatic onset. Of total injuries, 55.26% (21) were traumatic, and 44.74% (17) were overuse, with all overuse injuries being non-contact. Moderate injuries were of the highest frequency (36.84%), followed by mild injuries (34.21%), minimal (21.05%) and severe (18.42%).

The most commonly injured body part was the hamstring (21.05%), followed by the ankle (15.79%), thoracic region (15.79%) lower leg (10.53%), quadriceps/ groin (10.53%), head/neck (10.53%), knee (7.89%) and the upper limbs (7.89%). All hamstring injuries apart from one were non-contact, occurring at various points of the season, however moderate and severe hamstring injuries occurred towards the start of the season, after pre-season. Of ankle injuries, all apart from one were of traumatic onset, with only one being a traumatic contact injury, the rest were non-contact, with a total of 66.67% being moderate in severity. Ankle injuries occurred throughout the season with no visible pattern of incidence. All lower leg (calf, shin and Achilles tendon) injuries occurred prior to the middle of the season Christmas break, with there being 50% contact, 50% non-contact, and the same split for traumatic and overuse injuries. All knee injuries were non-contact, all resulting in under a week of time-loss, with no knee injuries occurring in early to mid-season. Quadriceps and groin injuries covered a range of severities with all occurring before Christmas (pre-mid season), and 75% being non-contact. All upper limb injuries were traumatic contact injuries, with 66% being severe, occurring in the mid-season, with one upper limb injury occurred in pre-season, resulting in one day lost. 83% of thoracic region injuries were non-contact, overuse injuries, with none occurring in the late season. All head and neck injuries were traumatic contact injuries, occurring entirely in the middle of the season, with only one concussion occurring.

Upper limb injuries, although not the most common, were the most severe, with an average of 35.3 days lost, and a total of 106, whereas hamstring and ankle injuries, whilst the most common, were classed as moderate on average, resulting in less time lost (10 days and 12 days lost on average, and 79 and 85 total days lost, respectively). The mean severity for lower limb injuries was moderate, with 22 days lost on average, and knee injuries were on average classified as “mild” injuries, resulting in 4 days lost on average, with a total time lost being 13 days. Mean time loss for quadriceps and groin injuries was 16.5 days, with the total days lost being 66. Mean severity for thoracic region injuries was 19.83 days lost, however 50% were minimal (3-7 days lost), with only one being severe (68 days lost). A total of 119 days were lost due to thoracic region injuries. Head and neck injuries resulted in a total of 26 days absent, with an average of 6.5 days lost, which alongside knee injuries are the only injuries to be classified as “mild” on average.

38% of injuries were to muscle strains, with 32% being ligament sprains or ruptures. Ankles were the most common location for ligament tears, and the hamstrings were the highest injured muscle group. 16% of injuries were identified as affecting skeletal structures, with only one being a break, and one being a bruise. The remaining four were injuries to the back, inclusive of the spine through affects of muscle tension caused by overuse and hard playing surface. Three contusions occurred (8%), two intramuscular and one intermuscular, with the latter occurring as a reinjury. There was one tendon injury identified throughout the season, and one laceration.

Availability

Availability was calculated as a percentage of time a player was available for training or match play, with total availability also being calculated. As a team, the mean availability was 89.71%, with match availability being 93.72% and training availability slightly lower at 88.53%. Availability was calculated at an individual level for data analysis, based on individual exposure. Availability refers to the number of sessions a player attended, with non-availability being due to injury or illness, loan or other reason such as family bereavement. At times, some players would be selected to train with the first team, however they would still be available to train and present for half of the session, therefore this was not included in the exclusion criteria regarding availability.

Descriptive Statistics

Table 2 shows the descriptive statistics for independent variables assessed in this study. All variables were assessed at two time points, pre- and mid- season, labelled Pre-Season Score (A) and Mid-Season Score (B) respectively. An average of both these scores is also assessed here as “Mean Score”. MAS is calculated from the 30-15 score, with both being included to show the average score of the test, and then to show the average relating to a more generalized measure. Table 3 shows descriptives for dependent variables, showing the mean score for the group.

Table2 - Independent Variables Descriptive Statistics

	Mean Score	SD	Pre-Season Score (A)	SD	Mid-Season Score (B)	SD
Decimal Age	17.24	0.91	17.3	0.89	17.9	0.89
Height (cm)	181.17	6.8	181.22	6.75	181.12	6.71
Weight (kg)	73.32	7.1	72.94	6.88	73.7	7.5
EHS-R (N)	369.9	62.76	361.6	74.46	378.2	65.89
EHS-L (N)	326.4	52.08	331.35	54.21	321.45	59.61
EHS Average (N)	348.15	54.95	346.48	60.27	349.82	58.84
CMJH (cm)	38.44	6.25	44.28	7.95	32.6	5.81
20m sprint time **(s)**	2.99	0.12	2.96	0.12	3.02	0.14
MSS (m/s)	9.93	0.39	10.63	0.64	9.24	0.57
30-15 score	20.55	0.853	20.28	0.98	20.83	0.92
MAS (m/s)	5.71	0.24	5.63	0.27	5.78	0.26
ASR (m/s)	4.23	0.51	5.00	0.69	3.46	0.70

