THE UNIVERSITY OF HULL

The effect of maturity status ‘bio-banding’ on the technical and tactical responses of talented adolescent soccer players during small-sided games

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by

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Abstract

The aims of this thesis were to examine the effects of bio-banding on academy soccer player technical and tactical characteristics during small-sided game match-play and investigate if different methods of estimating maturation effected player performance. Male (n = 92), academy soccer players, aged 11 to 16 years old were selected from three UK soccer academies. Player maturation was estimated using percentage of adult stature attainment (EASA) and maturity offset somatic equations. Using thresholds (>92.0% post-PHV, 87.0 - 92.0% circa-PHV and <87.0% pre-PHV for the Khamis and Roche (1994) equation and thresholds (<-1.0 post-PHV, -1.0-0.0 circa-PHV and >0.0 pre-PHV) for the Fransen et al. (2017) equation, players were organised into bio-bands (pre-PHV, circa-PHV and post-PHV) then competed in a series of maturity (miss)matched bio-banded small-sided games during which players were assessed using the game technical scoring chart (GTSC). Results showed large differences (*P* = 0.001) in anthropometrical measurements when bio-bands were mis-matched. Apart from pitch possession, no differences (*P* > 0.05) were found in match performance when bio-bands were matched or mis-matched. There were no differences (*P* = 1.000) found in GTSC total points awarded but there were in GTSC points scored (*P* = 0.001). Finally, there were very few differences in match performance between the different methods of identifying biological age and organising bio-bands. The findings of this research suggest that bio-banding is unable to provide useful insight into match performance, therefore, is limited in enabling the monitoring player development and talent identification. However, a number of limitations were present within this thesis therefore preventing accurate conclusions from being made.

Chapter 1. Introduction

1.1 Introduction

Soccer is one of the most popular sports in the world, played by 265 million people in more than 200 countries (The Football Association 2015; Kunz 2007). In England alone 2.1 million people participate in the sport at least twice a month, with 31-45% playing on a monthly basis (Statista, 2020a). As well high participation rates, soccer is also one of the most watched sports in the world, from 2010-2019 16,600 - 20,200 people attended Football League Championship Games in the UK (Statista 2019a). Additionally, the Premier League (2019) reported 70% of the UK population watched the 2018/19 Premier League Season through broadcasted means, with further increased viewing rates globally. High participation and viewing rates have a significant financial impact within soccer (Wilson 2018). During the 2019/2020 season £1.3 million was gained in revenue by Premier League clubs through match day attendance and an additional €3,030 million was gained through broadcasting (Statista 2019b). This is a small part of the overall financial revenue that soccer teams gain. According to Deloitte (2019) European soccer teams gain revenue during a season from a combination of match day attendance, broadcasting and sponsorship, however a significant amount of revenue was gained through player transfers. During the 2019-2020 season Premier League clubs' total transfer expenditure was £1367.3 million (Statista 2020). Additionally, as of January 2020 the highest transfer fee paid was £94.5 million by Manchester United for player Paul Pogba in 2016 (Statista 2020b).

Despite such staggering amounts of money being generated within soccer Franck and Lang (2014) found that European soccer teams suffered heavily from debt between 2006-2011 and there was a 760% increase in net loss. Financial difficulties have been found particularly within English soccer clubs, for example, 61 teams in the English Football League faced legal action or administration due to financial difficulties from 2007-2017 (Aloia 2018; Conn 2014). In 2009 the Union of European Football Associations (UEFA) introduced the Financial Fair Play (FFP) initiative which was a set of rules and regulations to stabilise the financial situation of European soccer with the hopes of reducing “both club losses and overdue debts of top division European clubs” (Union of European Football Associations 2019a). The FFP plan aims to ensure that soccer clubs do not spend more money than they earn and as a result allow soccer leagues to become less competitive and more balanced (Plumley et al. 2018). The consequences of breaking the FFP rules can result in teams potentially being penalised through a reduction of points in competition, warnings, fines, not being awarded competition winnings, transfer bans and other consequences (BBC 2019). For example, in 2014 Manchester City were fined £49 million and could only enter 21 players into the Champions League competition as a consequence of breaking the FFP rules (BBC 2014). In 2008 UEFA introduced further limitations on squad size, restricting team size to be no more than 25 players of which 8 must be ‘homegrown’ (Union of European Football Associations 2019b).

The UEFA defines homegrown players as individuals that have been training and playing with a team for a minimum of 3 years, between the ages of 15 and 21years old (Union of European Football Associations 2019b). The homegrown measures were introduced to allow more opportunities for younger players to be selected to train and compete with elite teams (UEFA 2019b). When the homegrown ruling was introduced in 2008, English teams were comprised by 59.2% of players from abroad. In a particular example, 90% of the Liverpool team, at the time, contained expatriate players (BBC Sport 2009). Therefore, with soccer clubs and teams under pressure to meet the FFP and homegrown player rules to avoid repercussions, more importance is being placed on teams to find and nurture younger players.

In 2011 the Elite Player Performance Plan (EPPP) was introduced and accepted by the Football League as a means of identifying and monitoring younger players to improve the quantity and quality of players (Premier League 2020). The aim of the EPPP is to create homegrown players through a long-term plan of development focusing on the empowerment of each player through a player-centred approach (Premier League 2020). The EPPP monitors the performance and well-being of elite youth players from ages 5 to 23 years, across three phases (Foundation (5 to 14 years old), Youth Development (15 to 17 years old) and Professional Development (18 to 21 years old)), that play for an academy team that is attached to a professional club (Premier League 2020). These academies are categorised from 1 to 4 (1 being the best) on their ability to meet the various EPPP requirements, with financial benefits awarded for each categorisation (Premier League 2020; Tears et al. 2018). The EPPP focuses on several elements: The Games programme (the provision of matches and tournaments for players), Education (supporting the development of players technical, tactical, mental, physical, lifestyle and welfare), Coaching (supporting coaches' development) and Elite Performance (performance management and injury surveillance). The multi-disciplinary approach of the EPPP aims to allow for better monitoring of player progression and development across a variety of factors and consequently makes it easier for talent identification to occur.

Talent identification is a complicated process of recognising players that are gifted, which is made all the more difficult by the fact that there is little agreement on the definition of talent (Sarmento et al. 2018a). Some researchers argue that talent is the potential for success that a player possesses, whereas other researchers define talent as a player's ability to perform better than others (Helsen, Winckel and Williams 2005; Williams and Reilly 2000). Traditional talent identification approaches have been influenced by coach's subjective analysis and opinion of players, however more objective and scientific approaches now include measurable factors that are attributed to success (Kelly and Williams 2020). For example, technical skill, physiological measurements and anthropometrical measurements, with more holistic approaches including psychological, sociological and cognitive factors (Mills et al. 2012; Ford et al. 2011). Modern talent identification frameworks are now interested in the interaction of these factors and how they contribute to talent, hence why the EPPP includes so many factors (McLaren-Towlson 2017). For example, Unnithan et al. (2012) examined how social, physical, physiological and psychological skills within a model can be potential predictors in success in soccer. A large meta-analysis by Williams, Ford and Drust (2020), published with the aim of improving talent identification in soccer, repeatedly pointed out how there are multiple factors that can impact upon the success of players and this includes sociological, psychological, skill and physical ability. Larkin and O'Connor (2017) took a slightly more applied approach than creating a model and asked coaches what they perceived the most important characteristics in players to be. Similar to Unnithan et al. (2012) and Williams, Ford and Drust (2020) responses included player technical ability, tactical ability and psychological skill. One factor that is becoming more popular in talent identification and talent identification models is detecting and measuring the maturity of players and how this can impact upon success and talent (Malina et al. 2019; Cumming et al. 2017b).

Often players are organised according to chronological age (e.g., 12 years old) however individual differences mean that players of the same age can be at different stages of maturation

(Malina et al. 2019). Maturity is the stage of being fully grown whilst the process of progressing towards maturity is referred to as maturation (McLaren-Towlson 2017; Malina 2014). Growth and development are unique to each individual and is influenced by numerous factors (e.g., hormones and genetics), therefore there are a number of methods in which maturation can be identified which will be discussed in this thesis (Fransen et al. 2017; Mirwald et al. 2002; Khamis and Roche 1994; Tanner-Whitehouse 1966; Tanner 1962; Greulich and Pyle 1959). As chronological age and maturity do not progress at the same rate the EPPP monitors individual player maturation so that training and development plans can catered to the individual player (Unnithan et al. 2012). Previous research has proven that there are several differences in player ability and performance dependent upon maturation and biological age (Malina et al. 2019; Cumming et al. 2017; Portas et al. 2015; Malina et al. 2007). Often more mature players have greater physical ability, such as greater strength and speed, which gives them more of an advantage over their less mature teammates (Kelly and Williams 2020; Parr et al. 2020; Malina et al. 2019). Consequently, more mature players are likely to be selected and/or retained in a phenomenon called the maturation-selection hypothesis (Cumming et al. 2018). However, this is detrimental later on in early maturing players careers because they fail to develop the technical and tactical skills needed in more challenging soccer environments (Malina et al. 2019; Cumming et al. 2018). Later maturing players eventually catch up to their early maturing counterparts, in terms of anthropometrical measurements, and often go onto to be more successful because they developed the needed skills when they were younger, as a consequence of being physiologically disadvantaged (Malina et al. 2019; Cumming et al. 2018). Due to the homegrown rule, teams/clubs want to identify talented players from a young age so that they can invest in their development, however the bias of the maturation-selection hypothesis means that opportunities are being missed when selecting and releasing players.

Consequently, attempts are being made to reduce this bias to allow all players the opportunity to demonstrate their abilities and talent. One such attempt is bio-banding.

Bio-banding is the grouping of players based upon their biological age and/or maturation rather than their chronological age (Salter et al. 2020; Malina et al. 2019; Cumming et al. 2017a; Cumming et al. 2017b; Malina et al. 2017). There has been limited research conducted investigating the effects of maturity status bio-banding but the potential benefits in terms of knowledge of injury reduction and talent identification have made research in this area more popular (Salter et al. 2020; Cumming et al. 2017b). What little research that has been conducted into maturity status bio-banding has reported it to be beneficial for players (Malina et al. 2019; Cumming et al. 2017a; Malina et al. 2017). Bradley et al. (2019) discovered that during maturity status bio-banded competition, early maturing players experienced greater physical and technical challenges whilst late maturing players experienced less challenge and had greater opportunity to demonstrate their skill. Romann, Lüdin and Born (2020) found that in comparison to competitions that were organised by chronological age, maturity status bio-banding resulted in more technical actions being performed, however the physical demand was reduced. This research may be useful for talent identification, as more skills are being performed allows for greater opportunity to showcase ability. Similar findings were reported by Abbott et al. (2019) in which there were differences in technical performance between competitions organised by chronological age and maturity status bio-banding but there were no differences on physical demand. However, the conclusions that can be made from this thesis are limited as there were only 25 male participants within the sample. Both Romann, Lüdin and Born (2020) and Abbott et al. (2019) compared the differences in player performance between chronological and maturity status bio-banded formats of competition, however greater insight would be gained if research focussed on the differences in performance between the different maturity status bio-bands and how players of different maturity status bio-bands perform against each other. This information would enable greater understanding of bio-banding and whether it is able to overcome the maturation-selection hypothesis and create even competition for all players. Therefore, the aims of this thesis are to investigate whether players in different maturity status bio-bands perform differently in maturity status bio-banded competition and if the various methods of identifying maturity status biological age and consequent bio-banding result in differences in player performance.

Chapter 2. Literature review

2.1 Elite Player Performance Plan

This review of literature is of ‘narrative’ design (Boland, Cherry and Dickson 2013) and analyses relevant research in relation to performance analysis, maturation and bio-banding in elite soccer, in the hopes that it will identify gaps within talent identification and how they may be overcome to improve the number of players available for selection at elite levels.

