Biological Maturation Status Variation within Chronological Age Groups and the Impact on Injury

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The candidate confirms that the work submitted is their own and that appropriate credit has been given where reference has been made to the work of others.

Abstract

This Study investigated the variation of biological maturation status within chronological age groups in a football academy and its impact on injury. The injury factors of type, incidence, severity, and burden were used. What is more, the timing and status of PHV were identified as well as biological to draw comparisons and identify differences within the injury patterns. An injury audit was kept throughout the season to attain this data for the 72 participants in the chronological age groups (under 12, 13, 14, 15, 16) along with the player's measurements being taken pre-, mid-, and post-season. Descriptive statistics and a between-groups ANOVA were completed for data analysis. The results found that the range of biological maturation within the chronological age groups increased up to under 15s, while under 16s although they had a variance it was not as much as those in under 15s. Injury incidence peaked in those who were chronologically U12. With no distinctive pattern for the rest of the age-grouped teams Injury burden and days lost were both highest in the U15s. While circa-PHV had the most association with all injury factors. Once further broken down into their PHV status timing, on-time maturers were found to have the greatest injury association. Overall, the results from this study do not directly align with those already found and more research is needed particularly into the players PHV timing.

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Introduction

Football is one of the most popular sports in the world with an estimated 5 billion fans (FIFA, 2021). The 2022 FIFA World Cup in Qatar had a record-breaking 5.4 billion views (BeIn Sports 2022), however, despite the popularity of those professionals on our screens they make up only a small percentage of the accumulative participants of the football population. Participants are predominantly made up of those under 18 (FIFA, 2007). Data from 2018/19 published by the UK Government found that 62.2% of their pool of 315 boys aged between 11- 16 had played football within the past 4 weeks (GOV.Uk, 2020). From toddler groups to grassroots most children at some point aspire to be a professional like the idols they see on the screen.

Despite the goal of a successful professional sporting career, it is advantageous for children and adolescents to participate in sports because of the wider benefits to the participant's overall health and well-being. This is why it has been stated that football is medicine (Krustrup and Krustrup, 2018). Not only does it benefit cardiovascular and neuromuscular (krustrup et al, 2010) fitness it also allows the participants to benefit from the social aspect of the sport, thus giving an advantage in their mental health (Swann et al, 2018). However, along with the positives, participation in football also poses risks, such as injury. Football is a high-intensity sport requiring complex movement patterns and probable contact or impact on a player. This then results in players and/or their caregivers being anxious or discouraged from playing the sport, in fear of suffering an injury (Faude, Röbler and Junge, 2013). Preventative measures are then needed in order to mitigate this risk. An example of this is the current trial by the Football Association of the no-heading rule for children in the under 12 age group. This trial aims to ‘mitigate against any potential risks that may be linked to heading the ball, including injuries from head-to-head, elbow-to-head, or head-to-ground contact, and it represents a cautious approach to playing and enjoying football while ongoing research continues in this area' (The Football Association, 2022). Although the evidence on the benefit of banning heading in this age group is limited the reasoning behind the implementation is because of the limited knowledge of neurological disease and its causes. Chronic Traumatic Encephalopathy (CTE) was initially thought to only be seen in former boxers but recently NFL players and retired premier league players have been diagnosed with the disease. It is thought to be caused by repetitive impact on the head. The ban on heading is thought to protect the longevity of adolescent players. What is more, it also reduces the risk of an impact or collision injury from the heading and so also aims at protecting the athlete in the more short-term and instant aspect (Stewart and Carson, 2022). Injuries increase the risk of a player dropping out of the sport and are associated with burnout. Burnout occurs as a result of stress that causes an athlete to stop participating in a sport they once enjoyed (DiFiori et al, 2014). This may be caused by an athlete being unable to fully perform and show their potential causing themselves stress on their position in the participation. Football is a seasonal sport and not usually the only sport played by athletes this age, this can result in over training which in turn increases the chance of an injury. Overtraining and injury can then have the consequence of burnout. What is more pressure from not only the child themselves but also parents and coaches can have a negative impact on the Child's psychological burnout ()

Football clubs worldwide commonly use academy programs as a developmental pathway to mould new talent for their affiliated clubs or to progress their players to bigger clubs in return for profit (Jones et al., 2019). For a smaller club with a more limited budget, the academy and talent identification process can be used to either enhance their senior squad or generate revenue by selling their players ageing out of the academy program. Academies usually span U9 to U23 age groups and will commonly use decimal age as a grouping agent within teams and training, in concordance with educational systems. Using chronological age is easily implemented as it is cost-effective and requires no screening or assessment. Age groups also are beneficial because of the seemingly linear development trajectories of behavioural, social, and cognitive system development (Thurlow, Kite and Cummings, 2022). However, this is not the case in relation to individual physical development, associated with biological maturation (Lloyd et al, 2014). Biological maturation is defined as ‘the progression towards the mature state and consists of two components: timing and tempo’ (Malina, Bouchard and Bar-Or., 2009 as cited by Bacil et al., 2015, p.1). The timing and tempo of development are highly individualised to each athlete, occurring at different times for decimal age in adolescents (Philippaerts et al., 2006) and therefore must be considered within the development continuum.

This biological bandwidth becomes a particular problem for adolescent age groups, during which they experience a phase of growth known as peak hight velocity (PHV) (Malina et al. 2012). This period can witness a growth of approximately 7.5-9.7 cm/year and occurs between the decimal ages of 10.7 and 15.2 years old (Philippaerts et al.,2006; Towlson et al.,2021). PHV is individual to each player so there is a potential for athletes to be ahead or behind their peers in their timing of PHV (Malina et al, 2015). Thus, causing some players to be more or less physically developed than their age-group counterparts. The players who mature earlier may have an advantage over the later maturing players through enhanced strength and power (Cumming et al, 2017). Yapici et al. (2022) found that biological maturation had a meaningful correlation with vertical jump height and power. What is more, Wilczyński et al. (2022) furthered the earlier finding by including a long jump the researchers found a significance between biological maturation, power, and strength. They then also stated that although not as significant there is a relationship being biological maturation and dynamic balance.

Biological maturity has also been shown to be linked with injury incidence, severity, and burden (Monasterio et al. 2022; Johnson et al. 2022; Materne et al. 2021). Players who are in their PHV are at a greater risk of sustaining a growth injury such as Osgood Schlatter's Disease or Sinding-Larsen-Johansson syndrome (Bult, Barendrecht and Tak, 2018). Managing PHV is important for practitioners to reduce injury incidence, thus creating an increase in positive longterm outcomes for young players (Salter, Johnson and Towlson, 2021). (Bult, Barendrecht and

Tak, 2018) found an increase in injury risk of 31% during a period of 6 months after an athlete's PHV, they then stated that this could be caused by a decrease in flexibility and bone density.

Based on the literature and the apparent increase in injury incidence around this turbulent period, this study aims to identify how variation in maturity status within chronological age groups impacts injury, specifically severity, incidence burden and type.

Injury in Adolescent Football

Definition

injury definitions used are dependent on the research question and the context in which the study is concerned (Østergaard-Nielsen et al. 2020). A consensus statement by Fuller et al (2006, p. 193) defined injury as 'Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.' This definition while it restricts injuries to the sport being played was proposed at the First World Congress on Sports Injury Prevention in 2005 by the Fédération Internationale de Football Association Medical Assessment and Research Centre (F-MARC). Using this definition gives consistent and comparable results for studies that investigate football injuries. What is more, if we were to include injuries from outside of football itself it may skew the findings as it may not be directly associated with the player's maturation status and the effect on their injury risk.