Table 3 - Dependent Variables Descriptive Statistics

	Mean	SD
Training Availability	88.53	8.84
Match Availability	93.72	6.08
Total Availability	89.71	7.92
Injury Incidence	0.15	0.11
Injury Burden	2.39	2.05

Correlations

The correlation matrix is presented in table 4, displaying relationships between variables. As expected, there are significant, positive correlations between all "same group" variables:

- EHS related variables (Eccentric Hamstring Strength Average – Left, Eccentric Hamstring Strength Average – Right, Eccentric Hamstring Strength Average – Overall Average)

- Sprint speed variables (20m speed, MSS)
- ASR and associated variables (MSS and MAS)
- Availability based variables (total availability, training availability, match availability)
-

Despite being highly significant, there was no linear correlation between CMJH and 20m sprint speeds (-.07***).

Anaerobic Speed Reserve (ASR) was, as expected through calculations, highly significantly highly correlated with MSS (.99**), with 100% correlation existing between 30-15 score and Maximum Aerobic Speed (1***), as follows from the calculation.

Regarding sprint speeds, ASR had a moderately sized and moderately significant correlations with 20m sprint speeds and 40m sprint speeds (-.58** , -.67**).

Injury Incidence was found to have a moderately significant, moderately correlated relationship with CMJH, with statistically significant, moderate correlations found between Injury Incidence and 30-15 average (-.52*), and Injury Incidence and MAS (-.52*).

Injury burden was found to have high correlations with Training Availability, Match Availability and Total Availability, that were all highly significant (-.9*** , -.82*** , -.92*** respectively).

Table 4 - Correlation Matrix

Variable	EHS-R (N) AVG	EHS –L (N) AVG	CMJH (cm) AVG	20M (s) AVG	40M (s) AVG	MSS (m/s) AVG	30-15 AVG	MAS (m/s) AVG	ASR (m/s) AVG	Training Availability	Match Availability	Total Availability	Injury Incidence
EHS-R (N) AVG	—												
EHS-L (N) AVG	0.83***	—											
CMJH (cm) AVG	-0.069	0.274	—										
20M (s) AVG	0.29	-0.046	-0.67**	—									
40M (s) AVG	0.171	-0.151	-0.687***	0.948***	—								
MSS (m/s) AVG	-0.21	0.014	0.361	-0.572**	-0.648**	—							
30-15 AVG	0.146	-0.067	-0.378	0.227	0.322	-0.254	—						
MAS (m/s) AVG	0.143	-0.069	-0.383	0.228	0.326	-0.259	1***	—					
ASR (M/S) AVG	-0.22	0.025	0.407	-0.58**	-0.667**	0.988***	-0.401	-0.406	—				
Training Availability	-0.063	-0.016	-0.044	0.004	0.061	-0.193	0.113	0.122	-0.203	—			
Match Availability	-0.253	-0.094	-0.089	0.131	0.238	-0.322	0.018	0.026	-0.312	0.745***	—		
Total Availability	-0.099	-0.031	-0.054	0.027	0.094	-0.223	0.101	0.11	-0.23	0.993***	0.817***	—	
Injury Incidence	0.297	0.425	0.568**	-0.325	-0.38	0.22	-0.515*	-0.52*	0.297	-0.301	-0.245	-0.302	—
Injury Burden	0.047	-0.019	-0.018	-0.072	-0.123	0.222	-0.226	-0.229	0.249	-0.896***	-0.816***	-0.915***	0.315

* p < .05, ** p < .01, *** p < .001
AVG = Average (mean)

Bivariate Correlations

Bivariate correlations were calculated through dependent (paired) samples T-Tests, ran to assess the significance of cross season changes to physical performance =and the results of this are displayed in Table 3. No significant change was found in height and weight across the season. The same was found for all hamstring variables, with there being no significant change in EHS-L, EHS-R or EHS-Average.

Table 5 - Bivariate Correlations

Variable	t value	df	p
Height (cm)	0.84	19	**0.41**
Weight (kg)	-1.08	19	**0.3**
EHS-R	-1.17	19	**0.26**
EHS-L	0.96	19	**0.35**
EHS AVG	-0.33	19	**0.75**
CMJ	8.47	19	**< .001**
20m	-2.46	19	**0.02**
30-15 (km/h)	-2.92	19	**0.01**
MAS (m/s)	-2.91	19	**0.01**
MSS (m/s)	6.69	19	**< .001**
ASR (m/s)	7.34	19	**< .001**

There was highly significant change in CMJH from pre-season to mid-season (t=8.47 p<.001 df=19), showing a decrease in jump height over time, with 20m sprint times shown to increase significantly (t= -2.56 p=0.02 df=19). Similarly, there was significant decrease in MAS and decrease in MSS across the season (t=-2.91 p=.009 df=19 ; t=6.69 p<.001 df=19), and as follows from ASR being calculated from MSS and MAS, a significant change in this was also observed (t=7.34 df=19 p<.001).