The Financial Fair Play was introduced in order to prevent clubs from spending beyond their capabilities and thus prevent financial difficulties arising (Mareque, Barajas and Lopez-Corrales 2018; Plumley, Ramchandani and Wilson 2018). In an attempt to aid clubs’ from overspending the English Premier League (EPL) created the ‘home-grown’ rule in which soccer teams must comprise of a minimum of eight ‘home-grown’ players (Reeves and Roberts 2013; Bullough and Jordan 2017). By introducing this rule clubs have less opportunity to spend money on foreign players whilst giving home-grown and/or novice players more opportunity (Union of European Football Associations 2019a). In response, soccer teams started to invest more time and money into the talent identification and development of younger players, which resulted in the EPL creating the elite player performance plan (EPPP) (Premier League 2020).

The EPPP is a long-term development initiative that focusses on creating more, high quality, ‘home-grown’ players through four main factors; the games programme, education, coaching and the elite programme (Kelly et al. 2018). The EPPP aims to develop players overall through a multidisciplinary approach that is based upon the ‘Four Corners Model’ (The Football Association 2020; Morley et al. 2014; Mills et al. 2012). The EPPP caters for players from ages 5 to 23 years and their development in the various disciplinary factors is monitored throughout the programme (Premier League 2020; Kelly et al. 2018). The monitoring of players in the EPPP allows for individual player progression to be identified and training can therefore be adjusted to suit individual needs and development. Players are organised into different groups dependent upon their age; players aged under-9 to under-11 are organised into the Foundation Phase, players aged under-12 to under-16 into the Youth Development Phase and under-17 to under-23 into the Professional Development Phase (Premier League 2020). Each group is focussed on different development goals to help players grow and improve as they progress towards the end of the EPPP in the hopes of obtaining a professional contract. These goals are informed by the information and data that is collected on the players through a multitude of tests and statistics.

2.2 Monitoring players in the Elite Player Performance Plan

Players within the EPPP regularly compete in matches and training which differs according to age and what phase they are in. For instance, players within the Foundation Phase train 2 to 3 times a week and will play 1 match. This soccer match is played in 4 15-minute quarters and is played on a significantly smaller sized pitch with limited players, usually 4 or 5. In contrast, players within the Professional Development Phase mirror the schedule of professional soccer players, therefore they will train up to 7 times a week and will play in 1 or 2 matches a week. These matches are played in 2 45 minutes halves and take place on a full-sized pitch with 11 players. During matches and training a multitude of data is collected (e.g., heart rate data, Global Positioning System data and Rate of Perceived Exertion data) in order to inform future training and monitor player performance, this is particularly useful when a player has sustained an injury and performance must be monitored to prevent re-injury during the return to play process (Owen et al. 2017). However, this information is most often used to monitor player progressions and development throughout the year and identify if players are reaching potential and performing up to standard

(Owen et al. 2017). This is achieved through various means, for instance players complete a battery of tests, three times a year, that assess players physical abilities. This involves taking anthropometrical measurements, to monitor players physical development, and physiological tests, to monitor players physical ability (Turner et al. 2011). These tests and measurements are informed by up-to-date research and are subject to stringent reliability and accuracy checks (ISAK 2021; Stewart et al. 2011). Whilst this information is useful in providing insight regarding player fitness and development, it is limited as the information is taken out of context and only provides insight from one perspective. In recent research some coaches shared their opinion that fitness testing is "important, but it's not everything" (McCormack et al. 2020). In order to make the physiological data collected more applied, players often wear Global Positioning System (GPS) units to monitor the physical performance of players during matches as GPS data can give insight into player workload (Anderson et al. 2015). However, the Four Corners Model used within the EPPP encourages a multidisciplinary approach to monitoring player performance and talent identification. Therefore, soccer academies also collect data on the technical abilities of players, in addition to the physiological and anthropometrical information, in order to gain a more well-rounded perspective of a players in the hopes of identifying talented players from more than just one perspective (Mustafović et al. 2020; The Football Association 2020).

2.3 Performance analysis and reliability

Larkin and O'Connor (2017) conducted interviews with 20 technical directors and coaches and reported that technical and tactical ability are two of the most important factors in soccer, especially when identifying talented players. Further research has identified that technical skills contribute to more than half of the actions performed by an individual during matches (Thomas, Fellingham and Vehrs 2009). There is numerous research that is devoted to identifying the key aspects of a performance due to the importance and prevalence of technical and tactical skills in soccer (James 2006). These aspects are often termed key performance indicators (KPI's) and their identification and selection is influenced by a number of factors (Hughes and Franks 2008). Choi (2008) proposed that KPI's should be influenced by coach opinions as they are the experts and possess experience and/or qualifications to drive their information (O'Donogue 2008). However, this can be influenced by individual, team and club philosophies and experiences which can impact upon the factors being identified. Another method, that is popular in research, is to identify the performance of KPI's according to successful and unsuccessful players/teams (Castellano, Casamichana and Lago 2012; Figueiredo et al. 2009a). However, this approach is also limited as the definition of success can differ depending upon the sample being analysed and the purpose of the research. For example, success for a grassroots team may be that all the members of the team get match time, whilst success for a professional team may be winning a league competition, therefore comparing the influencing factors of the two samples is meaningless. On the other hand, Lames and McGarry (2007) suggested that KPI's should be driven by a combination of mathematical and qualitative techniques to analyse performance as player and/or team performance is 'unstable', being influenced by a multitude of factors, and therefore cannot be fully explained by either equation or opinion/experience. However, Williams (2012) argued that the bespoke flexibility of KPI's and operational definitions means that they can be informed by and applied to various situations, sports, teams and individuals. Regardless of the selection method, once the relevant KPI's and operation definitions have been chosen, it is important to give these indicators descriptions, which are termed operational definitions (O'Donoghue 2007; Hughes and Bartlett 2002).

For the purposes of reliability and replicability it is key that KPI's and operational definitions are clear and easy to understand. Williams (2012) argued that the bespoke flexibility of KPI's and operational definitions is useful as they can be applied to situations that are unique to sports, teams, individuals and tactical approaches. When subjecting KPI's and operational definitions to reliability testing often inter- and/or intra-reliability tests are used. However, O'Donoghue (2007) argues that intra-rater reliability fails to prove the validity of the analysis that has been undertaken and instead it is merely testing the increasing awareness and learning of the analyst (Hopkins 2017). In a later publication O'Donoghue (2010) does however, acknowledge that intra-rater reliability is useful when there is no opportunity to train another analyst/operator. Likewise, there are some that argue that any attempt at reliability testing is better than none at all, which is further supported by the fact that there is published research that utilises intra-rater reliability (Drummond et al. 2019; Gong et al. 2019; McGarry, O'Donoghue and Sampaio 2013; Wells, Hughes and O'Donoghue 2009; Cooper et al. 2007). To assist practitioners in completing reliability and validity testing, Hopkins (2017) published spreadsheets to make testing simpler, which have been cited a number of times (Google Scholar 2021).

In conclusion, by selecting the most relevant KPI's, applying appropriate operational definitions and subjecting the results to reliability testing this should provide the most accurate representation and insight into player performance during games/matches/performance.

2.3.1 Performance analysis in elite soccer

Larkin and O'Connor (2017) reported that according to coaches and technical directors, technical and tactical ability are two of the most important factors in soccer. The study further reports that technical and tactical ability, including factors such as first touch, 1 v 1 and striking the ball, are perceived to be the most important skills because they are "fundamental", "extremely important" and "without…(them)…the other core skills of the game are not possible". Due to technical and tactical skills being so important in both team and individual success in soccer there is, consequently, a large amount of research that focusses on the KPI's and operational definitions used in soccer (Mackenzie and Cushion 2012). Hughes et al. (2012) took advantage of a performance analysis conference to use the input and experience of 66 sports practitioners (15 expert performance analysts, 51 wider practitioners) to create a comprehensive guide to KPI's in soccer according to playing position. It is common practice to divide analysis by playing position as the different roles have different and unique requirements, for example the role of goalkeeper is unique and therefore cannot be compared to the role of a striker and vice versa (Hughes and Franks 2008; Di Salvo et al. 2007). Whilst the work of Hughes et al. (2012) was wide-ranging, it failed to include or explain any operational definitions to accompany the identified KPI's. The study provides good insight the specific KPI's used within soccer however it lacks the detail necessary to make the findings fully applicable, for example "support play" is listed as a tactical KPI but what exactly does that entail? Whilst O'Donoghue (2007) argued that operational definitions do not need to be specific, as agreed understanding is enough, in this instance it is difficult to comprehend the necessary agreement through written means. Mackenzie and Cushion (2012) completed a large meta-analysis of performance analysis research published prior to 2012 and likewise found that out of 44 published articles only 9 fully defined the variables that were analysed. Williams (2012) reported similar findings in a meta-analysis in which 131 papers out of 278 referred to operational definitions that were utilised, however only 80 papers produced definitions that were clear and replicable. Williams (2012) concluded that in order to be able to fully compare the findings of different research, that the operational definitions used need to be clear and fully explained. Liu et al. (2013) investigated the reliability of a performance analysis company called OPTA sports and in the process the authors made a comprehensive list of all KPI's and operational definitions that the company utilises. OPTA sports is a company that specialises in producing analysis and statistics for a number of teams and sports around the world and are considered to be world leading in this area (OPTA 2020). Liu et al. (2013) completed an inter-operator analysis using four operators who did not know that the study was being conducted. The study reported high Cohen's Kappa values (0.92 to 0.94) and low typical error (0.00 to 0.37), therefore showing strong agreement and reliability between the different analysts. The authors concluded that this was due to "rigid operational event definitions and the high quality of strict user training" (OPTA 2012). The few errors that did occur were credited to incorrectly identifying individual players, for example when a number of players stand in the penalty area it is more difficult to identify who made contact the ball. Further errors were attributed to the interpretation of certain events where there is crossover between KPI's and operational definitions, for example when a player heads the ball to another teammate this could be defined as both 'aerial' and 'successful pass'. Following the reliability study of Liu et al. (2013), Liu et al. (2015) used almost identical KPI's and performance indicators to investigate these factors within a more applied tournament setting to try and identify differences in performance between more and less successful teams. The research collected data from 380 matches in the Spanish First Division Professional Football League from the 2012-2013 season. The findings reported that teams/players at the top of the league performed more assists, shots on target, ball touches, passes, successful passes, through balls and dribbles than teams/players at the bottom of the league. Harrop and Nevill (2014) also reported that passes ($P = 0.000$) and successful passes ($P = 0.001$) were KPI's that were able to predict success in League One soccer teams with shots and dribbling also being important factors. In contrast, Jones, James and Mellalieu (2004) completed research that focuses solely on possession as a KPI in soccer, reporting that successful teams had significantly ($P < 0.01$) longer possession in comparison to unsuccessful teams. Successful teams maintained possession for 20 seconds or more for 10.2 % of total possession time in comparison to less successful teams, that maintained possession for 20 seconds or more for 4.4% of total possession time. MacKenzie and Cushion (2012) completed a large meta-analysis that examined the performance analysis that had been completed in soccer and found that 48 studies analysed more than 20 different KPI's in soccer. These factors included converting shots to goals, shots on goal, shots within 16m, 1st time shots, creating chances, long passes, short passes, shooting from central areas, passes in offensive areas, possession, length of individual player possession, crosses, counter attacks, receiving the ball in the offensive areas, tackling, dribbling, one on ones, set plays, penalties and creating space. As the literature in this chapter has shown there are a number of key performance indicators that have been used to examine performance in an attempt to gain further insight. Therefore, the wide variety of KPI's that can be investigated make it difficult to select and identify those that are most important. Table 1. shows some of the indicators that have been used in previous research which shows that there are some KPI's that are examined more frequently, for example, passes, shots, dribbling and goals. Whilst all of the research presented in this section is useful in providing insight into the performance analysis of elite soccer, it is not applicable to young players (Harkness-Armstrong et al. 2020). For example, the findings cannot be applied to those players who are in the Foundation Phase as there are differences in match limitations (e.g., pitch size, number of opposition), tactical approaches (e.g., positions on the pitch, the number of players committed to set players) and physical capabilities (e.g., aerobic capacity, muscular endurance) between youth soccer and adult soccer, respectively. Therefore, the findings of this research cannot be used as a comparative resource when identifying talent in youth players.