Type

A study by Wik et al. (2021) investigated the injury patterns in an elite national academy over four seasons. They used 301 participants aged 11-18 years old and recorded 1,111 timeloss injuries. They found that the younger age groups U13 and U14 had a higher proportion of gradual onset injury or overuse injuries. The research paper found 33% in U13 and 37% in

U14 compared to the older age groups whose percentage didn't peak higher than 25%. Yang et al (2012) stated that an overuse injury results from cumulative trauma or repetitive use and stress. They then advanced the definition further to state that overuse injuries occur when there is insufficient recovery time and gave examples of different overuse injuries. Wik et al. (2020) found that Osgood-Schlatter's Disease was the most prominent growth-related overuse injury with 33 incidences the median time loss being 5 days. An overuse injury is caused by repetitive submaximal loading causing stress on the affected region which is then followed by insufficient recovery. Preferably the body will react to training by adapting and getting stronger, but if there is too much stress, not enough recovery or both together the body breaks down unable to handle the forces posed, resulting in injury (Johnson. 2008). Commonly overuse injuries transpire in the tendons, bursa, cartilage, and bone. Injuries include but aren't limited to stress fractures and tendinopathies (Pecina and Bojanic, 2003). This can be explained by the development of tissue, for example, woven bone makes up our skeleton from birth but when we begin to mature the process of replacing that bone with lamellar bone begins as it is stronger. Before maturation, the player's body is then made up of a relatively fragile skeleton and weak muscles compared to after maturation.

The causes of an overuse injury are multifactorial, they can be intrinsic or extrinsic. Intrinsic factors are internal and are challenging to control. Extrinsic factors can include poor technique and so it is easier to change. Maturing players are at a higher risk of an overuse injury because of their vulnerable musculoskeletal system. The changes in limb length, body mass, flexibility and bone density cause the capacity to deal with forces to alter (Leppänen et al., 2019). What is more Leppänen et al. (2019) found that the peak prevalence of knee growth-related issues such as Osgood-Shlatter's and Sinding-Larsen-Johansson syndrome is 10-14, while heelrelated growth pain such as severs is more common in those under 11.

The overall incidence of injury was higher in the older age groups this could be the outcome of past injury, greater playing intensity or competitiveness and aggression (Read et al., 2018). Traumatic injuries are caused by a specific event or incidence, such as a tackle or the player's own awkward movement, such as a difficult landing. Examples include a fracture, concussion, or contusion. (Fuller et al, 2006). Although the mechanism for acute traumatic injuries is comparative in adults and adolescents, the structure injured is vastly different and so requires extra caution and care. Fractures are more likely in adolescent athletes due to their bone structure with weaker bones and active growth plates (Levine et al., 2022).

Biological Maturation

Timing and Tempo

Timing refers to the chronological age at which a maturity event occurs. A maturity event can manifest as various changes for example growth spurts, age of appearance of pubic hair etc. (Baxter-Jones, Eisenmann and Sherar, 2005). Tempo signifies the rate of development and progress of such events. Bacil et al. (2015) modified timing and tempo to timing and time. They then went on to define timing as ‘the moment when a given maturation event occurs’ and give the example of the ‘growth spurt period’ also known as a growth in peak height velocity. Time was then outlined as the rate, at which the event such as the growth spurt is occurring. Although Bacil et al. (2015) are one of the limited papers in which a description of the definition is found, using timing and time may be confusing in the application with practitioners and academics, using ‘timing and tempo’ within the definition but defining tempo using the time description may be beneficial in the clarification. In a paper by Lloyd et al. (2014), they simplified the definition for practical application which allows for simple use and limited confusion. They identified that timing is the manifestation of the change whereas tempo is the rate of the said change. PHV is a key developmental stage within football academies that needs to be considered when making talent identification and selection decisions. For males, PHV usually occurs around the age of 13.8, however, it has been suggested that this transpires earlier in active males such as those in academy football (Tsutsui et al., 2022). In the Irish Talent Squad between their 159 players, 13 and 15s and 16s, 51% were early maturing, 39% were on time and 10% were late maturing (Sweeney et al., 2022). PHV occurs within the age range of 10.7 to 15.2 (Philipaerts et al., 2006; Towlson et al., 2018). We can use height and body mass to recognise growth, the average age to recognise growth using height in active boys is 13.1 compared to 13.8 in non-active boys, while body mass changes occur later, for active boys this occurs at 13.3, and in non-active boys, it occurs at 14.2 (Malina et al, 1997).

Physical Changes to Performance and Risk

During adolescence, growth occurs in a proximal to distal manner, stimulated by accelerated growth in long bones (Hill et al. 2022). At PHV, growth rates for boys can be 7-14 cm per year, compared to in childhood which is usually 4-5 cm per year. Changes in limb length can cause adolescent awkwardness which has been linked to changes in performance. Adolescent awkwardness is temporary and caused by disruption to motor coordination due to a growth spurt leading to a decrease in neuromuscular control. As the athletes mature and train their overall control of their stretch-shortening cycle function increases which helps as they progress through their age-grouped sport and motor skills (Radnor et al. 2018). For boys particularly during the three to six months after PHV, they have their Peak Weight Velocity (PWV), they will gain around 9-10 kg per year. Thus, impacting the power and strength they can produce, what is more with an increase in control over SSC function they can have the ability to then control their bigger stature. With changes in testosterone, there are developments in muscle mass and bone accretion (Hill et al., 2022). Biomechanically the moment of inertia increases during growth. Limb growth, PWV and moment of inertia all interrelate collectively but this is not essentially in a linear manner. This then affects limb dynamics, and the forces muscles are required to generate to perform. As the tissues become stronger there may be discrepancies in rate. The muscle itself may be stronger than the bone or tendonous structures causing asynchronous gain of strength, leaving them vulnerable to injury. It has been found that insertion sites are particularly vulnerable to repetitive load (Hawkins and Metheny, 2001 as cited in Wik et al., 2020).

This misalignment between soft and hard tissue development causes an increase in the risk of overuse and growth-related injuries (Johnson et al., 2022). As stated earlier, insertion or attachment sites are particularly vulnerable during maturation as growth-related injuries such as Osgood-Schlatter disease are caused by the inflammation of the patellar tendon attachment on the tibial tuberosity. Osgood-Schlatter's disease is common in adolescent football and so supports the statement indicated previously.

Biological maturation timing and tempo vary with each player, so it is not always appropriate to train and play in that way. Bio-banding uses biological maturity status rather than decimal age to group players with their more equal counterparts rather than having a player who is early maturing and a lot larger tackling and playing with a smaller less matured equivalent.

Two main benefits were found in a recent research article by Bradley et al. (2019), they observed that the early maturing players felt as though they had a greater physical and technical challenge, which is different from usual as they could overpower their other later maturing teammates. While the late maturing teammates perceived less physical and technical challenge thus allowing them to exhibit more technical and tactical abilities. For both groups, the bio-banding created new opportunities and challenges in which they could grow their skills. The research paper used male participants from three different professional academies who competed in a tournament, what is more, the players also stated that they enjoyed the biobanding and understood the purpose, acknowledging the apparent risk of injury decline. Overall, the paper found that bio-banding can facilitate development for all players regardless of their maturity status.