Linear regression

Linear Regressions have been run to assess the percentage (%) variance of each dependent variable explained by the independent variables, shown in Table 6.

Table 6 - Linear Regression Displaying R squared valued

	Injury Incidence	**Injury Burden**	**Training Availability**	**Match Availability**
CMJH	0.12	0.04	0.04	0.06
EHS	0.01	0.002	0.01	0.02
Change in 20m	0.06	0	0.001	0.01
Change in ASR	0.22*	0.01	0.03	0.03

P <.05 *

Values displayed are R^2 values

Change in CMJH was found to have no significant effect on Injury Incidence, Injury Burden, Training Availability or Match Availability (R^2=.115, p=.15 ; R^2=.04 p=.4 ; R^2=.04, p=.38 ; R^2=.06, p=.3).

Change in EHS-Average was found to have no significant impact on Injury Incidence, Injury Burden, Training Availability or Match Availability (R^2=.01, p=.67 ; R^2=.002 p=.84 ; R^2=.009, p=.7 ; R^2=.02, p=.57).

Change in 40m sprint times was found to have no significant impact on Injury Incidence, Injury Burden, Training Availability or Match Availability (R^2=.06, p=.29 ; R^2=.0 p=.97 ; R^2=.001, p=.92 ; R^2=.009, p=.7).

Change in ASR was found to have no significant impact on Injury Burden, Training Availability or Match Availability (R^2=.008 p=.71 ; R^2=.03, p=..45 ; R^2=.03, p=.04).

Change in ASR was found to have a significant effect on Injury Incidence, accounting for 22% of variance, which, whilst significant, is only a small effect (Cohen 1988).

Discussion

The aims of this study were:

i) To investigate injury burden in male, youth footballers in a non-league football club across a playing season
ii) To explore and address the relationship between physical fitness factors and injury burden in male, youth footballers in a non-league football club across a full season.

The main findings of this study are as follows:

Over a playing season, there was significant decrease in CMJH which has minimal, yet significant effect on injury incidence in male youth football players in a non-league academy.

There were significant correlations between physical fitness variables and injury burden indicators, such as CMJH and injury incidence, MAS and injury incidence and RSI and injury incidence.

There were significant correlations between injury burden and availability at all levels (training, match and total).

The hypotheses to be tested were:

1. Physical fitness factors will influence injury burden in male, youth football players.

2. There will be significant change in physical fitness levels over a playing season in male, youth football players in a non-league football club.

Following data analysis, these hypotheses have been found to be true on both accounts, as highlighted in the key findings.

Injury Burden in the PDP in Non-League Academies

Overall injury incidence was 3.44/1000 hours for the whole sample, significantly lower than what has been found in previous research, with youth footballers of the same age as the participants of this study experiencing 6.59/1000 hours on average (Tears, Chesterton and Wijnbergen 2018; Light et al. 2021; Bult, Barendrecht and Tak 2018; Hägglundet al. 2013). This discrepancy could be due to previous research examining youth footballers from ages 16-21, whereas this study only used players aged 16-19, and it has been noted by several studies that older players experience higher levels of injury (Light et al. 2021; Tears, Chesterton and Wijnbergen 2018; Gabbett 2016). Both training and match incidence was found to be lower than previously stated in youth football literature, with training incidence being 1.27/1000 hours, half the incidence identified by Bult, Barendrecht and Tak (2018), and Tears, Chesterton and Wijnbergen (2018), with match incidence being 20.5/1000 hours, compared with 30.5/1000 hours (Bult, Barendrecht and Tak 2018; Tears, Chesteron and Wijnbergen 2018).

Traumatic injuries had an incidence of 1.72/ 1000 hours (55%), significantly lower than the 6.29/1000 hours stated in previous literature (Tears, Chesterton and Wijnbergen 2018; Light et al. 2021; Bult, Barendrecht and Tak 2018; Hägglund et al. 2013). Additionally, overuse injuries were only slightly lower than traumatic injuries at 1.39/1000 hours (45%), compared with the average of 2.04/1000 hours found in research (Tears, Chesterton and Wijnbergen 2018; Light et al. 2021; Bult, Barendrecht and Tak 2018; Hägglundet al. 2013). 64.71% of overuse injuries occurred in pre-season, or early season (within the first 3 months of the competitive season), when players were potentially still adjusting to the increase in exposure and load from the off season to pre-season, and pre-season to the start of the season. Overuse injuries occur due to a “repetitive and excessive stress from physical activity applied to normal musculoskeletal tissues, and failure of normal adaptation of the tissue”, which often occurs when prescribed load and exposure increase (Patel, Yamasaki and Brown 2017 p. 161). Gabbett (2016) identified an increase in external load as being indicative of increased injury risk, with overuse injuries in youth football most commonly occurring when there is a sudden increase in the intensity, duration and volume of load prescribed (Patel, Yamasaki and Brown 2017). A sudden increase in external load (i.e training quantity increased) will create an increase in the acute training load (load over a short period of time i.e 2 weeks), despite the overall chronic workload (load over a longer period of time i.e 4 weeks) remaining low. This creates a low Acute Chronic Workload Ratio (ACWR), and thus increases the risk of a fatigued athlete developing, increasing injury risk (Gabbett 2016; Bahr and Krosshaug 2005). However, it has also been found that increasing load progressively, as outlined in figure 6, can elicit positive biological adaptations, wherein the body becomes more tolerant of load, and thus increases performance (Soligard et al. 2016; Bowen et al. 2020). Through these biological adaptations, athletes are able to recover quicker, and thus reduce injury risk even more (Laux et al. 2015).