Table 1. The Key Performance Indicators and Operational definitions investigated in previous elite adult soccer.

Study	Key Performance Indicators	Operational definitions
Hughes et al. (2012)	Tackle Pressing opposition Interception Clearance Heading/defensive heading Shooting Reception Passing Dribbling Running with the ball Support play Crossing	N/A
Liu et al. (2013)	Aerial duel	Two players competing for the ball in the air, for it to be an aerial both players must jump and challenge each other in the air and have both feet off the ground.
	Assist	The final pass or cross leading to the recipient of the ball scoring a goal.
	Ball recovery	The event given at the start of a team's recovery of possession from open play.
	Block	A defensive block, blocking a shot going on target. This must be awarded to the player who blocks the shot.
	Challenge	A defender tries to stop a player dribbling past him.
	Clearance	Players attempt to get the ball out of the danger zone, when there is pressure behind them, or there is pressure on the player to clear the ball from the danger zone.
	Cross	Any ball played into the opposition team's area from a wide position.
	Dispossessed	When a player is tackled without attempting to dribble past his opponent.
	Dribble	An attempt by a player to beat an opponent in possession of the ball.
	Foul	Any infringement that is penalised as foul play by a referee.

	Interception	An interception is given when a player intercepts a pass with some movement or reading of the play.
	Key pass	The final pass or cross leading to the recipient of the ball having an attempt at goal without scoring.
	Offside	Being caught in an offside position resulting in a free kick to the opposing team.
	Pass	An intentional played ball from one player to another.
	Shot	An attempt to score a goal, made with any (legal) part of the body, either on or off target.
	Tackle	The act of gaining possession from an opposition player, when he is in possession of the ball.
	Through ball	A pass playing a player through on goal which could lead to a goal scoring opportunity.
	Touches	A sum of all events where a player touches the ball.
	Turnover	Loss of possession due to a mistake/poor control.
Liu et al. (2015)	Assist	The final pass or cross leading to the recipient of the ball scoring a goal.
	Shot	An attempt to score a goal, made with any (legal) part of the body, either on or off target.
	Shot on target	An attempt to goal which required intervention to stop it going in or resulted in a goal/shot which would go in without being diverted.
	Ball touch	A sum of count values of all actions and events where a player touches the ball.
	Pass	An intentional played ball from a player to his teammate.
	Pass accuracy	A ratio calculated from successful passes divided by all passes.
	Through ball	A pass made by a player that split the last line of defence and plays a teammate through on goal.
	Key pass	The final pass or cross leading to the recipient of the ball having an attempt at goal without scoring.
	Cross	Any ball sent by a player into the opposition team's area from a wide position.
	Dribble	A dribble is an attempt by a player to beat an opponent in possession of the ball.
	Foul drawn	Where a player is fouled by an opponent.
	Aerial duel	Two players competing for a ball in the air, for it to be an aerial duel both players must jump and challenge each other in the air and have both feet off the ground.
	Dispossessed	When a player is tackled without attempting to dribble past his opponent.
	Turnover	Loss of possession to opponent players due to a mistake/poor control.
	Offside	A player being caught in an offside position resulting in a free kick to the opposing team.
	Tackle	Act of gaining possession from an opposition player who is in possession of the ball.
	Interception	A player intercepts a pass with some movement or reading of the play.
	Clearance	Attempt made by a player to get the ball out of the danger zone, when there is pressure (from opponents) on him to clear the ball.

	Shot block	A player blocks a goal attempt heading roughly on target toward goal, where there are other defending players or a goalkeeper behind the blocker.
	Foul committed	Any infringement committed by a player that is penalised as foul play by the referee.
	Yellow card	Where a player is booked by the referee due to illegal actions.
Harrop and Nevill (2014)	Total shots Shots on target Shots inside the penalty area Passes Successful passes Passes in opposition half Fouls received Dribbles Crosses Corners Offsides committed Fouls committed Crosses against Corners against Yellow cards Red cards	N/A
Delgado-Bordonau et al. (2013)	Total shots Shots on goal Shots off goal	N/A
Castellano, Casamichana and Lago (2012)	Goals scored Total shots (performed and received) Shots off target (performed/received) Shots on target (performed/received) Ball possession Offsides (committed/received) Fouls received Corners (committed/received) Yellow/red cards	N/A
Lago-Ballesteros and Lago-Peñas (2012)	Goals for Goals against Total shots Shots on goal Shooting accuracy Assists Crosses (performed/against) Offsides (committed/received) Fouls (committed/received) Corners (committed/received) Ball possession Yellow/red cards	N/A
Taylor, Mellalieu and James (2004)	Aerial Challenge Clearance Cross Dribble Interception	

	Loss of control Pass Tackled Tackle Shot Penalty Corner Throw-in Indirect free kick Direct free kick Rule breach	
James (2006)	Goal conceded Successful aerial challenge Interceptions Successful tackles Successful dribbles Successful passes Shots taken Goals scored	
Zhou et al. (2018)	Shot	An attempt to score a goal, made with any (legal) part of the body, either on or off target.
	Shot on target	An attempt to goal which required intervention to stop it going in or resulted in a goal/shot which would go in without being diverted.
	Possession	The duration when a team takes over the ball from the opposing team without any clear interruption as a proportion of total duration when the ball was in play.
	Possession in opponent half	Possession of a team in opponent's half of pitch.
	Pass	An intentional played ball from one player to another.
	Pass accuracy	Successful passes as a proportion of total passes.
	Forward pass	An intentional played ball from one player to another who is located in opponent's half of pitch.
	Forward pass accuracy	Successful forward passes as a proportion of total forward passes.
	Opponent 35m entry	Number of times when the ball (possessed by the attacking team) enters the 35 m area of the opponent's half of pitch.
	Opponent penalty area entry	Number of times when the ball (possessed by the attacking team) enters the penalty area of the opponent's half of pitch.
	Cross	Any ball sent into the opposition team's area from a wide position.
	Corner	Ball goes out of play for a corner kick.
	Offside	Being caught in an offside position resulting in a free kick to the opposing team.
	50-50 challenge won	50% challenge duels won by a team as a proportion of total duels of the match.
	Foul committed	Any infringement that is penalised as foul play by a referee.
	Yellow card	Where a player was shown a yellow card by the referee for reasons of foul, persistent infringement, hand ball, dangerous play, time wasting, etc.

2.3.2 Performance analysis in elite youth soccer

With increasing requirements for soccer academies/teams to identify 'home grown talent' there is likewise, an increasing need for talented players to be identified at a young age. There are several methods of identifying talent, such as anthropometrical measurements and coach and/or scout opinions, however the most contextual and applicable to soccer can be identified through information from match performances, which can be achieved through performance analysis information. Harkness-Armstrong et al. (2020) compared the performance of elite youth female soccer players and found that of the 24 KPI's investigated that interceptions, tackles and passes were the most commonly performed KPI's. These findings are somewhat similar to those reported in elite adult soccer performance analysis (Harrop and Nevill 2014; Liu et al. 2013). However, the majority of research completed in soccer has been conducted using male players, therefore the findings of Harkness-Armstrong et al. (2020) are less comparable to wider research due to the study using a sample of female players. Forsman et al. (2016) analysed the technical and tactical attributes of 114 male soccer players, aged 15-year-old and found that more talented players (players that went on to compete in men's first division or higher) were better at passing than less talented players (players that went on to compete in men's second division or lower). However, Huijgen et al. (2009) found that dribbling was the skill that was able to indicate talented players (those that went on to become professionals) in comparison to less talented players (those that went on to become amateur players). The sample used in the study was large (n = 131) and the dribbling data was collected using Shuttle Dribble Tests, which gives accurate insight into player ability, however the results are out of context as they are not taken from an in-game scenario (Russell, Benton and Kingsley 2010). Therefore, the findings may in fact be showing the impact of anthropometrical and physiological ability as opposed to the dribbling skill that differentiates players. Jamil and Kerruish (2020) completed a much more applied and contextual study by examining player performance during matches to identify the time point in time that players are 'most productive' and complete the most KPI's. The study reported that wingers aged 16-20 years old and 21-25 years old had more shots on target ($P = 0.022$ and $P = 0.04$) and more attempts from wide play ($P = 0.012$ and $P = 0.028$) than players aged over 26 years. Strikers aged 21-25 years old were also more proficient at shooting on target from outside the box ($P = 0.024$) and scoring goals from outside the box ($P = 0.021$) than players aged over 26 years. This supports the argument that talented players need to be identified at a younger age as this is when they are most productive. However, comparing players in this manner is limited, as individual differences can have an impact upon performance and the outcome of the research.

2.4 Small-sided games in elite soccer

One approach to talent identification that does not rely upon testing to gain insight into player ability is small-sided games (Williams, Ford and Drust 2020). Small-sided games were first designed a means of training players, as SSG's can be used to meet different training demands and therefore are highly flexible and adaptable (Hodgson, Akenhead and Thomas 2014). Small-sided games (SSG's) are adapted versions of full-sized games where the number of players in can range from 1-a-side to 6-a-side, with pitch sizes ranging from 100 m^2 to 2700 m^2 and the duration of the matches also varying in length (Clemente and Sarmento 2020; Aguiar et al. 2012). Despite being used as a training method, SSG's have been proven to be able to mimic the demands of full match play and are therefore useful as both a tool for training and talent identification (Fenner, Iga and Unnithan 2016; Aguiar et al. 2012; Rampinini et al. 2007). Heart rate, blood lactate levels and rate of perceived exertion can all be altered in response to changing pitch size and number of players on the pitch, with fewer players and larger pitch size's often resulting in higher reported occurrences (Sarmento et al. 2018b). For example, Williams and Owen (2007) reported that differences in pitch size in a 3 vs 3 SSG format resulted in differences in heart rate when pitch dimensions were 20 x 15 m (mean HR = 164 ± 12), 25 x 20 m (mean HR = 166 ± 9) and 30 x 25 m (mean HR = 171 ± 11). Rampinini et al. (2007) used very similar pitch dimensions, also with a 3 vs 3 SSG format, and also reported differences in heart rate; 20 x 15 m (mean HR = 89.5 ± 2.9), 25 x 15 m (mean HR = 90.5 ± 2.3) and 30 x 18 m (mean HR = 90.9 ± 2.0). This suggests that larger pitch sizes result in greater aerobic demand of players due to the larger surface area that is available to each player. Larger differences in heart rate were reported when the pitch dimensions remained the same but the number of players in each team differed (Hill-Haas et al. 2011). For example, Owen, Twist and Ford (2004) reported differences in percentage of maximal heart rate between different SSG formats of 1 vs 1 (89.0%), 2 vs 2 (87.4%) and 3 vs 3 (81.7%). Rampinini et al. (2007) also reported differences in mean heart rate between 3 vs 3 (90.0 ± 2.0), 4 vs 4 (89.4 ± 1.8), and 5 vs 5 (87.8 ± 1.8) SSG game formats. Sannicandro and Cofano (2017) reported differences between game formats in heart rate (3 vs 3 (87.2 ± 3.3%, $P > 0.05$), 4 vs 4 (83.8 ± 3.8%, $P < 0.05$) and 5 vs 5 (83.7 ± 3.6%, $P < 0.05$)) and RPE (3 vs 3 (17.5 ± 0.7, $P < 0.05$), 4 vs 4 (16.4 ± 1.3, $P < 0.05$) and 5 vs 5 (15.8 ± 1.1, $P < 0.001$)). This suggests that SSG's are a useful method when training aerobically as differences in pitch size and the number of players in each team can impact upon the mean and maximal heart rates achieved. However, Sannicandro and Cofano (2017) reported that whilst smaller teams resulted in greater aerobic demand the performance of the athletes declined in quality. For instance, fewer successful passes (3 vs 3 = 65%, 4 vs 4 = 69% and 5 vs 5 = 76%) were performed, a greater number of poor passes (3 vs 3 = 35%, 4 vs 4 = 31% and 5 vs 5