Measuring Injury and Maturity in Adolescent Football

Measuring Maturity

Not one individual characteristic can determine the timing and tempo of biological maturation, however, the common indicators are largely used as a method of defining the process (Malina et al., 2012) to not cause confusion and limit the applicability. Various methods can be used in the estimation of biological maturity status, some common measures include skeletal age and secondary sex characteristics. Measures used can be separated into invasive and noninvasive categories.

Invasive Measures

Currently, X-rays of the left hand and wrist are regarded as the gold standard method in measuring skeletal age as they have the greatest validity and reliability (Cavallo et al. 2021). Skeletal age refers to the stage of biological maturation as indicated by the skeletal tissue (Lloyd et al, 2014). The maturation of the skeletal system involves the transition from a cartilaginous structure to fully developed ossified bones. Several methods of assessment of radiographs exist. Most of them use a left-hand image and are compared to predetermined measures (Malina. 2011). The most commonly applied assessment modalities used are the Greulich-Pyle method, Fels method and Tanner-Whitehouse method.

The Greulich-Pyle method was first validated using a collection of radiographs from white children of a high socioeconomic status (Greulich and Pyle, 1959). A left hand/wrist X-ray was compared against X-rays of various levels of skeletal maturation. Skeletal age was then determined depending on which reference x-ray it reflected best. For example, if a 12-yearold x-ray best matched the reference x-ray of a 14-year-old they were said to be an early maturer. This however has limitations as bone tissue doesn't mature in a uniform manner and so doesn't account for individual rates of bones. What is more, the study was done solely on white participants, and so is not applicable to other ethnicities. Zhang et al. (2009) stated that ethnic and racial differences in growth patterns exist and that the Greulich-Pyle method doesn't acknowledge this. This is especially prominent in boys aged 11-15 which is when this study is measuring biological maturation and is in peak the PHV period.

The Tanner-Whitehouse method has been revised twice since the original in 1962, with the most recent update in 2001. This method unlike the previously mentioned requires various criteria for the wrist and hand of 13 or 20 bones (Tanner et al, 2001). Each bone is analysed and compared with detailed analyses. The bones are then given their individual maturation score, with a cumulative score given from these to determine skeletal age. This method used British children in the first two validations however the third and final used samples from European, South American, North American, and Japanese youth. A limitation of this method is that it is time-consuming and complex.

Fels longitudinal study used data collected from the 1930s and 1970s to construct the Fels method. A maturity assessment on the radius, ulna, carpals, metacarpals, and phalanges provides a grade on each according to age and sex. Using a specific software, the skeletal age and a standard error of the estimate are provided. Although like the others this method is time-consuming and complex the standard error of the measurement is a benefit, particularly for the long-term tracking of the biological maturation of the participant.

Secondary sex characteristics are an indicator of pubertal status. Features include pubic hair and axillary hair for both sexes. For males, it also includes voice changes, facial hair, and genitalia (testes, testicular volume, penis, and scrotum). In females, it can be the growth of breasts and their first menstrual period. Genitalia, breasts, and pubic hair are assessed relative to exclusive conditions from initial development to the mature state. The stages are assessed clinically, however self-assessment can be used (Malina et al, 2015). The Tanner method uses a five-stage grading system for breasts in females, genitalia in males and pubic hair in both sexes (Tanner, 1962). The Tanner method doesn’t allow for differentiation within stages as with

2 children one could be at the start, and one could be at the end of said stage, but both condemned to the same category. This methodology also doesn't reveal information about the tempo of the child's maturation, complicating the comparison between the maturation status of children. What is more, this method is only applicable during the pubertal phase, limiting its time frame for its applicability (Lloyd et al, 2014).

Skeletal age is a less distressing measure compared to secondary sex characteristics which include the measure of pubic hair, genitals, and testicular volume. However, using X-rays on the children exposes them to harmful radiation. Contrary to this Serinelli et al. (2015) found that there is evidence that MRI is more accurate than X-ray due to its resolution, furthermore, it also does not use ionizing radiation. What is more, skeletal age is available from childhood through to adolescent age, while secondary sex characteristics are limited to pubertal years (Malina et al., 2012). The cost of using radiographic modalities to explore biological maturation is not appropriate for all academies, especially those from lower league teams. Both skeletal age and secondary sex characteristics require a specialist and so causes not only a financial issue but also a time and availably concern. Non-invasive measures include measuring height and weight which is more applicable in this environment with youth football academy players.

Non-Invasive Measures

Somatic maturation is a sign of biological maturation, which can be observed by growth. The longitudinal collection of height, weight and changes in limb length can provide the data to create growth curves. The growth curves created allow for the identification of PHV, thus pinpointing the age of a child's maximum rate of growth during their growth spurt. Although this method allows for the identification of PHV, it can only be recognised after the peak has been observed, so using maturity offset approaches allows use from 8 years old, which can be used to give an indication of maturity timing. What is more, peak adult height percentage (PAH%) can then help predict the timing as we have gained from this in studies done that PHV occurs around 90%. The knowledge that the child is either later, average, or early maturing is helpful however to the coaching staff in their assessments of players and coaching style. What is more, for medical staff this knowledge allows the identification of predisposed risk to certain injuries and if applicable the steps can be put in place to reduce said risk.

Mirwald et al. (2002) created an equation in which the age from PHV can be calculated. The equation has a standard deviation of 6 months; however, this approach does consider that long bones such as the legs have a differential growth rate compared to shorter bones or the trunk. The longer bones in the leg's peak growth are found to be earlier. This was done by not only incorporating standing height but also sitting height. What is more, there are two separate equations for males (figure 1) and females (figure 2) considering the typical differentiation in age the PHV occurs. This method although at first thought to be able to 95% of the time reliably predict PHV within 1 year was re-evaluated by various articles and it was found to overestimate in older age groups and underestimate in those who are younger. Furthermore, it was found it overestimated the timing of PHV when it was imminent, thus being unreliable for studies (Salter et al. 2022).

$$\begin{aligned} \text{Maturity offset} = {} & -29.769 + 0.0003007 \\ & \times \text{leg length and sitting height interaction} - 0.01177 \\ & \times \text{age and leg length interaction} + 0.01639 \\ & \times \text{age and sitting height interaction} + 0.445 \\ & \times \text{leg by height ratio} \end{aligned} \tag{1}$$

$$\begin{aligned} \text{Maturity offset} = {} & -16.364 + 0.0002309 \\ & \times \text{leg length and sitting height interaction} \\ & + 0.006277 \times \text{age and sitting height interaction} \\ & + 0.179 \times \text{leg by height ratio} + 0.0009428 \\ & \times \text{age and weight interaction.} \end{aligned} \tag{2}$$

The Khamis-Roche method was a development from the Fels method stated previously. It uses the child's decimal age, height, and weight, with both their parent's height ([Mothers + Fathers]/2) to produce a predicted mature height excluding the use of an x-ray for skeletal age. The player's current height is presented as a percentage of their overall predicated mature height, this then provides an estimate of their biological maturity status (Malina et al, 2007). This methodology has been compared to the actual values reached and demonstrates satisfactory constancy. This is a suitable alternative to a non-invasive method as it doesn't require highly trained personnel or expensive equipment which aren't always attainable, especially at the academy level. Because of the simplicity of the collection of data for the equation, this technique can be used on larger sample sizes (Olivares, De León and Fragoso, 2020).

Measuring Injury

Taking an active approach to injury prevention within academy football is becoming increasingly popular because of the immediate and long-term benefits of player availability and growth. By collecting and analysing data key risks and issues can be identified within age groups and maturation groups which clinicians and coaches can try to mitigate by introducing various protocols or practices.