Gabbett (2016) found that athletes competing in team sports have a 50-80% chance of becoming injured in pre-season, with training load steadily increasing. Additionally, Gabbett (2016) hypothesised that it may not be the amount of training load that increases injury risk, but the type of load, with high- speed running being found to increase injury risk by 2.7 times when implemented suddenly into a training regime. In team sports, pre-season often consists of fitness-based protocols to increase speed, agility and overall fitness prior to the start of the season, including high speed running (Gabbett 2016; Gabbett 2020). The increase in load quantity coupled with the type of load experienced in pre-season, and another sudden load increase at the start of the season can account for the high number of injuries seen in pre-season and early season in this study, especially given that over 25% of all injuries occurred in pre-season. It is worth noting the research of Silver (2021) that suggests pre-season in youth football might not be long enough for training adaptations to form which allow players to sustain acceptance of the high level of load they are exposed to during a playing season. Therefore, it is recommended that there is further research into the relationship between ACWR and injury risk in this population (PDP non-league footballers), and an examination into how changes in load from the off season, through to pre and the start of season create biological adaptations through progressive overload. Additionally, it would be beneficial to examine the influence of PHV and those who matured later within this research area.

Overall injury incidence levels are potentially lower in this study due to the reduced number of participants compared to previous studies of a similar nature; previous prospective cohort studies have used upwards of 170 participants to ensure reliability and validity, and accuracy of results (Bult, Barendrecht and Tak 2018; Tears, Chesterton and Wijnbergen 2018; Light et al. 2021)

Tears, Chesterton and Wijnbergen (2018) stated that youth football players experienced 2x higher injury incidence levels than their senior counterparts. However, López-Valenciano et al. (2020) and Van Beijsterveldt et al. (2014) found the average incidence for senior players to be 8.05/1000 hours, significantly higher than found in this study for youth players, thus not supporting the claim of Tears, Chesterton and Wijnbergen (2018). In senior football, Ekstrand, Hägglund and Waldén (2011) found, across a playing season, an average of 2 injuries per player occur, which the present study supports, finding an average of 1.9 injuries per person across the season. However, there is currently minimal research to support this claim in youth football, given the fact that other researchers have found injury incidence increases from the PDP to senior sport (Tears, Chesterton and Wijnbergen 2018; Gabbett 2016; Bannister et al. 1975). Few studies have calculated injury incidence at an individual level, however this study calculated it to be 0.15/1000 hours, with incidence at an individual level being used for data analysis

The present study found similar findings to research by (Light et al. 2021), who found moderate injuries to form 35% of all injuries, with this study finding that to be 31.58%, with an incidence level of .98/1000 hours. However, Light et al. (2021) also found severe injuries to be of the highest incidence in youth football at 37%, whereas this study found severe injuries to only account for 15.79%, with an incidence of 0.49/1000 hours. Contrastingly, Tears, Chesterton and Wijnbergen found severe injuries to equate to 21% of all injuries sustained, highlighting the lack of consistency in the results regarding severity ranking of injuries, and the need for further research into this in youth football. In senior football, there is still a discrepancy regarding the reporting of injury severity, with Van Beijsterveldt et al. (2014) supporting the findings of Light et al. (2021) and this study to state that moderate injuries are of higher incidence than mild and minimal injuries, however other studies have found severe injuries to be the most common (López-Valenciano et al. 2020). Similarly, Van Beijsterveldt et al. (2014) found, similar to this study, that severe injuries are of the lowest incidence, showing consistency from the PDP to senior football in this aspect. In recent years, research in youth football has focused more on injury burden than severity, with few studies quantifying severity as this one has, again indicating the need for further research here.

Recent research has found injury burden in youth footballers ages 12-19 to be 58.37/1000 hours, consistent with the findings of this study, which found burden to be 56.35/1000 hours (Bult, Barendrecht and Tak 2018). Given the significantly lower level of injury incidence found in this study compared to previous literature, the consistency found in injury burden between studies could be due to the level of severity of injuries, yet severe injuries were still found to be lower than in previous literature (Bult, Barendrecht and Tak 2018). When injury burden is calculated, it takes into account the overall number of days lost due to injury, which, for this study, may be significantly higher than other papers have found, however this is not commonly reported in similar studies, and therefore is difficult to assess (Bult, Barendrecht and Tak 2018). It is recommended that, if further study is done, overall days lost due to injury is included in data analysis. At an individual level, injury burden was 2.39 days lost/1000 hours, which can cause significant disruption to training and match protocols, reducing availability and exposure.