= 24%) were performed and fewer tackles (3 vs 3 = 33, 4 vs 4 = 39 and 5 vs 5 = 59) were performed. In terms of performance analysis, studies have found that the number of technical actions also alter dependent upon team size, with smaller teams resulting in more KPI's being performed overall per player (Almeida, Ferreira and Volossovitch 2013; Aguiar et al. 2012). This may explain why Sannicando and Cofano (2017) reported a greater number of poor passes and fewer unsuccessful passes in a 3 vs 3 SSG format than in 4 vs 4 and 5 vs 5 formats, as smaller teams are able to perform more passes that are more successful. Owen et al. (2014) reported that passes, receiving passes, dribbling, tackles and shots were all performed significantly ($P < 0.05$) greater in 4 vs 4 SSG's than in 5 vs 5 to 11 vs 11 SSG's. In contrast Da Silva et al. (2011) found that the number of passes, tackles and headers performed were not influenced by team size however, the number of dribbles, crosses and shots on goal were more prevalent in smaller teams. Katis and Kellis (2009) found that smaller teams resulted in significantly ($P < 0.05$) more performances of short passes, kicks, tackles, dribbles and goals scored. The pitch size has also shown to impact upon performance of technical actions (Williams, Ford and Drust 2020). Kelly and Drust (2009) reported that smaller pitch sizes resulted in greater numbers of tackles (30 x 20 m = 45 ± 10, 40 x 30 m = 15 ± 4, $P < 0.05$) and shots (30 x 20 m = 85 ± 15, 40 x 30 m = 60 ± 18 and 50 x 40 m = 44 ± 9, $P < 0.05$) being performed. Hodgson, Akenhead and Thomas (2014) also reported that a smaller (30 x 20 m) pitch size resulted in greater technical demand on players with passes, shots and tackles being performed more than on medium (40 x 30 m) and large (50 x 40 m) pitches. This combined research suggests that larger pitch sizes result in greater physiological demand but less tactical demand, whilst smaller pitch sizes result in lesser physiological demand but greater tactical demand. Therefore, the flexible nature of SSGs are useful as they allow players the opportunity to showcase their abilities (Sarmento et al. 2018). However, this adaptability means that there is a variety of SSG formats (e.g., rules, player numbers and pitch area) used in research as there is no one method nor structure that is considered best or 'gold standard' (Williams, Ford and Drust 2020). A recent study by Fenner, Iga and Unnithan (2016) was able to provide some validity to the SSG format they used (4 vs 4, 18.3 x 23 m) by investigating athlete performance in relation to TID. The study attempted to identify if the performance of players during SSG's correlated with coach perceptions of player ability. The study used GPS units to track player motion and activity during each SSG and combined this with a game technical scoring chart (GTSC) and total points achieved. The GTSC gives a total score of an observer's perception of a player and is based around a number of multidisciplinary factors. These factors include cover/support, communication, decision making, passing, first touch, control, 1 vs 1, shooting, assists and marking, with each factor given a score out of 5 (where 1 is poor and 5 is excellent). The total points were awarded based upon the outcome of each game rather than the number of goals scored in each game, i.e., 0 points were awarded for a loss, 2 points for a draw and 4 points for a win. The study found that GTSC had a strong relationship ($r = 0.545$) with total points awarded ($P < 0.001$) and high-speed running ($P < 0.05$). However, Unnithan et al. (2012) reported a "low but meaningful" relationship ($r = 0.39$, $P = 0.07$) between GTSC and total points therefore with a larger sample of players more talented players could surface. Therefore, this particular SSG format can be used to accurately and validly identify talented players in elite youth soccer, however there are limitations. Whilst using coach perceptions as a means of validation is a useful tool there will always be an element of error when using something so subjective as opinion (Dugdale et al. 2020). Also, within SSG's it is easier for individual differences to influence the outcomes, for example, different playing positions can have an effect (Unnithan et al. 2012). Due to the demands of playing positions in full-sided games, certain positions are predisposed to do well in certain aspects of the GTSC in comparison to other positions. For example, a striker is more likely to be able to complete goals and assists in comparison to a goalkeeper, which would consequently impact upon the GTSC points given by observers. Using the same example of goals and assists, if a striker is awarded full points for these two factors, they would receive 10 points, whilst a keeper who is awarded the lowest points would receive 2 points. This resulting 8-point difference does not seem like much, however over a number of games an even larger difference would start to accumulate therefore impacting upon the conclusions made about players. Additionally, individual differences can make it difficult to identify talented players due to biological differences and maturity (Kowalski and Humbert 2020; Bass et al. 2000).

2.5 Maturity

One particular aspect that the EPPP monitors is the maturity and maturation of players (Premier League 2020). Maturity is the state of being fully grown, biologically mature or having reached adult stature, whilst maturation is the process towards reaching maturity (Malina 2014). From birth to adulthood an individual is continually developing and growing, with certain points during this development that are prominent for periods of rapid growth. Figure 1. shows that the greatest growth and development occurs during the period following birth to early childhood, ages 0 to 4 years old. Following this, growth and development continues at a slightly slower pace from ages 4 to 10 years old for females and 4 to 12 years old for males, respectively. Another rapid period of development can be observed from adolescence to adulthood, 10 to 12 years old for females and 12 to 14 for males. Finally, the rate of development slows post adolescence to adulthood, ages 12 to 16 for females and 14 to 18 for males. Figure 2. shows that there are a number of indicators that can indicate growth and development. The lymphoid and genital factors refer to sexual characteristics and maturation. The neural factor refers to the development of the brain and nervous system. The general factor refers to the overall development of an individual for instance, the development of the skeletal system and body mass, which in turn impacts upon overall height and weight (figure 1.). Each of these factors provides valuable insight into maturation and maturity, however each method of identify maturation has limitations that impact upon the accuracy and usability of each of the factors listed. There are several consequences should maturation be incorrectly identified, particularly in talent identification and soccer. The following chapters will discuss and critically analyse the various methods of identifying maturation and comment on the impact of each method in soccer.

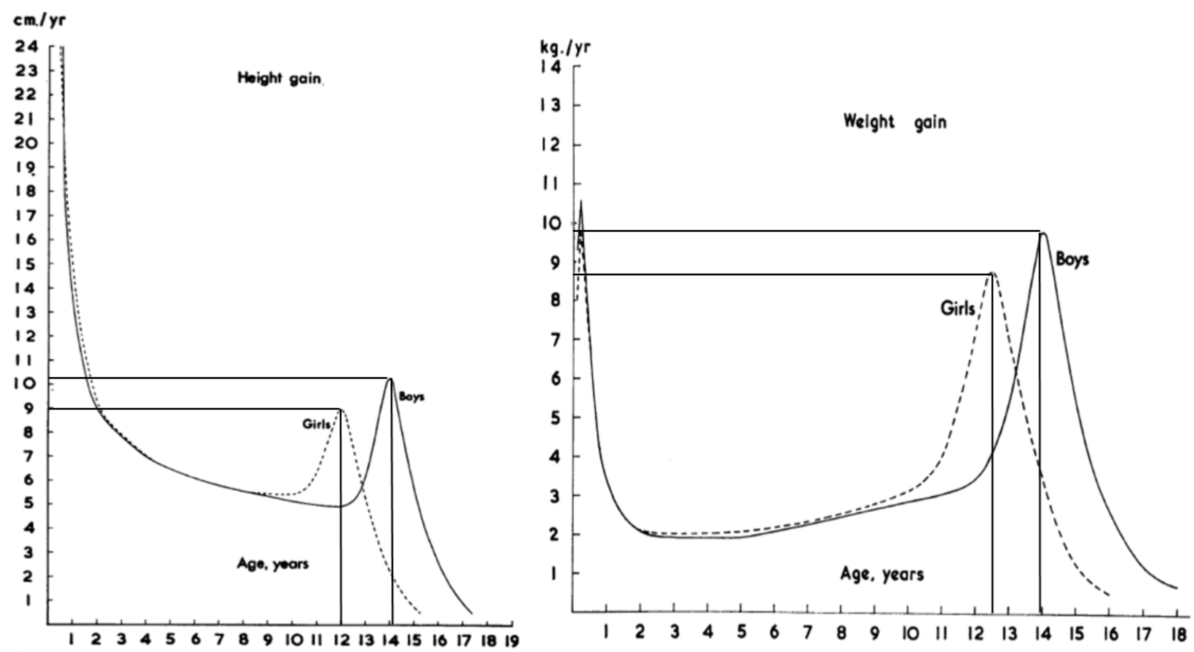


Figure 1. The height and weight gain velocity curves for boys and girls (Adapted from Tanner et al. 1966).

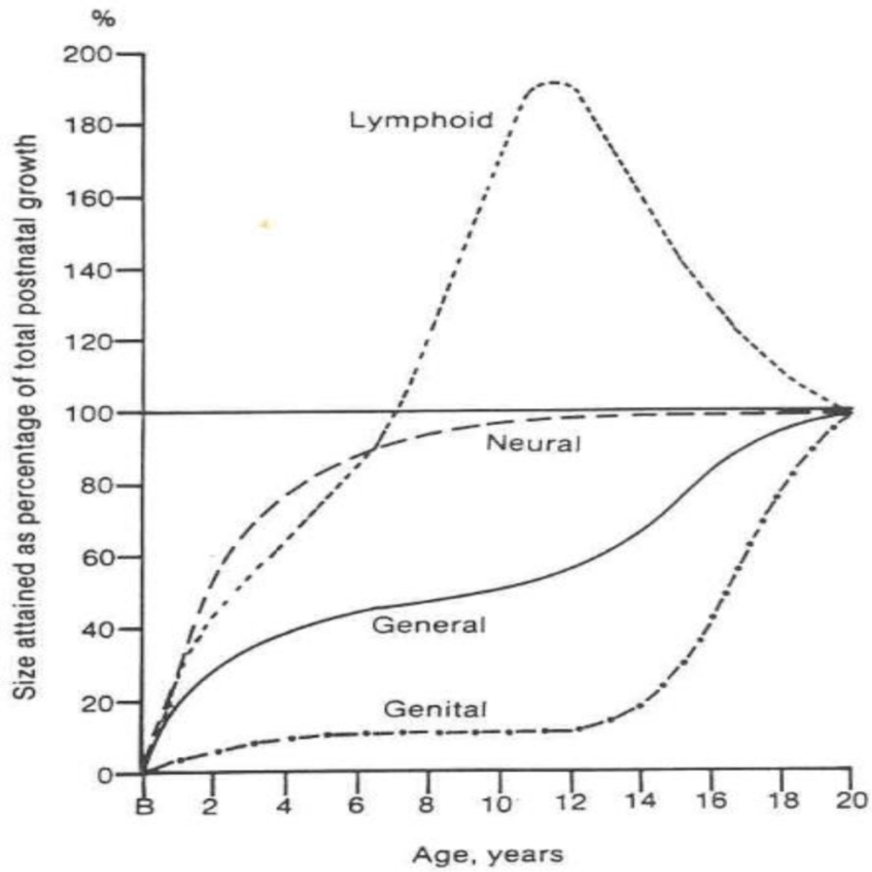


Figure 2. The growth curves for lymphoid, neural, general and genital development (Taken from Malina, Bouchard and Bar-Or 2004).