The lead sports therapist and on-hand medical personnel used an injury audit to collect the injury data being measured. An injury audit allows for the collection and analysis of injuries within the season. Various elements can be included in the injury audit to measure the injury itself such as injury type, severity, incidence, and burden. What is more, all the injuries recorded can also be compared to the player's maturity status and whether they are on time, late or early maturing. Before an academy can identify the risks or common injuries for their players an injury audit is needed to track the various measures. Audits are free to do, for a smaller academy or sporting team this is useful, what is more, they can include any factor you would like to fit in with the medical and team needs.

Injury Incidence

Injury incidence is the number of injuries per exposure time, to standardise this it is common to report incidence rates as number of injuries per 1000 hours. This method allows comparison across sports teams. However, using actual exposure time makes a more specific and refined calculation (Hodgson-Phillips, 2000). Overall exposure time includes matches as well as training, but results can also be produced to show the incidence rate in matches and training to allow for comparison. Compared to professional football players, youth players have an increased incidence rate of injuries during training (Materne. 2021), which is why it is important that this is included in this particular study. The academy in which this project was completed trains for 1.5 hours twice a week and in compliance with the league's rules for under 12s to under 16s play 80 minutes in any matches played which was on a Saturday. In team sports, exposure hours are calculated using the number of players on the pitch at one time multiplied by the duration of the game, which is 1.33 hours for the age groups used, then multiplied by the games in the season.

There is a linear relationship between growth rate and injury incidence. As players get older the incidence of injury increases. Robles-Palazón et al. (2022) investigated injury patterns over 9 months within a Spanish male youth soccer academy. They had an overall incidence of 3.1 injuries per 1000 h, the majority of these injuries being muscle and tendon injuries to the player's lower extremities. The study also identified that not only does the incidence of injuries increase with maturation and age but that during PHV the risk of overuse injuries is heightened, Materne (2021) went further to state that fractures should also be included in this period. They also stated that there may be a potential that early maturing players have a higher incidence rate (Johnson et al., 2009 as cited in Materne, 2021). Contrary to this Van der Sleuis et al (2014) found that late-maturing players who were more gifted had a higher incidence of overuse injuries, particularly in the year before their PHV.

The documentation of injury incidence rates allows practitioners to recognise players who may be at a greater risk for certain injuries and allows surveillance and strategies to be put in place to help either reduce or manage the risk. This then benefits not only the player but also the academy as it allows them to be more prepared for what could come (Toselli et al., 2021).

Injury Severity

Not only can the Oslo Sports Trauma Questionnaire discussed earlier, be used to define injury it can be used to measure injury. As mentioned previously, a severity score is made if an athlete has a health issue, this was determined by their level of participation and impact on performance and training. Within this paper the applicability of the Oslo Sports Trauma definition although preferred is limited as adherence to a questionnaire is limited, furthermore, the reliability of depending on athletes to notify the medical personnel of any health problem is ambiguous.

The Injury Severity Score (ISS) is a scoring method that provides an overall score for patients with multiple injuries. Each of the patient's injuries are given an abbreviated injury scale (AIS), which is allocated to one of six body regions. The three most severely injured regions then have their score squared and added together to produce the ISS score between 0 and 75 (Javali et al., 2019). The ISS scale was validated and sorted by Bolorundo et al (2011) less than 9 is mild, 9-15 is moderate, 16-24 is severe and 25 or more is profound. The disadvantage of the ISS is that only one injury is considered per body region, thus overlooking other injuries in that region.

Time loss from full participation in training and matches can be used to determine injury severity (Ekstrand et al., 2021). This definition however can cause difficulties as participation in sport can be a cycle of full participation and partial participation especially in the management of certain overuse injuries, such as severs where at some point the injury is manageable and the athlete can train or play a full match whereas sometimes the athlete can only partake in so much of the session. Instead of using the term 'full participation' Sprouse et al. (2020) used regular training or match play this leaves the definition more open to interpretation of the athletes still partaking in the sessions even if it is not a full session or full recovery as some injuries do not have a full recovery. This definition may be more applicable, especially in the environment of an adolescent football academy where multiple players have a growth-related injury. Sprouse et al. (2020) then classified injury severity into thresholds of 1-7 days being a minor absence, 8-28 days being a moderate absence, 29-89 days being a severe absence and more than 90 days being a major absence. These thresholds were created using multiple pieces of literature and research that had tried and tested the process the first being a consensus statement by Fuller et al. (2006) and the other also a more recent consensus statement from the International Olympic Committee by Bahr et al. (2020).

Injury Burden

Injury burden is the combination of injury incidence and severity (Bahr, Clarsen and Ekstrand, 2018). Reporting of injury burden is usually analysed by the calculation in Figure 3. It is the total number of days lost per 1000 hrs of exposure whether this be training, match-play, or a combination of the two, and it can represent and be equal to the product of injury incidence.

Player-days' absence / player-hours

Biological maturation has been recognised as a potential risk factor for injury and so resulting in the injury burden of football injuries being high. Only reporting injury incidence provides an incomplete picture of injuries. While reporting injury burden allows for the consequence of injuries to be highlighted (Bahr, Clarsen and Ekstrand. 2018). What is more, there is a variation in burden in the maturation and growth phase itself. The Study by Robles-Palazón et al. (2022) mentioned previously not considering injury incidence but also burden they found that like injury incidence PHV causes the greatest impact on injury burden. Not only do clinicians and coaches need to be aware of the heightened risk of injury and its burden for maturation but they also need to be mindful of the variation in said risk within the stages of biological maturation whether that be circa-PHV or post-PHV. Monasterio et al (2023) used longitudinal growth data collected from elite academy soccer players over two decades to find that the burden of growth-related injuries was greater in players with an excelled pace of PHV rather than those who are average or slower in circa-PHV. The research paper hypothesised that this is due to adolescent awkwardness as mentioned prior in this paper which is caused by the rapid growth causing a variation to usual movement kinematics. Or that a temporary decrease in bone mineral density caused by skeletal growth causes vulnerability. The detection of those with fast-paced PHV circa-PHV allows for extra care to be taken to reduce their risk of growth-related injuries. This can be done by controlling load and monitoring any complaints or symptoms to identify early any growth-related issues.

Early Maturing players or those who are post-PHV were found to have a higher injury burden, especially for muscle and joint/ligament. Specifically, hamstring injuries are found to be the most burdensome (Robles-Palazón et al., 2022). This was in agreement with Wik et al. (2021) who also found hamstring injuries to be the most burdensome. What is more, both studies described that ankle injuries also had a high burden rate. The data allows the academy staff to prioritize any preventative measures taken then aiming to have a positive impact on the player's longevity and growth within the team (Bahr, Clarsen and Ekstrand. 2018).

Links to Injury and Importance of Dose-Response

The volume of the activity the adolescent is involved in is important for practitioners, coaches, and other key stakeholders to know as with inappropriate training load injury risk increases as stated by Drew and Finch (2016) in their systematic review. Biological maturation develops at different rates for each individual, adolescents of the same chronological age may be at different points of decimal age in the maturation process (Philippaerts et al., 2006). This makes individual load management difficult in team settings for growing athletes. Jones et al. (2019) found that in male soccer players non-contact injuries have a high prevalence of 53%72%. This emphasises the significance of load management to reduce the risk of injury, which would result in time lost. Additionally, for adolescents, injuries sustained at the youth level can have longer-term consequences, an example of this would be the athlete becoming more susceptible to future injury and long-term health risks (Salter, Johnson and Towlson. 2021).