The research by Hägglund et al. (2013) indicated that in senior professional football, lower injury burden and higher availability increases the end of season ranking for a team, and it can be expected that similar results would be found in youth football. However, in professional football injury burden is significantly higher than found in both this study and others, with Hägglund et al. (2013) finding it to be 130 days lost /1000 hours, more than double that in youth football. This indicates an increase in the severity of injuries in professional football, and builds on research by Røynesdal, Toering and Gustafsson (2018), who indicated that the transition from the PDP to professional football is a key development stage wherein players need the ability to conform to increasingly high physical and psychological demands.

Interestingly, whilst there is still an increase from youth to senior football, amateur football has higher injury incidence than professional football, hypothesised to be due to reduced medical care and knowledge at that level, and increased match exposure due to reduced squad sizes (Van Beijsterveldt et al. 2014). Given the fact that only 0.5% of youth footballers will sign a professional contract, it is expected that in order to continue playing the sport they love, many will resort to playing amateur level football, where they are almost 1.5 times more likely to sustain an injury (Van Beijsterveldt et al. 2014; Røynesdal, Toering and Gustafsson 2018). Therefore, it is imperative that youth players are prepared for the demands and expectations of senior sport, no matter what level they participate in, and that training load at a youth level can prepare them for this transition.

Injury Statistics

Over a quarter of all injuries occurred in pre-season, with an average of 9.8 days lost, and being predominately to the lower limb (81.8%). This finding is similar to that of Salter et al. (2020), who found that injuries commonly occur after a period of relatively high or low exposure, such as the post-season break. Injuries were mainly traumatic, however there was not a significant difference between traumatic and overuse injuries (54.5% traumatic, 45.5% overuse), whereas research by Salter et al. (2020), López-Valenciano et al. (2020) and Light et al. (2021) identified a higher variance between these injury types, as highlighted previously.

Results of this study are similar to that of Light et al. (2021) and Tears, Chesteron and Wijnbergen (2018), who found muscle strains, tears and cramps to be the most common in U21s footballers (29%), with this study finding this accounts for 38% of injuries. 32% were ligament sprains or ruptures, again supporting the work of Light et al. (2021) to highlight this as the second most common injury. Ankles were the most common location for ligament tears, and the hamstrings were the highest injured muscle group, in line with previous literature highlighting hamstring injuries as one of the most common in football, especially at a youth level (Suarez-Arrones et al. 2019; Bautista et al. 2021).

Contrastingly, Bult, Barendrecht and Tak (2018) found bruises to be the most common injury among male youth football players aged 12-19. However, that particular study used the previous version of the Orchard Sports Injury Classification System to classify injuries, potentially resulting in discrepancy between more recent results, and difficulty allowing cross-study comparison (Bult, Barendrecht and Tak 2018).

Physical Fitness Factors Affecting Injury in the PDP

There was minimal alteration in height across the season, supporting the fact that all participants were post-PHV at the time of the first testing date, and the findings of Van der Sluis et al. (2015) that the average age for PHV in young footballers is 14.04 ±0.65 years. It has been found previously that athletes as old as 15 are still experiencing PHV, with the youngest participant in this study turning 16 one week before testing commenced (van der Sluis et al. 2015). Therefore it is hypothesised that younger participants were still vulnerable to injury, with van der Sluis et al. (2015) stating that those who reach biological maturity later are 7 times more likely to experience an overuse injury. This hypothesis will need further research to determine the level of risk players who have matured later are at when in the PDP, with current research focusing on the YDP predominately (van der Sluis et al. 2015; Salter et al. 2022; Bult, Barendrecht and Tak 2018).

Eccentric Hamstring Strength

Eccentric Hamstring Strength (EHS) was selected as a measure for physical fitness due to the fact that numerous studies have highlighted hamstring injuries in youth football as one of the most common time-loss injuries, and that in order to reduce this risk, eccentric strength of the muscle groups must be improved (Suarez-Arrones et al. 2019; Bautista et al. 2021; Bishop et al. 2022; Riberio-Alvares et al. 2020).

Markovic et al. (2020) found PDP players to have lower levels of EHS than senior players (287 ±50 N compared to 336±50 N for stronger legs). Interestingly, players in the YDP preparing to transition to the PDP had higher EHS levels than the PDP (300±64 N), indicating a drop in strength during the transition (Markovic et al. 2020). This study found PDP players to have a significantly higher level of EHS, with the average being 348 ±54.95 N. This study did not assess different levels of the EPPP, and so it is unclear whether the findings of Markovic can be supported. Research by Markovic (2020) reported similar EHS levels to what has been found previously in both senior and youth football, and therefore the results of this study appear to be above the average observed in the PDP (Buchheit et al 2016). Participants in this sample were not exposed to specific hamstring strengthening programmes unless required in line with an identified weakness or injury, and whilst they were familiar with exercises such as Nordic Hamstring Curls, they were not implemented as a strict regime during training, but as a part of the strength and conditioning sessions done once per week. Therefore, this study needs repeating with other clubs, and at this club once more, with the potential inclusion of the first team and YDP teams to ensure this is not an anomalous result for this squad alone.