2.6 Measuring skeletal maturity

The skeleton is vital in growth and development as it is one of the building blocks of body composition, for instance it determines stature and limb length (Malina, Bouchard and Bar-Or 2004). As an individual develops towards maturity the skeleton goes through several phases of development before reaching full growth. This is termed skeletal maturation and it refers to the ossification of the skeletal system from initial bone formation to full adult growth (Macha et al. 2017). This method of identifying maturation is often measured through x-rays or radiographs which allow for stage of bone development to be identified (Mughal et al. 2014; Nahaas et al.

2013). The main approaches to identifying skeletal maturation are the Greulich-Pyle method (1959), the Tanner-Whitehouse method (1966), Tanner-Whitehouse method (1975; TW2), Tanner-Whitehouse method (2001; TW3) and the Fels method (1988).

<u>The Greulich-Pyle method (1959)</u>

The Greulich-Pyle method involves comparing the hand and wrist bones against predetermined 'reference' radiographs from different age groups (Bull et al. 1999). Each of the bones in the hand and wrist are measured and a median value is used to compare the results against the 'reference' radiographs from which the skeletal age is identified, with recent studies reporting that this method of identifying maturation is reliable (Chaumoitre et al. 2017). Paxton et al. 2013 reported that skeletal age was calculated as being only 2.2 months less than chronological age in their study of 654 children. Chronological age refers to the age of a child in relation to their birth date i.e., 12 years old. Despite its reported accuracy the Greulich-Pyle method is limited in its applicability as it is based upon the radiographs of Caucasian American Children. Studies that have used the Greulich-Pyle method on more diverse ethnicities have reported more significant differences. Dembetembe and Morris (2011) found a 12-month lesser difference than chronological age when using the Greulich-Pyle method with a sample of African males. An earlier study by Lewis, Lavy and Harrison (2002) found an even greater average difference of 20 months between skeletal age and chronological age within 139 Malaysian children. However, a more recent study by Alshamrani et al. (2019) reported no significant differences between skeletal age and chronological age in Caucasians, Hispanics, African males and Asian females, but reported that there should be some cautiousness applied when the method is used in connection to Asian male and African female groups.

Tanner-Whitehouse method (1966, 1975 and 2001)

Similar to the Greulich-Pyle method the Tanner-Whitehouse method also uses x-rays of the hand and wrist to identify skeletal age (Malina et al. 2018). However, the Tanner-Whitehouse method matches specific features against a specific criteria, with each bone being given a score based on how it meets each condition. The Tanner-Whitehouse method also has a wider ethnic representation, where the initial 'reference' images and criteria are based upon American, Argentinean, Italian, Japanese and Spanish children, therefore this particular method is more widely applicable. The first Tanner-Whitehouse method was introduced in 1966 changes made in 1975 and 2001, resulting in TW2 and TW3 versions of the method (Ahmed and Warner 2007). Schmidt et al. (2008) conducted a study to compare the TW2 and TW3 versions of the method and found that the TW2 version resulted in a difference of -1 month and +16 months between skeletal age and chronological age, whilst the TW3 version resulted in a difference of -4 months and +2 months between skeletal age and chronological age. Pinchi et al. (2014) also compared the TW2 and TW3 versions and reported that the TW2 version was only able to accurately report skeletal age in 80.88% of males and 75.67% in females whilst the TW3 version was able to accurately report skeletal age in 88.24% of male and 81.57% of females. Schmidt et al. (2008) recommend that the most recent version of the Tanner-Whitehouse method, TW3, should be used to allow for greater accuracy whilst limiting over estimation. Despite the improvements that have been made to the method to increase the accuracy, there are still limitations to this method. For instance, the position of the hand and wrist during the x-ray impacts upon the results of the accuracy of the skeletal age given (Cox 1996). A further limitation is that the scoring of each bone is subjective and based upon human decision, despite the set criteria, resulting in differing inter-observer agreement (Cox 1996). Attempts to overcome this subjectivity resulted in the use of computer programming to categorise the stage of bone development (Cox 1996). Studies have found high levels of accuracy and reliability when using computer programming, particularly in comparison to manual methods (Lee et al. 2017; Tanner and Gibbons 1994).

<u>Fels method (1988)</u>

A further method of measuring skeletal maturity is the Fels method, which was created through a longitudinal study of 667 American Caucasian children (aged 1 month to 22 years), over a period of 45 years where measurements were taken on 13,823 occasions (Nahhas et al. 2013). Similar to the Greulich-Pyle and Tanner-Whitehouse methods the Fels method also uses radiographs of the hand and wrist to assess skeletal maturity by grading the various bones according to a criterion. However, the Fels method is unique as it provides skeletal age as an estimate with standard error, therefore acknowledging that there may be a degree inaccuracy (Nahhas et al. 2013). Despite this, the Fels method has been shown to significantly under report skeletal maturity when compared to the Tanner-Whitehouse method (Malina et al. 2007; Lenthe, Kemper and Mechelen 1998). Malina et al. (2007) found that when measuring a sample of soccer players, the Fels method reported that two individuals were skeletally mature whilst the Tanner-Whitehouse method reported 11 players were mature. When comparing the Greulich-Pyle, Tanner-Whitehouse and Fels methods, Vignolo et al. (1992) reported that whilst the Fels method had the highest repeatability and reproducibility (RMSE = 0.83), the Greulich-Pyle was the most accurate (± 0.3 – 0.4 years) as the Tanner-Whitehouse (± 0.7 – 0.8 years) and Fels methods over-reported (± 0.4 - 0.6 years) skeletal age. Similar findings have been reported in more recent studies where the different methods of identifying skeletal maturation fail to reach the same results (Alshamrani and Offiah 2019; Büken et al. 2009; Malina et al. 2007). The diverse range of nationalities and ethnicities that are present within different studies may explain the variation in results the different methods have shown, particularly as the original sample that the different methods were based upon were mainly Caucasian (Muller et al. 2019; Mughal et al. 2014; Khan and Elayappen, 2012). Studies have concluded that whilst each of the three different methods can indicate skeletal age and maturation, they should be used with caution, particularly with different ethnic groups and nationalities (Alshamrani and Offiah 2019; Muller et al. 2019; Mughal et al. 2014; Khan and Elayappen, 2012; Büken et al. 2009; Malina et al. 2007). Further concerns were also raised over the implementation of using x-rays and the potential harm that regular exposure to radiation may cause (Fransen et al. 2017). More recent developments have attempted to circumvent this by using x-rays alternatives that expose the individual to less radiation, however this does not remove the fact that using skeletal age as indicator of maturation may be problematic (Fransen et al. 2017; Romann and Fuchslocher 2015; Wren et al. 2014).

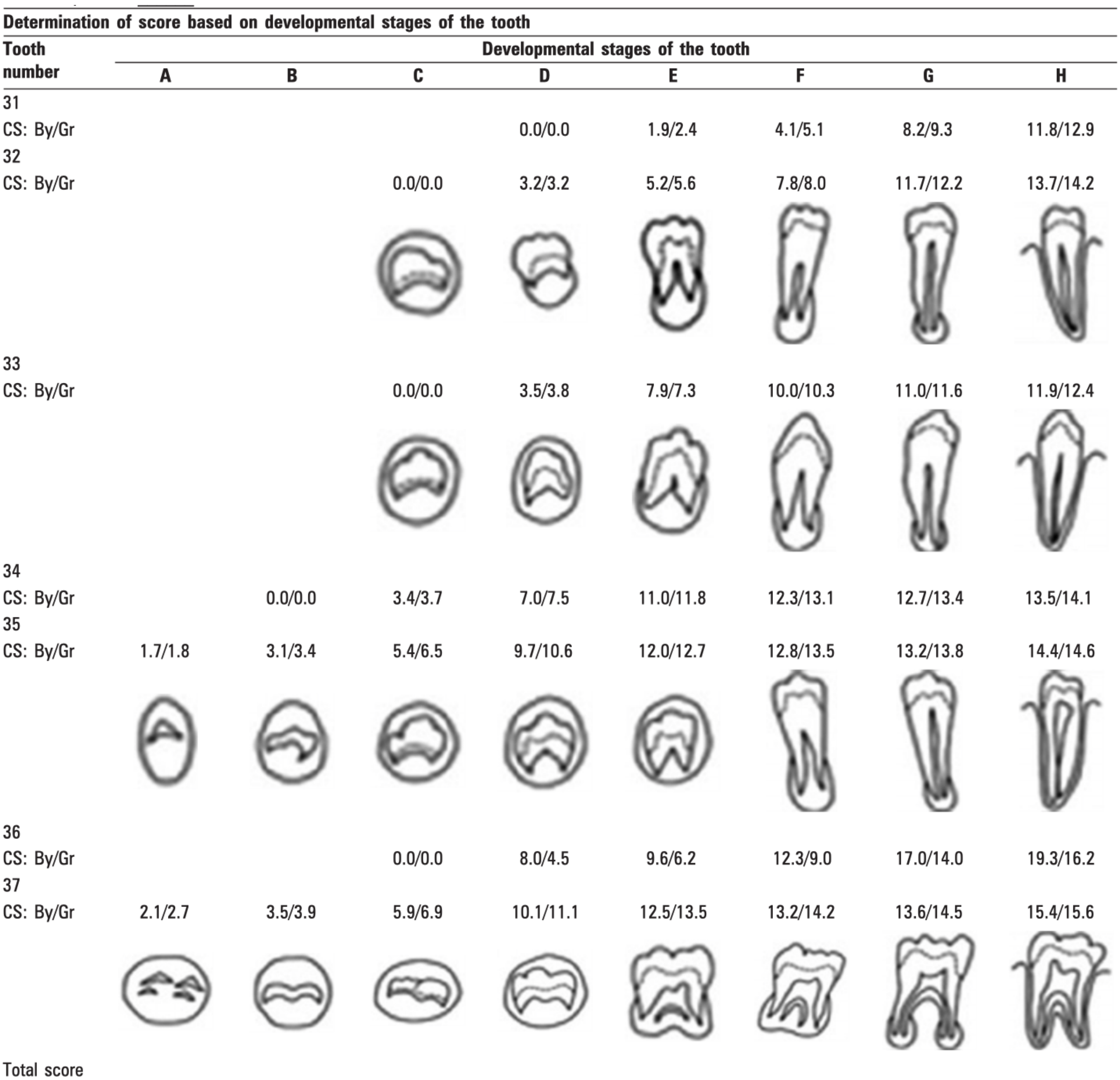
2.6.1 Skeletal maturity in elite youth soccer

Skeletal maturity is identified and/or monitored within elite youth soccer for a number of reasons. One factor is to examine the relationship between skeletal age and soccer player performance and/or ability, to identify if it is an influencing factor on performance and potential talent identification. Figueiredo et al. (2009b) compared the performance of 159 soccer players in relation to skeletal maturity, soccer specific skills and functional skills and found no relationship or impact between the factors. Gouvea et al. (2016) found slightly different results. The study used a sample of 60 youth male soccer players from under-14 to under-17 years old and likewise compared performance of soccer specific skills and functional skills in relation to skeletal maturity. The authors concluded that skeletal maturity has no impact upon soccer specific skills but it did impact upon flexibility, muscular strength and cardiorespiratory fitness. Further research has been conducted focussing solely on the fitness and functional skills of soccer players in relation to skeletal age with results showing significant relationships between player performance and skeletal age (Borges et al. 2018; Gall et al. 2008). It can therefore be concluded that skeletal age has an impact upon fitness and functional skills but less so on soccer specific skills (Borges et al. 2018 Figueiredo et al. 2010).