Recovery is important for both healthy and injured athletes when reducing the risk and treating overuse injuries, recovery of an athlete can target both psychological and physical aspects (Brink et al., 2010). Limited research has been done on the training prescription for adolescent athletes (Salter, Johnson and Towlson., 2021). Recovery that corresponds to the load prescribed is vital, inadequate recovery increases the chances of fatigue or overuse injury and reduces performance (Brink et al., 2010), the risk of this is already elevated for adolescents due to their biological maturation during their PHV.

Methods

Study Period and Participants

In this prospective study, injury data was collected over the August 2022 to June 2023 football season from a professional academy using chronologically aged teams where biological maturation is likely to take place and be a factor in their development in football (under 12, 13, 14, 15 and 16s). In total 72 participants from the male youth development programme were included in the study, they were excluded if their injury was not sustained at academy training and/or game or if they did not engage in the general health screening to obtain the relevant data. Those who could not provide parental height were not excluded from taking part in the general health screening, however, their data was not analysed. Before the start of the study, all information on experimental procedures, benefits and risks was given to gain informed consent by both the athlete and their parent or guardian as they are all under the age of 18. Written consent was acquired before the start of the study. All the measurements were taken voluntarily. Due to the study being non-invasive, there is minimal risk for participants, however, the option to drop out was available throughout the project at any time.

The club themselves then gave permission to collect and use the data. The recruitment of the participants came from working with the academy teams and all measures were built into the youth development programme. Throughout the study the participants remained anonymous by being allocated a participant ID, this data was then be kept confidential on a password-protected computer. What is more, if the study caused the participants psychological harm they will be directed to a suitable professional. Physical harm from training, games etc. will be assessed, treated, and referred if needed by the lead sports therapist and medical team at the club. The general health screening was held during pre-season (September), post-season (December) and mid-season (May) to allow the year to capture the participant's growth and development phases. Player's height and weight were measured for use in the maturation equation, while jump height, sprint time and endurance testing were also done to monitor their overall fitness but was not used for this specific study.

Participant Retention and Drop-out

Initially, the study comprised of 80 players, but due to various participants not meeting the inclusion criteria 72 made up the used data set. No participants dropped out who met all criteria however, some were excluded due to having no maturation data caused by illness, or in-season transfers meaning they couldn't make the general health screening when the measures were taken.

Measures and Procedure

Various measures have been proposed to quantify biological maturation, however, the gold standard is the Greulich-Pyle method using hand X-rays, but this was not feasible in this specific study due to the financial cost and ethical considerations of unnecessary radiation exposure. What is more, it requires a trained physician to carry out X-rays (Cavallo et al. 2021). Nevertheless, the estimated percentage of adult stature attainment (%EASA) also named the Khamis-Roche equation will be used as it has an accuracy within 2% and is a noninvasive, affordable measure unlike the aforementioned. The equation requires the athletes' biological parents' heights which were collected at the start of the season while the player registered to the club. The athletes' sitting height, standing height and weight, all of which were acquired during the standard health and fitness testing which took place three times the first in pre-season, Christmas break and the final postseason.

A standard stadiometer was used to collect the standing and seated height of the players using The International Society for the Advancement of Kinanthropometry (ISAK) guidelines (Norton, 2018). As per the guidelines the players were instructed to face away from the stadiometer standing as tall as they could with their feet hip-width apart and heels touching the back of the back plate. Three measurements were taken by the same practitioner to reduce inter-rater reliability issues. Using the same stadiometer seated height was taken by asking the players to sit with their backs up to the stadiometer on a 40 cm box. Again, they looked straight ahead and were told to sit as tall as they could while three measurements were taken from the same practitioner. With the standing and sitting height values, you can then calculate leg length (Standing – sitting height). Weight also needed to be taken for the maturity calculation which required a scale. Again, for validity, 3 measures were taken. All measurements were taken in a laboratory setting with the same equipment, while following international standards on anthropometric assessment to mitigate any external factors and ensure reliability and validity.

The data collected from the general health screening was inputted into a customized excel spreadsheet (Towlson et al, 2021) which contained a 'control panel' in which all player information was inputted including their name, age, age group, position, date of birth and parental height. The cells were then programmed to utilise this data on a separate tab with the anthropometric data collected periodically through the season. Using this data the spreadsheet calculated the player's biological age, percentage of peak adult height also known as Khamis-Roche and biological vs chronological offset. Biological vs Chronological offset is the player's biological age subtracted from their chronological age using the Khamis-Roche approach. This allows us to see the discrepancy between where chronologically they should be to their actual body's age or maturation (Khamis and Roche, 1994), we can then gather from the data we collect if this causes an impact on injury.

An injury audit was used to collect injury data by the lead sports therapist. They used the definitions stated prior for example for injury the definition by Fuller et al (2006) and with regards to injury severity classification, the system created by Sprouse et al. (2020) and then tried and tested by Fuller et al (2006). It allowed for the collection and analysis of all the injuries over the season, 12 injuries had to be excluded from the analysis, the criteria for this was due to not having maturity data on the affected player which excluded 9 injuries, while also injuries from outside football training or games at the academy from external factors cannot be determined if football participation and maturation had an effect and so excluded another 3. Injuries should also be excluded if all data on the player is not available such as an injury that started before the season and when maturation data was calculated, or if they do not return to full participation before the end of the academy season. After each assessment of an injury to a player, the lead sports therapist would document the findings. Throughout the management and rehab of the injury reassessments and return to plays were documented to give key information which was then inputted into the various elements recorded which were the injury type, severity, incidence, and burden

Data Analytic Strategies

As this study uses a quantitative approach the data was pooled by the players age group, maturation status and timing, it was then cleaned meaning any data that met the exclusion criteria was removed, this data was then analysed using Jeffrey's Amazing Statistics Program (JASP). Descriptive statistics were used to compare and analyse the data to try to determine patterns within the data this was done using mean ±SD values. What is more, confidence intervals (95% CI) were used on the p values reported in table 5. A three way between-groups ANOVA was also completed to compare players categorised as either early (>0.6 years), on-time (±0.6 years) or late (<0.6 years) developers based on biological age offset. The level for significant findings was set at $p<0.05$, Cohen's D was also used to determine any meaningful difference specific to the data's used sample size. The data found was then identified by its threshold to determine whether it was Trivial (<0.1), small (>0.2) or moderate (>0.5).

Results

Biological Maturity

This study commenced with over 100 academy football players, within this cohort players were excluded due to not having maturation data, because of illness or in-season transfers to or from another club, resulting in 72 players creating the functioning data. Of the remaining players observed over the season the biological age was calculated and it was found within a single age group it could range from 1.4 to 3.5 years, with the largest variance found in U15s (Table 1). The table below represents the variation of biological age and biological vs. chronological age offset within the chronological age groups.