Overall, EHS increased minimally from 346.48 ± 60.27 to 349.82 ± 58.84, however the change in EHS for left, right and between limb averages was not significant in any aspect, following bivariate correlations. This study found a unique phenomenon wherein EHS in the right leg increased across the season from 361.6 ± 74.6 N to 378.2 ± 65.89 N, whereas the left leg decreased from 331.35 ± 54.21 to 321.45 ±59.61. Upon examination of injuries, there was no significant pattern of limb injury, meaning neither right nor left legs experienced more injury than the other, therefore the variance between strength alterations may be to another external factor. Potential factors affecting this could be limb dominance, something that was not collected in this study, but could contribute to strength variance (Markovic et al. 2020). Subsequently, this study may need repeating to ensure this is not an anomaly for this sample.

There was 15% asymmetry found when examining average EHS for the left and right legs, corresponding with the research by Markovic et al. (2020), who found PDP athletes to have an asymmetry of 11% between limbs, whereas professional players have a lower asymmetry of 8%. Given that previous literature has identified a correlation between EHS and injury risk, and that between limb asymmetry of over 15% also increases injury risk, it could be expected that EHS should have had a significant correlation with injury incidence (Bishop et al. 2022; Ribeiro-Alvares et al. 2020; Bautista et al. 2021). Hamstring injuries were the most common in this study, yet there was no correlation between EHS and injury incidence. However, as highlighted, EHS in this study is higher than found previously in the PDP, and therefore is less of a risk factor than initially thought in this study population. There were no significant correlations between any EHS factors and any other variables in this study.

Neuromuscular Function

In this study, neuromuscular function was assessed through use of the countermovement jump protocol. Both jump height and reactive strength index were collected from testing through reliable and valid methods. Buchheit (2010) found that intermittent, high intensity sprints, as found in football, can put strain on the neuromuscular system, and is associated with increased energy costs, and thus the development of fatigue (Deeley et al. 2022). Bahr and Krosshaug (2005) identified neuromuscular function and strength as being internal risk factors contributing towards the development of an athlete predisposed to injury. In previous studies, CMJH has been found to be 46.35 ± 3.5cm in PDP players (Saward et al. 2020; Deeley et al. 2022), with this study finding an overall lower average at 38.44 ±6.25cm. However, pre-season testing found CMJH to be 44.28 ±7.95cm, consistent with current findings (Deeley et al. 2022; Saward et al. 2020). There was a significant decrease in CMJH from pre-season to mid-season, with a 25% reduction in jump height (44.28 ±7.95 cm pre-season; 32.6 ± 5.81 cm mid-season).

Deeley et al. (2022) identified a significant reduction in CMJH by 5cm 24 hours post-exercise, which recovered by 48 hours. This can potentially explain the lower number reported in mid-season testing, however the mean reduction of 11.68cm is higher than can be accounted for by fatigue from one previous training session. Buchheit (2010) found that energy use is increased through strain on the neuromuscular system caused by the repetitive intermittent nature of football, which has been found to contribute to the fatigued state of an athlete. Gabbett (2016) highlighted that increases in acute load (2 weeks) without an increase in chronic load (4 weeks) results in a low ACWR, and results in an athlete in a fatigued state, with reduced strength, neuromuscular function and sporting ability (Gabbett 2020; Gabbett et al. 2016; Impellizzeri et al. 2020). Whilst training load was not monitored in this study, it can be hypothesised that the reduction in CMJH could be due to athletes being in a fatigued state, having not successfully adapted to training load implemented (Impellizzeri et al. 2020; Gabbett 2016). Whilst overload and progression are key principles of training, it is important that load is progressively and systematically increased to ensure overtraining does not occur (Gabbett 2020; Impellizzeri et al. 2020).

Through measuring other factors, Deeley et al. (2022) found neuromuscular function to have not fully recovered 72 hours post-exercise, meaning sometimes it had not recovered before the next game. Despite these factors not being measured in this study, it can be hypothesised that CMJH was 25% lower in the mid-season due to this reduction in neuromuscular function following intense training protocols, however further investigation is required before conclusions can be made. CMJH was found to be significantly negatively correlated with 20m sprint times (-0.67**), which supports the findings of Deeley et al. (2022) that CMJH, as a measure of neuromuscular function, correlates with sprint performance, as a measure of physical fitness and neuromuscular function.