Skeletal maturity in elite youth soccer is also identified to prevent age fraud and age fabrication. There have been numerous examples where teams and players have entered into competitions illegally, as they are over aged (Barrie 2019; Cryer 2014). For instance, in 2019, the Guinea team were fined and disqualified from the Under-17 World Cup for age cheating following discrepancies with player passports (Barrie 2019). In April 2013, MRI scans revealed that nine players were overaged in the African Under-17 Championship and were consequently excluded from the competition (Cryer 2014). However, it is unclear if the results of these MRI scans were due to cheating or due to the limitations of identifying skeletal maturity as studies have shown that the differing methods of identifying skeletal maturation can report different findings from the same sample (Alshamrani and Offiah 2019; Büken et al. 2009; Malina et al. 2007). Malina et al. (2007) compared the Tanner-Whitehouse and Fels methods of measuring maturity of 40 elite youth soccer players and found that different methods reported different players as being skeletally mature. The Fels method reported only two players as being skeletally mature whilst the Tanner-Whitehouse method reported 11 players. Malina et al. (2017) compared the skeletal age of a group of soccer players and found that the earlier version of the model (TW2), reported that the players skeletal ages were lower than the those reported in the later version of the model (TW3). Therefore, caution should be considered when using certain methods of identifying skeletal age to indicate maturity and maturation. It is also worth noting that soccer players sometimes have more advanced maturation overall, with their skeletal age reflecting this, consequently players may be identified as being older than their age group using skeletal age methods (Malina et al. 2010). Malina et al. (2010) reported that in their study of youth soccer players, 8% of 15-year-olds and 23% of 16-year-olds were classed as skeletally mature, therefore they would be ineligible to compete in their age category. Similar conclusions can be found in sports such as gymnastics, where athletes are often smaller, therefore may be identified as being too young for an age category (Malina 2011; Daly et al. 2005; Bass et al. 2000). Additional consequences of incorrect identification of skeletal age may also result in player injury (Eisenmann, Till and Baker 2020; Cumming et al. 2017b). There are numerous studies that have identified that older players have advantages over younger players in terms of anthropometrical measurements and physiological ability e.g., greater strength, power and aerobic capacity (Cumming et al. 2017b; Malina, Bouchard and Bar-Or 2004). If skeletal age provides a 'false positive' result and identifies a player as being older than they are and that player consequently trains and competes with older players then they may get injured, particularly in physical sports like rugby or martial arts (Cole 2015; Malina 2011; Malina et al. 2010). The same can be applied for players that are identified as being younger who then train and compete with other younger players, whereby those other younger players may become injured (Cole 2015; Carling, Gall and Malina 2012; Malina 2011; Malina et al. 2010). Thus, skeletal age can provide insight into maturity and maturation, but it should be used with caution, particularly with diverse nationalities and within specific sports, as the ramifications of incorrect skeletal age identification can be negative. Timme et al. (2016) goes as far as to suggest that because of the inaccuracy of identifying the skeletal age of players, that it should not be used and that other methods such as dental development are much more suitable and accurate.

2.7 Measuring dental maturity

Dental maturation can be used as a method of identifying maturity as the formation and development of the teeth changes throughout childhood and into adulthood (Metsäniitty et al. 2019; Demirjian et al. 1975). Dental maturation can be particularly useful at indicating an estimated age when identifying birth date can be a challenge, for example in less developed countries and/or unaccompanied child asylum seekers (Jain, Kapoor and Miglani 2016; Olze et al. 2006). X-rays of the mouth can be used to identify the stage of tooth calcification and jaw development to indicate maturation and estimated age. In particular identifying the stage of development of the roots of the teeth, wisdom teeth and jaw structure, whilst also accounting for any missing teeth and fillings (Timme et al. 2019; Mansour et al. 2017). The two main approaches to identifying estimated age from dental maturation are the Demirjian method (1975) and Willems method (2001); the Willems method (2001) follows a similar methodology to the Demirjian (1975) method but includes more detail to the images and descriptors (Esan et al. 2017). Both approaches use X-rays of the teeth and classify the images into stages (A-H) according to an image chart with accompanying descriptors that allow estimated age to be identified (see figure 3.).



Tooth number	A	B	C	D	E	F	G	H
31								
CS: By/Gr				0.0/0.0	1.9/2.4	4.1/5.1	8.2/9.3	11.8/12.9
32								
CS: By/Gr			0.0/0.0	3.2/3.2	5.2/5.6	7.8/8.0	11.7/12.2	13.7/14.2
33								
CS: By/Gr			0.0/0.0	3.5/3.8	7.9/7.3	10.0/10.3	11.0/11.6	11.9/12.4
34								
CS: By/Gr		0.0/0.0	3.4/3.7	7.0/7.5	11.0/11.8	12.3/13.1	12.7/13.4	13.5/14.1
35								
CS: By/Gr	1.7/1.8	3.1/3.4	5.4/6.5	9.7/10.6	12.0/12.7	12.8/13.5	13.2/13.8	14.4/14.6
36								
CS: By/Gr			0.0/0.0	8.0/4.5	9.6/6.2	12.3/9.0	17.0/14.0	19.3/16.2
37								
CS: By/Gr	2.1/2.7	3.5/3.9	5.9/6.9	10.1/11.1	12.5/13.5	13.2/14.2	13.6/14.5	15.4/15.6
Total score								

Determination of score based on developmental stages of the tooth (Developmental stages of the tooth A–H)

Figure 3. Image chart to show tooth development according to stages A – H (Taken from Kapoor and Jain 2016).

Esan et al. (2017) conducted a meta-analysis of 28 published articles that attempted to identify the estimated age of children (N = 24,941) using the Demirjian and/or the Willems methods. The study concluded that the Demirjian method significantly overestimated age ($p < 0.05$), in both males and females in comparison to the Willems method, therefore the Willems method is more reliable (Ambarkova et al. 2014; Ye et al. 2014). Studies have found that when comparing dental age estimation with other methods of measuring maturity such as skeletal age or sexual maturation, dental maturity is independent (Beunen, Rogol and Malina 2006; Malina et al. 2004; Demirjian et al. 1985). On the other hand, whilst dental age estimation can give insight into maturation, it is not often used in connection to physical activity and performance, as it fails to explain the differences in performance that can be observed in differing maturity levels (Cumming et al. 2012; Sherar et al. 2010). Such differences are often explained by other maturational factors such as sexual maturation or skeletal maturation (Sherar et al. 2010). Consequently, there is little research that investigates dental maturity and physical activity, or more specific to this thesis, there is little research completed into dental maturity and soccer players, therefore it has limited use in talent identification (Malina et al. 2019; Sherar et al. 2010).

2.8 Measuring sexual maturity

Sexual maturity is another method of identifying maturation, in which sexual characteristics are identified and categorised into stages of development that indicate the point of maturation (Roche et al. 1995). As children progress towards maturity, hormones cause the onset of puberty and sexual development in which breasts (in females), genitalia (in males) and pubic hair (in both genders) develop (Emmanuel and Bokor 2017). Tanner (1969) created a scale (commonly referred to as the Tanner Scale or sexual maturity rating scale), which categorised these characteristics into 5 stages of development (from stage 1 – no development to stage 5 – adult development) that indicate the stage of maturation (Cameron 1993). Due to its highly invasive nature this type of maturation is typically assessed by medical professionals who are highly qualified and trained, therefore making this method of assessing maturation less replicable (Pompéia et al. 2019; Fransen et al. 2017; Leone and Comtois 2007). Additionally, studies have shown that when testing the Tanner scale for reliability there have been differences in agreement between professionals (Rothman et al. 2011; Matsudo and Matsudo 1994). This lack of agreement may be explained by an individual being between stages, therefore their classification is rounded up or down subjectively (Malina et al. 2004). To overcome these concerns, adaptations have been made in which self-reports are utilised rather than professional assessments. However, the use of self-reports is subject to bias and inaccuracy. Ernst et al. (2018) conducted a study investigating the inter-rater agreement of children assessing themselves using the Tanner scale and reported that agreement was 75% in girls and 69% in boys, which may therefore lead to incorrect classification. Similar findings were reported by Chavarro et al. (2017) where professional assessment and self-assessment using the Tanner scale were compared and results showed that males under reported (r = 0.50, 95% CI = 0.31 – 0.65) sexual stage in self-assessment in comparison to professional assessment (r = 0.75, 95% CI = 0.56 – 0.93) and females over reported (r = 0.89, CI = 0.79 – 0.97) sexual stage in comparison to professional assessment (r = 0.89, 95% CI = 0.70 – 0.89). Additionally, self-reports may be inaccurate due to conditions such as anorexia nervosa, where the physical and psychological state may affect reliability and accuracy (Hick and Katzman 1999).

2.8.1 Sexual maturity in elite soccer

Despite its invasive nature and reports of inaccuracy, sexual maturity has been used with elite soccer settings. Malina et al. (2004) investigated the impact that of a variety of factors, including sexual maturity, had upon the performance of soccer specific skills. The study utilised six soccer specific skills to test the accuracy, agility, coordination, speed and skill of 69 elite, male soccer players, aged 13 to 15 years old. Sexual maturity was assessed via experienced paediatrician using the Tanner scale and was primarily based upon the stage of pubic hair development, as opposed to a combination of genitalia and pubic hair development that has been used in previously mentioned research (Ernst et al. 2018; Chavarro et al. 2017; Rothman et al. 2011). Results showed that sexual maturation had a small impact upon the performance of these specific skills however, there was little statistical significance to allow for a definitive conclusion, therefore the variation in differences may be explained by other factors. Similar conclusions were observed in an earlier study by Figueiredo et al. (2010) in which pubic hair had no impact upon the performance 143 youth soccer players, completing four movement skills and 4 soccer skills. Matta et al. (2014) conducted a similar study in which 245 male soccer players were assessed for maturation, via pubic hair, in relation to performance of soccer skills and functional movement tests. Results showed that sexual maturation had a no impact upon the performance of soccer specific skills, however sexual maturation did have some effect on the performance of functional movement tests in the players aged under 15 years. The observed differences were concluded to be caused by anthropometrical changes that are associated with maturation (Malina et al. 2004). Figures 1. and 2. show that as sexual maturation develops so does height, weight and general physical characteristics that may explain the differences in player performance.

Research has shown that those players who are more mature have greater anthropometrics that consequently allow them to perform better in tests of movement and fitness (Mujika et al. 2009; Malina et al. 2007; Malina et al. 2004). For example, soccer players who are more mature have greater muscle mass and muscle strength therefore, perform better on the standing jump test in comparison to less mature players (Philippaerts et al. 2006). Consequently, this may explain the inconsistencies in findings from different studies when reporting the influence of sexual maturity on soccer specific skills. Malina et al. (2007) found that sexual maturation was a significant factor in predicting soccer skill however acknowledged that the interaction of movement and function skills present in the soccer specific skills may have an impact. For example, the study reported that players with greater sexual maturity had greater shooting accuracy in comparison to less mature players. However, this is not solely due to the impact of skill but because more mature players possess greater speed, power and agility, therefore allowing them to complete the task more accurately than less mature players. Whilst sexual maturation seems not to have an impact upon player ability to perform specific soccer skills it does have an impact upon wider fitness and physiological ability, therefore those players with advanced sexual maturation have an advantage over less mature players. The further impact of sexual maturation can also be seen in talent identification, whereby players with advanced sexual maturation are more likely to be selected/recruited into teams/clubs due to greater physical ability (Rowat, Fenner and Unnithan 2016). There is some benefit to mis-matching players of different maturation in games, (see chapters 4 and 5) however, players competing against other players that are largely dissimilar in maturity, may result in potential injury (Eisenmann, Till and Baker 2020; Cumming et al. 2017b). In conclusion, there is an impact between more mature and less mature players in elite soccer in terms of sexual maturation however, the difficulties associated with measuring sexual maturation (invasiveness, lack of reliability in self reports and the need for qualified professionals when not using self-reports) mean that other methods of identifying maturation are more commonly utilised (Matta et al. 2014; Malina et al. 2007).