	U12 (N=11)		U13 (N=15)		U14 (N=15)		U15 (N=21)		U16 (N=10)	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Chronological Age	11.55 (0.20)	11.3 – 11.8	12.83 (0.32)	12.1 – 13.5	13.59 (0.34)	13.0 – 13.9	14.71 (0.31)	14.1 – 15.3	15.49 (0.22)	15.2 – 16

Biological Age	11.46 (0.42)	10.8 – 12.2	12.72 (0.70)	11.3 – 13.8	14.17 (0.66)	13.3 – 15.8	14.88 (0.79)	13.7 – 17.2	15.99 (0.66)	15.2 – 16.9
Bio v Chron Offset	-0.10 (0.46)	-0.70 – 0.70	-0.13 (0.55)	-0.90 – 0.90	0.57 (0.54)	-0.3 – 1.8	0.16 (0.63)	-0.5 – 2.3	0.48 (0.61)	-0.2 - 1.5

Table 1. The variation of biological age and biological vs chronological age offset within the chronological age groups

Injury

Injuries documented across all age groups in the season totalled 48, however, 12 injuries were unusable as we didn't have the biological maturity data or it was an external injury, because of this, 36 injuries made up the useable data set of 72 players. Equating to the average injury rates shown below as well as their mean time loss (Table 2). No significant differences were found in injury incidence between the age groups, the U12s had the greatest mean while the U13s and U14s had the lowest. U15s also had the greatest number of days lost resulting in the greatest severity and burden (Table 2).

	U12 (N=11)		U13 (N=15)		U14 (N=15)		U15 (N=21)		U16 (N=10)	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Injury Incidence	0.55 (0.69)	0.00 – 2.00	0.47 (0.74)	0.00 – 2.00	0.47 (0.64)	0.00 – 2.00	0.48 (0.60)	0.00 – 2.00	0.500 (0.71)	0.00 – 2.00
Injury Burden	0.01 (0.03)	0.00 – 0.11	0.06 (0.13)	0.00 – 0.37	0.035 (0.08)	0.00 – 0.32	0.07 (0.11)	0.00 – 0.32	0.03 (0.06)	0.00 – 0.16
Days Lost	1.27 (4.22)	0.00 – 84.00	7.93 (16.91)	0.00 – 49.00	4.67 (10.80)	0.00 – 42.00	8.67 (13.98)	0.00 – 42.00	3.50 (7.56)	0.00 – 21.00

Table 2. Chronological age group teams and their injury incidence, burden and days lost

Within the data set the 72 players were then grouped by their maturity status (Table 3). The average injury incidence rates are shown below as well as their mean time loss. No significant differences were found in injury incidence between maturation status (Table 4). Those who were post-PHV had the greatest mean while those who were circa-PHV had the lowest. PostPHV also had the greatest number of days lost resulting in the greatest severity and burden (Table 3).

	Pre (N=22)		Circa (N=28)		Post (N=22)	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Injury Incidence	0.59 (0.73)	0.00 – 2.00	0.29 (0.46)	0.00 – 1.00	0.64 (0.73)	0.00 – 2.00
Injury Burden	0.05 (0.10)	0.00 – 0.37	0.03 (0.07)	0.00 – 0.32	0.06 (0.10)	0.00 – 0.32
Days Lost	6.045 (14.377)	0.000 – 49.000	3.500 (8.834)	0.000 – 42.000	8.591 (13.821)	0.00 – 42.00

Table 3. Maturation status and their injury incidence, burden and days lost

Maturation status was then broken into maturation timing to further see the impact on injury (Table 4, 5). The average injury incidence rates are shown below as well as their mean time loss. No significant differences were found in injury incidence between maturation status. Those who were on-time in their maturation had the greatest mean while those who were late had the lowest. This was the same for the greatest number of days lost resulting in the greatest severity and burden (Table 4). When the data was inputted into an ANOVA to compare the timings of biological maturation, no significant P values were found for injury incidence, burden or days lost. However, Cohens D did produce a trivial relationship between burden and days lost that was found despite the small sample size of those who are late maturing (n=5) (Table 5).

	Early (N=16)		Ontime (N=51)		Late (N=5)	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Injury Incidence	0.44 (0.73)	0.00 – 2.00	0.51 (0.64)	0.00 – 2.00	0.40 (0.55)	0.00 – 1.00
Injury Burden	0.04 (0.09)	0.00 – 0.32	0.05 (0.10)	0.00 – 0.37	0.00 (0.00)	0.00 – 0.00
Days Lost	4.81 (12.18)	0.00 – 42.00	6.73 (12.90)	0.00 – 49.00	0.00 (0.00)	0.00 – 0.00

Table 4. Maturation timing and their injury incidence, burden and days lost

		Injury Incidence		Injury Burden		Days Lost	
		Cohen's D	P_{bonf} (95% CI)	Cohen's D	P_{bonf}	Cohen's D	P_{bonf}
Early	Late	0.06 Trivial	1.000 (-1.20 – 1.31)	0.39 Small	1.000 (-2.12 – 2.90)	0.39 Small	1.000 (-0.87 – 1.65)
Early	On-time	-0.11 Trivial	1.000 (-0.81 – 0.59)	-0.16 Trivial	1.000 (-0.86 – 0.55)	-0.16 Trivial	1.000 (-0.86 – 0.55)
Late	On-time	-0.17 Trivial	1.000 (-1.32 – 0.98)	-0.54 Moderate	1.000 (-2.97 – 1.89)	-0.54 Moderate	1.000 (-1.70 – 0.61)

Table 5. ANOVA of maturation timing and their injury incidence, burden and days lost

Type

Of the 36 injuries, they were made up by 29 of the 72 players in this study. The injury type and to whom it affected is depicted below in table 6.

	Early		On-time		Late	
Injury Type	Injuries	Days lost	Injury incidence	Days lost	Injury incidence	Days lost
Foot	-	-	2	0	2	0
Physis injury -Sever's Disease	-	-	2	0	2	0
Ankle	1	14	4	35	-	-
Joint Sprain	-	-	3	35	-	-
Synovitis/Capsulitis	1	14	1	0	-	-
Lower Leg	-	-	3	70	-	-
Bone Stress Injury	-	-	2	42	-	-
Muscle Injury	-	-	1	28	-	-

Knee	2	7	8	112	-	-
MCL Sprain	-	-	2	63	-	-
Physis Injury – Osgood-Schlatter's Disease and SLJ Syndrome	-	-	2	0	-	-
Contusion	2	7	4	49	-	-
Thigh	1	42	5	32	-	-
Hamstring Strain	1	42	3	21	-	-
Quadriceps Strain	-	-	1	14	-	-
Adductor Strain	-	-	1	7	-	-
Hip/groin	1	14	2	14	-	-
Muscle Injury	1	14	-	-	-	-
Impingement	-	-	2	14	-	-
Trunk	1	0	2	7	-	-
Non-specific Pain	1	0	2	7	-	-
Head and Neck	-	-	2	49	-	-
Concussion	-	-	2	49	-	-

Table 6. Biological Maturation Timing and Injury Type Sustained

Discussion

Biological Maturation Status Variation Within Chronological Age Groups

The aims of this study were to identify relationships with biological age variation within chronological age groups and the impact this has on injury incidence, severity, burden, and type. Novel to other literature this study explores the status of biological maturation and timing. This is then used to investigate the injury factors to identify any disparities between the influence of biological age and chronological age. The primary findings of this study were that as age increased up to the U15s the range of biological maturation increased with it. Injuries were most common in the U12s and there was no distinctive pattern with the rest of the chronological age groups. However, injury burden and days lost were highest in U15s. Those who were circa-PHV were found to have the highest injury incidence, burden and days lost. When further broken down into early, on-time and late maturing those who were on-time maturing had the greatest association with the injury factors.