Notably, CMJH was significantly positively correlated with injury incidence (0.57**), indicating that as CMJH increased so did injury incidence. When linear regressions were run, there was no significant impact of the change on CMJH on injury incidence, however this does not mean that there is no relationship between the variables. It could be hypothesised that athletes who have higher neuromuscular power are more likely to experience injury due to the forces produced during maximal voluntary contractions (Deeley et al. 2022; Arnason et al. 2004), however this may be influenced by other variables. This study had fewer participants than other similar studies, and as already highlighted, it is important to repeat this study with more participants and a broader sample to ensure anomalies are reduced.

Sprint Performance Factors

This study found sprint speeds slightly decreased from pre-season to mid-season, with less than 5% reduction in 20m sprint times, however, bivariate correlations found this change to be significant. 20m sprint times are used universally to calculate maximal sprint speed (MSS) and for other data analysis of sprint performances (Sandford et al. 2019; Ortiz et al. 2018). Different biomechanical and physiological mechanisms are used during acceleration (5-10m) and sprinting (20-40m), it was important to use a 40m distance to measure 20m sprint speeds, allowing for acceleration. Data on 5m, 10m and 40m sprint speeds was not collected as it was not relevant for the study, however future analysis could use these as a factor for consideration.

Brocherie et al. (2015) assessed sprint times across 30m, however did not identify any significant change following 5 weeks of sprint training, and this result cannot be applied to this study due to difference in data collection for this variable. Saward et al. (2020) investigated 20m sprints in the PDP, and found similar findings to this study, with sprint times being 2.96s for U19s, and 2.95s for U18s who progressed to have professional contracts, whereas those who did not were only marginally slower with 2.97s and 3s for future non-professionals in U19s and U18s respectively.

Only one significant correlation was found with 20m sprint times, that with ASR (-0.58**), which has only occurred due to the use of 20m sprint times correlating with MSS, due to the nature of the variables, and the subsequent use of MSS in calculating ASR.

Previous research has found MSS to be 8.71m/s, with this study finding a higher average at 9.93 ±0.39 m/s (Al Haddad et al. 2015; Buchheit 2010; Brocherie et al. 2015). The findings of this study support that of Al Haddad et al. (2015) and Buchheit (2010), which state that MSS in the PDP is higher than in senior football. In this present study, MSS decreased across the season from 10.63 ±0.64 m/s to 9.24±0.52 m/s, with bivariate correlations identifying this change as being highly significant ($t=6.69$, $p<.001$). Following 5 weeks of sprint training, Brocherie et al. (2015) found a decrease in MSS, however it was non-significant, and the starting values were significantly lower than any value identified in this study, at 8.61m/s for PDP athletes. This indicates again that this study population had above average levels of fitness in the starting stages of the study, with sprint performance indicators remaining high despite the decrease seen here.

Maximal Aerobic Speed (MAS) is an indicator of the highest speed an athlete can reach before reaching VO_2 Max, the point where they are unable to take onboard any more oxygen, following which they use anaerobic reserves (Grgic, Lazinica and Pedisic 2021; Buchheit 2010; Sandford et al. 2019).

This study investigated MAS through implementation of the 30-15 Intermittent Fitness Test (Buchheit 2010), whereas other studies may have used different protocols, which can reduce the comparability of results (Grgic, Lazinica and Pedisic 2021). This study found MAS in PDP footballers to be 5.71±0.24 m/s, higher than previous rates of 4.75m/s (Brocherie et al. 2015; Baker and Heaney 2015; Ortiz et al. 2018; Mendez-Villanueva et al. 2012). This significant difference can be attributed to the already higher than average results found for this study population indicating that this group of athletes may be above the norm for physical fitness, or potentially due to the measures used in this study differing to those used previously, giving different results. However, the latter is less likely to be the case, as methods used here are found to be reliable and valid, producing reproducible results in line with studies using other methods (Mendez-Villanueva et al. 2021; Grgic, Lazinica and Pedisic 2021).

MAS and MSS are used to calculate Anaerobic Speed Reserve (ASR), which is the "reserve" of running speed left once a player has reached VO_2 Max prior to reaching MSS (Buchheit 2010). Previously, ASR in the PDP has been found to be 3.67m/s (Ortiz et al. 2018; Brocherie et al. 2015), however this study found data to be much higher, with an average of 4.23 m/s, starting at 5 m/s at the beginning of the season, and ending with 3.46 m/s in mid-season. The mid-season result reflects previous literature, and is due to the reduction in MSS from the start of the season, as highlighted above.

Previous literature has identified ASR as influencing injury incidence (Buchheit 2010; Bahr and Krosshaug 2005), with this study supporting these claims. This study found that the significant decrease in ASR ($t=7.34$, $p<.001$) across a season significantly influenced injury incidence, accounting for 22% of variation. Despite this finding being significant, the effect size is minimal, indicating that there are other variables which influence injury incidence.

Availability at any level was not affected by physical fitness levels, with the only significant finding related to availability being the correlations between match, training and total availability, and injury burden, indicating that as injury burden increases, availability decreases. This finding is not novel and is expected given the nature of these variables.