2.9 Estimation equations of maturity

Perhaps the least invasive and most widely available method of identifying maturation is through somatic maturity, where anthropometric measurements alongside predictive equations are used to estimate player maturity (Malina et al. 2019). Anthropometric measurements can be used to approximate the maturation of a player by calculating age at peak height velocity (APHV) and/or estimated adult stature attainment (EASA) (Towlson et al. 2020). Thereafter the players current state of estimated maturation can be identified in relation to estimated peak maturation. Evidence has shown that estimation equations are often used within elite soccer academies, in part because the Premier League and EPPP mandates the monitoring of player growth and development, but also because it is a much more accessible method in comparison to those methods previously discussed in this thesis (Premier League 2020; Salter et al. 2020). There are several estimation equations that have been developed and improved over the years, each with their own strengths and limitations, which will be discussed below (Malina et al. 2019).

The Khamis and Roche (1994) estimation equation

The earliest estimation equation attempt was created by Khamis and Roche (1994) which used anthropometric measurements in a regression equation (see equation 1) to predict adult stature. Adult stature is used as it is considered to be an indication of full growth being reached and therefore an indication of full maturation (Malina et al. 2019). In identifying a player's current stature in relation to their final estimated adult stature, estimated maturation can be ascertained i.e., estimated adult stature attainment (EASA), then expressed as a percentage of full growth. The closer a player is to their estimated adult stature the more mature they are and the further away a player is from their estimated adult stature the less mature they are (Gillison et al. 2017). To calculate estimated adult stature measurements of stature, weight and mid-parental height are needed (Khamis and Roche 1994). These measurements are more easily obtained and implemented than dental records or x-rays, hence current research is trending towards estimation equations (Salter et al. 2020). However, this method of identifying maturation is limited as validation studies have concluded that the Khamis and Roche (1994) equation underestimates predicted adult stature in early maturing children and overestimates predicted adult stature in late maturing children (Fragoso et al. 2014; Malina et al. 2012). The Khamis and Roche (1994) equation has an approximate median error of 2 centimetres in estimating adult stature and whilst this is a small disagreement, it can ultimately lead to an incorrect identification of maturation, which, as previously discussed, can have wider ramifications for elite youth players (Cumming et al. 2017a; Cumming et al. 2017b). The applicability of the equation can also be questioned as the sample of children used when creating the equation were all middle class, white, Americans (Towlson et al. 2020). Additionally, there has been some criticism about using mid-parental height as a measurement. Though the use of parental height acknowledges the influence of genetics upon maturation, circumstances may not allow for this information to be collected, for example adoption and/or single parent families (Baxter-Jones et al. 2020; Braziuniene et al. 2007). Furthermore, studies that have utilised self-reports of parental height have found that self-reports are inaccurate for both male and female parents (Baxter-Jones et al. 2020; Braziuniene et al. 2007). Therefore, when using self-reports of parental height needs a percentage of error must be allowed for within calculations, which would reduce the accuracy of the results (Baxter-Jones et al. 2020; Gozzi et al 2010; Braziuniene et al. 2007). As a result of the limitations of the Khamis and Roche (1994) equation further calculations have been created to overcome these barriers.

Equation 1:

Predicted adult stature = $\beta 0 + \beta 1$ stature + $\beta 2$ weight + $\beta 3$ mid-parent height.

$\beta 0$ See smoothed regression coefficients in Khamis and Roche (1994). Where $\beta 1$, $\beta 2$ and $\beta 3$ are the coefficients by which stature, weight, and mid-parent height should be multiplied by.

<u>The Mirwald et al. (2002) estimation equation</u>

Mirwald et al. (2002) created the maturity offset equation (see equation 2 and 3), which estimates the number of years that a player is away from achieving peak height velocity (YPHV). Maturity offset uses measurements of height, sitting height, leg length and chronological age (in decimals) and highlights the interaction between these measurements as an indicator of maturation. Therefore, removing the need for parental height measurements needed for the Khamis and Roche (1994) equation (see equations 2. and 3.). The equation was created using one sample and then tested on a further two samples where the data had been used in previous longitudinal growth and development studies, which allowed for the equation to be tested and verified against a sample where the outcome was already identified. The initial sample used to create the equation was created using longitudinal data where 152 Canadian children (male = 79, female = 73) aged 8 to 16 years were followed for 6 years from 1991 to 1996. The study found that identifying maturation was accurate ± 2.4 years, however there were larger margins of error the further away a child was to PHV. For instance, it underestimated APHV by -0.32 years in males 3 years prior to peak height velocity and overestimated APHV by +0.56 years in males 3 years post peak height velocity (Mirwald et al. 2002). Similar findings were reported by Malina and Koziel (2013) in which their study of 193 Polish boys, over an 11-year period, reported that APHV was underestimated (-0.32 years) in younger aged boys and overestimated (+0.56 years) in older aged boys. The Mirwald et al. (2002) equation is not the most accurate and the authors themselves warn that using the equation should be done so with caution, despite this it is widely used within soccer academies (Parr et al. 2020b; Salter et al. 2020; Mirwald et al. 2002). Moore et al. (2014) attempted to improve the accuracy of the maturity offset equation by removing seated height and modifying the regression equation by accounting for possible overfitting. The study used three different samples to validate the equation and reported that maturity offset was accurate (± 1 year) in 90% of the sample. Koziel and Malina (2018) further validated the Moore et al. (2014) equation when they compared it to the original Mirwald et al. (2002) in a sample of 193 boys and 198 girls, aged 8 to 18 years. The study found that the Moore et al. (2014) equation was more reliable than the Mirwald et al. (2002) equation however there were still instances of late identification in early maturing children and early identification in late maturing children. As both the original maturity offset equation, consequent developments and validation studies all report inaccuracies regarding children that are furthest away from PHV it can be concluded that the maturity offset equations are inaccurate (Towlson et al. 2020; Mills et al. 2016).

Equation 2:

Male Maturity Offset:

Maturity offset (years) YPHV = -9.236 + (0.0002708 x (Leg Length x Sitting height)) + (-0.001663 x (Age x Leg length)) + (0.007216 x (Age x Seated height)) + (0.02292 x (Body mass/Stature)).

Equation 3:

Female Maturity Offset:

Maturity Offset = -9.376 + (0.0001882 x (Leg length x Sitting height)) + (-0.0022 x (Age x Leg length)) + (0.005841 x (Age x Seated height)) – (0.002658 x (Age x Body mass)) + (0.07693 x (Body mass/Stature)).

<u>The Fransen et al. (2017) estimation equation</u>

Fransen et al. (2017) proposed that the reported inaccuracies of using maturity offset equations may be due to trying to calculate a "linear estimation of an inherently non-linear biological process" (Fransen et al. 2017, p6). In an attempt to fit this non-linear relationship, Fransen et al. (2017) created the maturity ratio (chronological age/APHV) (see equation 4), using chronological age, body mass, standing height and leg length. This maturity ratio was tested on two data sets; the original sample from the Mirwald et al. (2002) study and a sample of elite male soccer players. The first data set was selected in order to compare the findings of the maturity ratio equation against the findings from the maturity offset equation, giving the best opportunity for direct comparison by using the same sample. The second data set was used to test the validity of the maturity ratio equation beyond a general population, in wider, more specialised samples, therefore data utilised information on 1330 elite, male soccer players from Belgian soccer academies. Findings reported that the maturity ratio is useable and accurate (± 1 year) in both the general and athletic populations. Whilst there is still some error for early and late maturing players, it is less than that reported in the Mirwald et al. (2002) and Moore et al. (2014) equations. However, Nevill and

Burton (2017) reported that there were mathematical errors present within the maturity ratio calculations, therefore the calculations and findings are not reliable. Fransen, Baxter-Jones and Woodcock (2017) responded in kind, refuting the claims, however there has been little research to further support this (Towlson et al. 2020).

Equation 4:

$$= 6.986547255416 + (0.115802846632 \times Age) + (0.001450825199 \times Age^2) + (0.004518400406 \times Body\ mass) - (0.000034086447 \times Body\ mass^2) \times (0.151951447289 \times Stature) + (0.000932836659 \times Stature^2) - (0.000001656585 \times Stature^3) + 0.032198263733 \times Leg\ length) - (0.000269025264 \times Leg\ length^2) - 0.000760897942 \times (Stature \times Age)).$$

2.9.1 Estimation equations in elite soccer

Despite the limitations of the various methods discussed above, predictive equations are less invasive methods of measuring maturity and are a viable method for measuring maturation, particularly when alternative methods of measurement are limited by time, cost and/or accessibility (Malina et al. 2015). It is worth noting that there is currently no predictive equation method that is considered to be the best or most widely used, therefore caution should be used as there is little research to support the ideal approach (Towlson et al. 2020). The EPPP states that the monitoring of youth players is a priority so that accurate information can be used to effectively track player development, injury, fitness and bio-banding (Premier League 2020). Consequently, most academies within the EPL, following the EPPP, monitor players using predictive equations, however the EPPP fails to state which method/equation must be used to track maturation, possibly due to a lack of research (Salter et al. 2020). A recent study by Salter et al. (2020) found that the most popular methods utilised in elite soccer academies are the Mirwald et al. (2002) maturity offset equations and the Khamis and Roche (1994) estimated age at peak height velocity approach (Salter et al. 2020; Towlson et al. 2020). Parr et al. (2020b) conducted a study to compare the accuracy of the maturity offset equation and estimated APHV by monitoring 23 elite soccer players over a 5-year period. The findings showed that the maturity offset equation was only able to accurately predict maturation in 61% of the sample, whilst the estimated APHV was able to accurately predict maturation in 96% of the sample, respectively. This shows that in this particular elite football sample the Khamis and Roche (1994) approach was more accurate than the maturity offset equation, which may be due to the errors reported when identifying early and late maturing children/ players (Koziel and Malina 2018; Moore et al. 2014; Mirwald et al. 2002). However, the study is limited by a small sample size (n = 23) and has a small representation of early maturing players which may have affected the results. The findings of this study also differ with the findings of Fragoso et al. (2014) and Malina et al. (2012) who report large errors in predicting maturity using the Khamis and Roche (1994) equation. Fragoso et al. (2014) reported $F = 68.828$, $P < 0.001$ and Malina et al. (2012) reported Kappa coefficients between 0.02 and 0.23, these results may be due the inaccuracies associated with using parental height (Braziuniene et al. 2007).

The use of predictive equations in soccer academies and soccer research extends beyond just validation and reliability studies. Johnson et al. (2019) identified that those players who were closest to peak height velocity were more likely to sustain injury (24.5 injuries per 1000 hours playing time) in comparison to those players who were pre-peak height velocity (11.5 injuries per

100 hours of playing time). However, Van der Sluis et al. (2013) were more specific in their findings and stated that 6 months pre- and post-peak height velocity was the time period for the most injury occurrence and risk (P = 0.030, ES = 0.03 to 0.50). It is relevant to highlight that Johnson et al. (2019) used the Khamis and Roche (1994) method to calculate maturation whereas Van der Sluis et al. (2013) used the maturity offset equation, which may explain the differences in reported findings. Both Johnson et al. (2019) and Van de Sluis et al. (2013) noted that there was no difference in injury likelihood between the different maturation statuses of players, i.e., early maturing players were not more likely to be injured in comparison to late maturing players or on time maturing players, and vice versa. The lack of reported differences between different maturation levels seems to be unique to injury research as all other avenues of investigation using predictive equations and maturation in soccer indicate there is some difference (Malina et al. 2019). For example, Rommers et al. (2018) identified maturity using the maturity offset equation and found that in their sample of 619 elite soccer players, that more mature players possessed greater anthropometrical measurements and outperformed late maturing players in speed, agility and coordination tests. These findings are similar to those reported by Malina et al. (2015) who reported differences in anthropometrical and movement tests that were influenced by maturational differences, whereby more mature players performed better than less mature players due to the anthropometrical advantages they possess. Parr et al. (2020a) used the Khamis and Roche (1994) method to identify the maturation of 84 elite male soccer players and found that during games, more mature players were faster in 5 metre sprints, 20 metre sprints and in changing direction. Goto et al. (2019) likewise found differences between in match performance of early and late maturing players. The study used the GPS data of 80 elite male soccer players and reported that early maturing players covered greater distance both running and walking and spent more time completing high-speed

running than later maturing players. Research clearly shows that more mature players have advantages over younger players, consequently this can impact upon talent identification.