Due to the variation in the timing and tempo of biological maturation, there can be disparities within chronological age groups. This study found the U15s had the greatest variation in maturation status, which is consistent with the existing literature. Malina et al (2000) found that their U15-16 age groups had the greatest biological diversity compared with all other age groups. Using various methods to determine reliability and accuracy, Ruf et al. (2021)

determined that U14-U17 have the greatest range in biological maturation in chronological age groups and that the Khamis -Roche approach is sensitive enough to detect this. This paper not only supports the findings of this thesis but also concludes that the Khamis-Roche method is a viable method and is superior to the reliability of the other methods. A reason for the greatest range during this time is because of the timing of maturation, as the U15 and U16s are most likely to be approaching their mature state (i.e., 100% PPAH). Physiologically the body is trying to reach a mature state, and as this materialises at different timings and tempos the PPAH % can range per player, this is specifically found in U15 and U16s.

It is found that there is a maturity selection bias within football academies. Hill et al. (2020) found that there was a bias for players who are advanced in the maturation status that increased with age. Comparable with this study they found no late maturing players in the U15-U16s signifying a selection bias to those who are earlier maturing. Despite this finding, this bias is only clear when using specific banding criteria (±6-months), when analysed using more conservative criteria (±1-year) it was found that only 1.9% of the U16 group were late maturing. Although this thesis used the ±6-months criteria, biological age was used ensuring limited bias. We can infer from this nonetheless that with a bias toward the earlier maturing players those who are later maturing cause an increase in the variation found within the chronological age groups and their biological maturation. This research paper supports this narrative as it was found that 22.2% were early maturing, 70.8% were on-time, and 7% were late maturing athletes, again affirming the bias.

In a study by Ginés et al (2023) they used elite and nonelite youth soccer academies and divided the players up due to their chronological age. The categories they formed we U12, U14 and U16. Their U16 had the greatest range of maturity age similar to the data found in this study. In nonelite academies, higher expectations were assigned to taller players, creating a relationship with PHV and assessment of players. Leaving those who are slower maturing at a disadvantage in the selection process within academies, again supporting the selection bias. This can then have a negative effect on the player's psychological state and lead to burnout. However, players who are slower in their PHV are found to have been able to adapt to this disadvantage constructing the ‘underdog hypothesis’ in which they must develop quicker psychologically to reconcile if they lack physically (Kelly et al., 2020).

The U12s had the lowest variation in maturation status, however, as stated earlier the timing of PHV in biological maturation usually occurs at ages 13-15 which the findings in this study suggest. In a study by Hirose and Hirano (2012) they found that their U12 and U13 teams had the most significant difference or incline in skeletal age and body measurements such as height and weight. This is again because of the timing of maturation usually manifesting from age 13 onwards. It is still important to track the biological maturation of U12 to a better understanding of predicted growth as they advance through the academy. What is more, as already stated injury risk can increase during PHV (Bult, Barendrecht and Tak. 2018; Monasterio. 2023), so being able to predict when this will occur allows key stakeholders and academy staff to be proactive in implementing precautions to modify load and activity levels. Such as using the common practice of periodisation which allows for the manipulation of training variables to amplify any adaptions while trying to moderate the threat of overtraining (Johnson et al, 2023).

Injury Incidence

Regarding the relationship between Chronologically age-grouped teams and injury incidence, this paper found that the U12s had the greatest injury incidence (Table 2). Along with those who are post-PHV (Table 3) and on time in their PHV (Table 4). When comparing the biological offset groups in an ANOVA there were no significant findings between their tempos.

Within the existing literature on academy football, there has been vagueness when trying to depict the trends. Bell-shaped and unclear relationships have been reported. This article will try to provide a clear answer and reasoning. Van der Sleuis et al (2015) found in their study that 13.5-14.5 have the greatest injury incidence, which contrasts the findings of this thesis. They determined that this was because of the inability to handle the load placed on them due to the fragile skeleton and weaker muscles before maturation, the Van der Sleuis et al (2015) paper is limited however because of this finding as although 13.5-14.5 do have weaker skeletons and muscles due to immaturity they gave no indication of chronological age groups as they used biological age as their grouping factor. Nevertheless, in this thesis, the biological age of the U12s was no higher than 12.2 and they still had the greatest injury incidence. As stated earlier those pre-PHV have a weak skeleton which Van der Sleuis et al (2015) stated was the reasoning behind their finding and can also be the reasoning behind this thesis resulting in their paper being narrow. John et al. (2019) tried to explain this finding by identifying that there is a lack of postural control and adolescent awkwardness during a growth spurt which increases the risk of injury thus having a direct impact on injury incidence. However, this paper only used U14 and U15 which limits its findings as it eliminated the chance to find significant relationships elsewhere. What is more, although U12s aren’t found to be in their PHV they are still growing and so because of the limited applicability of this paper, we cannot determine whether they also suffer from a misbalance due to growth. Compared to the John et al. (2019) study, this thesis uses various age groups creating a larger sample age, and a more biologically diverse sample, injury risk is then objectively measured allowing greater insight and breakthrough.

Despite various studies stating that injury incidence increases with age, this is not consistent with the findings in this article (Wik et al., 2022; Read et al., 2018; Price et al., 2004). The pattern they found could be rationalised by various hypotheses such as the prospect of players being stronger (Cumming et al, 2017). Muscle growth for males peaks post-PHV and increases with age, accelerating from 13 years (Brown, Patel and Darmawan, 2017). The increase in strength allows for more power to be applied in tackles potentially injuring others. What is more, in athletic and nonathletic populations alike there is found to be a misbalance in muscletendon units, the biomechanical demand on tendons then results in injury (Charcharis et al., 2019). Additionally, training session intensity may have increased, which then increases the risk of injury (Robles-Palaźon et al. 2022). The likelihood of having a past injury also increases with age, which also increases the chance of reinjury (Wik. 2022). Nonetheless, injury trends are not always comparable as injury type and location can all be affected by maturation status
(Wik. 2022), this could explain the findings of this study. 75% of the injuries sustained by the U12s were overuse or growth-related issues which is most prominent at this age (Leppänen et al., 2019).

Comparable to this study Hall et al. (2022) found post-PHV to have the greatest overall injury incidence followed by pre-PHV. Those who are post-PHV as stated above have the greatest muscle growth, the increase in power and speed results in more intense training and games. Although games have an increase in intensity and risk-taking behaviour, the older players in this study who are post-PHV play longer games and so have less recovery time and a higher contact time despite said increase in intensity which can result in an increase in injury incidence from improper recovery, which would explain our findings. Finding post-PHV players to have a higher injury incidence than those who are pre-PHV partially contrasts our finding of

U12s having the highest injury incidence as none of them were post-PHV. However, as stated earlier the injury incidence with respect to injury type changes which should be kept in mind when other studies are completed. Those who have a pre-PHV status are found to have the highest incidence of growth-related injuries, which this study also suggests. As identified earlier this can be due to a weaker skeleton and weaker muscles. Muscle injuries occur mostly in those who are post-PHV, because of the said increase in physical demands and risk of past injury (Salter, 2022).

Descriptive statistics found those who were on-time to have the greatest injury incidence however statistically there was no significant correlation. Limited studies have included maturity timing in their study. Johnson et al. (2019) was one of the limited studies which did, and they support the findings in this study. They themselves also found on-time players to have the highest injury incidence but it was insignificant. A large sample size may be required to find a significant result as the Johnson et al. (2019) paper similarly only used 76 athletes. Nevertheless, Cohen's D, which standardises results to the sample size, found a trivial relationship between those who were on time compared to those who were late or early.

Injury Burden

In this thesis, the under-15s had the greatest mean injury burden followed by the under-13s (Table 2). Post-PHV (Table 3) and those who are on-time (Table 4) in their maturation also had the greatest injury burden. When comparing the biological offset groups using an ANOVA there was no significant difference, however, there was a trivial effect size found for comparing those who were late and on time.