Limitations and Recommendations

This study had several limitations which may restrict its application to the wider population. Using a youth team at a non-league football club can be restrictive, as youth clubs can vary in age group, from U19s, to U21s and U23s; typically, non-league clubs will only have a U19 or U18s team due to the financial constraints attached to having more teams, and thus more players, however this study is limited to players 16-19 only, reducing population application. Due to financial, time and locational restraints only one club was included in this study. One age group was included (U19s), therefore at the start of the study participant numbers were lower than desired, which reduced further with participant exclusion and withdrawal, reducing final participant numbers to 20.

A control group was not used for this study, however this was not feasible for the study design (Deeley et al. 2022). When testing occurred, players were not fully rested due to the structure of the training and match programme; participants were required to complete their normal schedule of training and college attendance, with testing fitting into gaps around this. Therefore, it was likely that participants had participated in physical activity in the 24 hours prior to testing. Research by Deeley et al. (2022) found that both maximal voluntary contraction and muscle impairment were still present 72 hours after a training session in youth football, indicating that results for this study may have been influenced by fatigue and therefore cannot be entirely accurate.

This study would benefit from assessing both internal and external load, however due to financial constraints the use of GPS and HR monitors was not possible. Internal load was attempted to be monitored through self-reporting questionnaires once per week for an injury audit, and after every training session or match to assess sRPE, however attrition levels were low and not enough data successfully gathered to allow meaningful interpretation. Therefore, this was removed as a measure prior to the end of the study.

A progression of the research completed would benefit inclusion of load monitoring, both internal and external. Additionally, increasing the battery of tests ran to assess physical fitness and increase the study population to include a wider geographical sample will allow increased reliability and applicability of results.

The validity of this study may be compromised by only using two time points for data collection of physical fitness factors, despite three being scheduled originally. In future research, this study would benefit from being repeated with more data collection days, including extra days for mitigation.

Conclusion

This study aimed to investigate the influence of physical fitness levels on injury burden and associated factors in male youth footballers in a non-league academy, and the incidence of injury in this population.

The key finding of this study was that there is minimal significant impact of physical fitness factors on injury burden and associated factors, with only Anaerobic Speed Reserve having a mild influence on injury incidence. Research by Del Rosso, Nakamura and Boullosa (2017) found that athletes with higher ASR (a larger difference between MSS and MAS) have slower heart rate recovery, which can be evaluated in relation to this current study, wherein sprint speeds correlates negatively with ASR. There is a negative correlation between sprint speeds and heart rate recovery (Reinhardt et al. 2020), supporting the findings of the current study. Additionally, lower recovery rates are associated with higher risk of injury in professional men's (over 18) football (Laux et al. 2015). Therefore, the higher levels of injury incidence associated with change in ASR can be attributed to the discussed relationship between ASR and recovery rates (Laux et al. 2015; Reinhardt et al. 2020). To summarise, this study supports previous literature to confirm that increased sprint speeds and the associated decreased ASR have an inverse relationship with recovery rate, and therefore will lower injury risk, and through this study lowers injury incidence (Laux et al. 2015; Reinhardt et al. 2020; Del Rosso, Nakamura and Boullosa 2017)

Novel findings in this study include an increase in EHS in the right leg, but a decrease in the left leg across a season, even more impactful given that the right leg average EHS was significantly higher than the left leg EHS at the start of the season, and increased, whereas the left leg remained and increased in weakness. This indicates an increased injury risk in this population, and identifies the reason behind hamstring injury being the most common, as found in previous studies (Suarez-Arrones et al. 2019; Bautista et al. 2021). Additionally, CMJH was found to be lower than average in mid-season, indicating a reduction in neuromuscular function, due to athletes being in fatigued states, potentially due to a high ACWR. However, this cannot be confirmed as load was not assessed in this study. Finally, Maximal Aerobic Strength increased throughout the study, but Maximal Sprint Speed decreased, indicating variance in aerobic and anaerobic capacity developing throughout the season, however this was not assessed in further detail, so conclusions cannot be drawn from this alone.

Given that several physical factors in this study were found to be higher than identified in previous studies (EHS and MSS), injury risk may have been reduced, following the theory of Bahr and Krosshaug (2005), who identified physical factors such as these as increasing injury risk. Injury incidence was lower than found in previous studies, which may be due to the higher levels of physical fitness found here, despite the significant reduction found in several variables.

This study assessed the internal risk factors influencing injury incidence, identified in the work of Bahr and Krosshaug (2005) as being the factors which create an athlete predisposed to injury. Not explored were external risk factors which create a susceptible athlete, nor the inciting events (mechanisms) which incite injury (Bahr and Krosshaug 2005).

Whilst many authors have hypothesised that both inadequate and excessive training loads can increase injury risk, and increase fitness and performance, association does not always mean prediction (Impellizzeri et al. 2020; Gabbett et al. 2016; Hulin et al. 2015). Therefore, further research is needed into the impact of load and load alteration, and physical fitness factors and the influence this has on injury incidence and risk in youth footballers. Additional research should look into the novel findings found here, and explore this in a wider population using a larger battery of testing procedures to further explore these phenomena.

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