Like injury incidence, the literature available on injury burden is indistinct due to the limited studies. Materne et al. (2021) completed a four-year prospective study to try and fill the gap in the research area and found that as their chronologically aged teams increased so did injury burden. However, they themselves stated that this does not align with other studies done like in this thesis. Various other findings within the limited and uncertain literature do support the findings of this study as they also found U15s to have the greatest injury burden (Johnson et al. 2019; Read et al. 2017). This is due to an increase in the severity of injuries sustained by the U15s compared to the other chronological age groups, in this study 9% of injuries were severe with the rest being 63.6% moderate and 27.4% minor. Highlighting the minimal minor injuries within the U15s, within this study it can be contrasted to the U12s who had the lowest injury burden and had 100% minor injuries. Although the Johnson et al. (2019) paper supported our findings the only explanation they provide is that the increase is due to training load demands. This is one possible explanation however as chronological age progresses there is an increased chance the player has had a past injury, which then leaves said player more susceptible to additional injuries (Wik. 2022), although in this thesis this is not included in any analysis.

Bult et al. (2018) in a paper primarily about PHV status and injury burden found in their data that u15s had a high injury burden and suggested research on the injury risk factors which this paper is eager to achieve. The research into biological maturation alongside and within chronological age groups allows us to see the impact a misbalance has. They stated that postPHV, specifically 6 months after has the highest injury burden, comparable with this study. This is potentially because severe injuries are found in those in the older age groups (Johnson et al. 2022), this study found predominantly moderate injuries in those who are post-PHV, however, there were few Minor injuries. Salter (2022) stated this may be because they are underprepared for the demands placed upon them. This would support our findings in this thesis as the injuries suffered by those who are post-PHV were found to be overuse injuries rather than traumatic, so it is not that they were unable to cope with tackles from larger players but that their bodies couldn't withstand the load. This is why muscular injuries are found in older chronological age groups as they are post-PHV (Wik, 2020). What is more, as an athlete progresses through an academy and improves their skill and athleticism, they gain value to the club whether that is to advance in the future to their first team or monetary wise to be sold. This can influence medical staff and the rehab that they deliver may be more conservative to ensure the athlete's value (Johnson et al. 2022). Monasterio et al. (2023) supported the findings in this article as they found post-PHV to have the greatest injury burden regarding muscular, joint and ligament injuries. What is more, they supported the use of player-season equation rather than per 1000h as usually seen in older literature, which was recommended by the International Olympic Committee Consensus Statement (Bahr et al. 2020).

Those who were on-time in their maturation had the greatest injury burden. Monasterio et al. (2022) supported these findings and found that it was 2.8 times higher than those who are late maturing. What is more, they furthered this finding by stating that growth-related injuries were the most burdensome in all three groups. Within the on-time maturers muscle injuries were 4 times more burdensome than for the rest of the groups. The article however only included those in the U14 team, so although it indicated the types of injuries for the manifestation and timing of biological maturation it does not indicate the universal applicability. Monastrio et al. (2023) split players into their PHV status and then again by timing. No matter what stage the player was in, regarding their maturation status, those who were on-time had the greatest injury burden overall. However, Monasterio used ± 5 months while this paper used ± 6 months as it was a more conservative method. When conducting an ANOVA to compare the timing of maturation although no significant relationships were found observing the P value, a moderate variance between late and on-time maturers was found in Cohen's D. It was found that those who were late had the lowest injury burden compared to those who were on-time in the maturation.

Injury Severity

Observing the relationship between Chronologically age-grouped teams and injury severity, this paper found that the U15s had the greatest injury severity (Table 2). Along with those who are post-PHV (Table 3) and on time in their PHV (Table 4). This was determined by days lost and then categorised by the criteria mentioned earlier. When comparing the biological offset groups using an ANOVA there was no significant difference, however, there was a trivial effect size found for comparing those who were late and on time.

As injury burden is the product of injury severity and incidence, the findings and causes are similar. 9% of the injuries to the U15s were traumatic while the rest were overuse injuries again confirming the increase in non-contact injuries. Although Hall et al. (2020) found that their U16s had the greatest injury burden they displayed the distribution of the severity per age group and their U15s although less severe overall than the U16 and U14s had less minimal injuries that the U16s and more moderate injuries than the U14s. Conversely, this paper did not use the same categorisation for the severity of injury. Despite this, the data produced is still comparable as they included minimal injuries which this study did not and unlike this study, they did not include major injuries. 64% of the injuries in this study were moderate however in the data collected by Hall et al. (2020) approximately only 45% were moderate injuries, although, in this study, only 9% of injuries were severe compared to their approximate 30%. This could be explained by biological maturation, this study did not identify PHV or maturation status, and so they may have had a large misbalance within their age groups resulting in more severe injuries. What is more, the potential that due to the academy, this study was completed in seemingly handling biological maturation better could result in less severe injuries as the players are equipped to handle the load. They did, however, depict the types of injuries their U15s had. Comparable to this study muscle issues were the most prevalent which as stated earlier indicates that the athletes are underprepared for the loads imposed on them rather than there being a physiological misbalance within the chronological age groups.

Post-PHV had the greatest days lost which then results in a greater overall severity. This is confirmed by (Mandorino et al. 2023) who found that more mature players had a higher number of injuries which in turn were more severe. They noted that this can be justified because of an increase in competition intensity, which as mentioned earlier the players have longer games but equal recovery than younger players despite the game having a higher intensity. Robles-Palaźon et al. (2022) also found that post-PHV had the greatest injury severity, however, they included re-injury data. The data they included was only from the season they studied as they didn't have historic data. This thesis included all injuries from the season including any re-injury like the study abovementioned, however, we did not differentiate between new and re-injuries which can cause the severity to increase with reinjury, 35 days vs 17 respectively. Ontime PHV had the greatest days lost and so had the greatest injury severity. When using an ANOVA, no significant relationship was found when comparing the timing of biological maturation. However, consistent with injury burden a moderate variance between late and on-time maturers was found in Cohen's D. It was found that those who were late had the lowest days lost compared to those who were on-time in the maturation. Due to the novelty of analysing the data using the timing of maturation with the injury factors there is limited availability to compare results, this however, can be used for future studies.

Conclusion

In conclusion, biological maturation although mostly trivial in this study does influence injury. Measuring maturation status through the football season will allow practitioners to predict the times in which their players are most at risk. What is more, specific maturation programmes can be put in place to prevent injuries and prepare players for their athletic careers. Studies of different football academies and their load management would be useful in the study of maturation and injury to detect whether these findings are consistent through various academies. Furthermore, studies into the effect of the tempo (fast, slow, average) on one's maturation process would be beneficial regarding injury factors.

Limitations

The initial proposal for the study was to use the Oslo Sports Trauma Research Centre (OSTRC) Overuse Injury Questionnaire, although the measure is found to be reliable through the literature to date ((Bailón-Cerezo et al., 2020; Kaewkul, Chaijenkij and Tongsai., 2021)) it was unattainable to be used across such a large group of children. It was attempted however the lack of compliance made unreliable data. Which there for limits the data, what is more, because of this the actual number of injuries reported was potentially less as the player had to see the medical team for it to be accounted for which not all players would for a niggle. Furthermore, although this study had a similar number of participants overall in the cohort, those who are late or early maturing were under-represented in the data as the majority were made up of those who were on-time, which in the literature to date isn't commonly found.

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