2.10 Comparison of methods identifying maturation

Part of the EPPP states that soccer academies must track athlete growth and maturation for the purposes of identifying biological growth and development (Premier League 2020). Despite this stipulation there is no specification as to which method of identifying/estimating biological age should be used (Premier League 2020; Towlson et al. 2020). Research has shown that as a consequence soccer academies use several different approaches, with no one method being more popular than the other (Salter et al. 2020). As this literature review has discussed, there are a variety of approaches to identifying and estimating biological maturation (see table 2.). Currently there is no 'gold standard' or 'best method' of identifying biological age and maturation, which may explain why the EPPP fails to advise soccer academies which method should be used (Salter et al. 2020; Towlson et al. 2020). This section of this thesis aims to compare these different approaches, highlighting the benefits and limitations of each.

Some of the earliest methods of identifying maturation are through ascertaining skeletal maturation (see table 2.). The oldest method being the Greulich and Pyle (1959) method which compares x-rays of the hand and wrist against standardised images of children at a certain age. It has reportedly been able to accurately report age with an average error of just 2.2 months less than chronological age (Paxton et al. 2013). However, the initial 'reference' images used to make the comparisons were taken from children in the 1930's and as time has progressed there have been several developments within the population which mean that these images are not comparable to today's children. Similar to the Greulich and Pyle (1959) method the Tanner and Whitehouse

(1966, 1975 and 2001) and Fels (1988) methods also use x-rays of the hand and wrist to identify maturation. However, these approaches use a criterion of comparison as oppose to images, allowing for greater analysis to be conducted as the bones are compared in relation to each other and a detailed description (Pinchi et al. 2014; Schmidt et al. 2008). The sample of children used in these approaches were much more diverse and the information was collected over a longitudinal period allowing for greater accuracy when comparing to today's population of children (Towlson et al. 2020). However, there are overall limitations to using skeletal age as a means of identifying maturation that act as barriers. For instance, the exposure of children to radiation is a cause for concern (particularly longitudinal data collection with the same participants), it is time consuming, costly, invasive and requires an expert to administer (Fransen et al. 2017; Malina et al. 2015). These limitations are a particular barrier to soccer academies as there are several teams and players which makes this method more challenging to use. Additionally, the positioning of the hand and wrist during the x-rays impacts upon the accuracy of identification as the slightest mis-positioning changes the angle of bones and therefore the final image produced (Towlson et al. 2020). Similar limitations apply to the Demirijian (1975) and Willems (2001) methods as they both use dental x-rays to identify maturation and therefore are impacted by radiation exposure concerns, time, expenses and the need for highly trained practitioners to administer (Towlson et al. 2020). More specific to this thesis however, is the fact that dental maturation fails to explain differences in the physical performance of soccer players and therefore is not useful in explaining or monitoring biological maturation and development (Cumming et al. 2012; Sherar et al. 2010).

In contrast to skeletal and dental maturity is sexual maturity, whereby sexual characteristics are compared to 'reference' images and descriptions to identify maturity (Tanner 1969). The identification of sexual characteristics through self-report and by clinicians have both proven to be in inaccurate when identifying maturity (Ernst et al. 2018; Chavarro et al. 2017; Rothman et al. 2011; Malina et al. 2004; Matsudo and Matsudo 1994). Despite this inaccuracy the method has been reported to be able to explain differences in athlete performance and can provide valuable insight into monitoring athletes, unlike methods of using dental maturity identification and therefore (Matta et al. 2014; Malina et al. 2007; Malina et al. 2004). However, the highly invasive nature of this method makes it unpopular with researchers and practitioners (Pompéia et al. 2019; Fransen et al. 2017; Leone and Comtois 2007). As table 2. shows there is only one method that has been created to monitor sexual maturation whereas the other methods have several approaches and attempts to recreate. Therefore, current research trends are now focussing on the development of less invasive assessments to identify and assess maturity (Malina 2014; Malina, Bouchard, and Bar-Or 2004).

Somatic equations of identifying maturity are non-invasive and more easily accessible than using skeletal, dental and sexual maturity (Malina et al. 2019; Malina et al. 2012). Somatic equations are more accessible for soccer academies because it is cheaper, easy to use with a large number of athletes and does not require a trained specialist. Whilst the EPPP fails to state which method of identifying maturation should be used in soccer academies, it does facilitate the use of estimation equations through an online player management and monitoring system (Salter et al. 2020; Towlson et al. 2020). The earliest calculation created was the Khamis and Roche (1994) equation that identifies predicted adult stature using stature (cm), body mass (kg) and mid-parent stature (cm). This calculation has proven to have a median error of plus 2 centimetres in boys and minus 2 centimetres in girls, with early maturing children being underestimated and late maturing children being overestimated (Cumming et al. 2018; Cumming et al. 2017). Additional error can also be gained through data collection constraints, such as using parental height (which is may be unavailable due to factors such as adoption or single parent families) or incorrect (e.g., due to self-report inaccuracy) (Romann, Lüdin and Born 2020; Towlson et al. 2020). Despite this, the Khamis and Roche (1994) approach is popular and often used in maturation and soccer research (Malina et al. 2019; Cumming et al. 2017). Likewise, an additional equation that is popular is the "maturity offset" equation created by Mirwald et al. (2002) in which stature (cm), seated height (cm), body mass (kg) and leg length (cm) are used to calculate where an individual currently is in relation to PHV. A degree of error is removed from this equation by not using mid-parental height however, research still reports inaccuracies when identifying maturation (Towlson et al. 2020). In particular, early maturing children are overestimated and late maturing children are underestimated, which is opposite to the overestimation and underestimation that is reported in the Khamis and Roche (1994) approach (Malina and Koziel 2014). Later researchers attempted to mitigate this error by adjusting the calculations and sample size however similar errors were still reported (Koziel and Malina 2018; Moore et al. 2014). In an effort to increase accuracy and reliability a more recent estimation equation created was by Fransen et al. (2017) in which the researchers created the "maturity ratio" from the sample used by Mirwald et al. (2002) when creating the "maturity offset" equation. Rather than calculate the "maturity offset" and how far away an individual is from PHV, Fransen et al. (2017) calculated a non-linear relationship between the anthropometric measurements and the maturity ratio. Whilst the equation still reports a level of error it is less extreme than the values reported by Mirwald et al. (2002) and Moore et al. (2014) particularly in relation to early and late maturing children (see table 2.). Despite the increased accuracy, the approach has been reported to possess mathematical errors which Fransen et al. (2018) responded to and countered, however there has been no further testing or validation following these events (Nevill and Burton 2017).

This section highlights that predictive equations of maturation are not perfect and have limited accuracy the further a child is from peak height velocity. However, the limitations highlighted in relation to identifying skeletal maturity, dental maturity and sexual maturity make predictive equations more accessible and preferrable (Cumming et al. 2017; Towlson et al. 2017). In particular relevancy to soccer and soccer academies, the implementation of estimation equations are more feasible than other approaches due to the number of players within clubs and the impact this has upon costs. As previously mentioned, there is no 'gold standard' or particular method that is recommended by researchers or the Premier League. However, it seems that the Fransen et al. (2017) method is most accurate for estimating maturity offset whilst the Khamis and Roche (1994) method is most accurate at a estimating the percentage of estimated adult stature attainment (EASA) (see table 2.) (Parr et al. 2020b). Parr et al. (2020b) compared the Mirwald et al. (2002) approach with the Khamis and Roche (1994) approach in a 5 year longitudinal study and reported that maturity offset was able to accurately report 61% of PHV whilst the Khamis and Roche (1994) approach reported 96% of PHV. As this literature review has discussed, there are consequences to incorrectly identifying biological age and maturation (Eisenmann, Till and Baker 2020; Cumming et al. 2017b; Malina et al. 2010). Therefore, research that compares the different attempts at estimating maturation and the impact that they have on elite youth soccer players would be useful for talent identification and soccer academies when monitoring maturation, particularly because maturity impacts upon physical performance (Towlson et al. 2020).

Table 2. Summary of the various methods of identifying maturation.

Author	Method/Equation	Creation/validation method	Considerations

Greulich and Pyle (1959)	Measuring skeletal maturity through radiographs of the hand and wrist and comparing the images against 'reference' radiographs to determine maturation.	Able to reliably identify the skeletal age for 654 children. Skeletal age was reported to be an average of -2.2 months less than chronological age (Paxton, Lamont and Stillwell 2013).	Expensive. Requires highly trained individuals. Initial 'reference' radiographs were created from a sample of white children therefore not applicable to wider ethnicities. 'Reference images based upon sample of children in the 1930's therefore not applicable to today's youth. Inter- and intra-reliability testing was not significantly different.
Tanner and Whitehouse (1966, 1975) and 2001)	Measuring skeletal maturity through x-rays of the hand and wrist and comparing the images against a specific criteria.	TW2 reported -1 month and +16-month difference between skeletal age and chronological age. TW3 reported -4 month and +2-month difference between skeletal age and chronological age (Schmit et al. 2008).	Expensive. Requires trained professionals. Uses a wide ethnic sample for the 'reference' images. Differences in accuracy of between the different methods (i.e., between 1966, 1975 and 2001). Position of hand/wrist during the x-rays impacts upon accuracy. Scoring each bone against the criteria is subjective.

Fels (1988)	Measuring skeletal maturity through radiographs of the hand and wrist and comparing the images against a criterion.	Used a longitudinal study (45 years) using a large sample (667 children). Included standard error when estimating skeletal maturity.	Expensive. Requires trained professionals. Often miss reports skeletal age in comparison to other methods of measuring skeletal age. Uses American Caucasian children as sample therefore not applicable to other ethnicities. When compared to the other methods of measuring skeletal maturity it had the highest repeatability and reproducibility (RMSE = 0.83).
Demirijian (1975)	Measures dental maturity through x-rays of the teeth and compares the images against an image chart with descriptors.	Can be used independent of other methods of identifying maturity.	Expensive. Requires trained professionals. Overestimates dental maturity in both males and females (Ambarkova et al. 2014; Ye et al. 2014). Rarely used in soccer studies as it cannot explain differences in physical performance.
Willems (2001)	Measures dental maturity through x-rays of the teeth and compares the images against	More reliable than the Demirijian method	Expensive. Requires trained professionals.

	an image chart with descriptors	(Ambarkova et al. 2014; Ye et al. 2014).	Rarely used in soccer studies as it cannot explain differences in physical performance.
Tanner (1969)	Identifies and categorises sexual characteristics into stages of development to indicate maturation.	Lack of agreement between professionals when tested for reliability (Rothman et al. 2011). The use of self-reports to overcome the invasiveness have reported inaccuracy (Ernst et al. 2018; Chavarroe et al. 2017).	Highly invasive. Requires trained professionals. Has been used within soccer studies. Can explain differences in physical performance.
Khamis and Roche (1994)	Estimation equation that uses anthropometric measurements to identify current stature in relation to final estimated adult stature.	Easy to obtain measurements. Approximate error of 2 centimetres when estimating height (Cumming et al. 2017a; Cumming et al. 2017b).	Requires parental height. Underestimates early maturing children and overestimates late maturing children (Cumming et al. 2017a; Cumming et al. 2017b). Sample used to create the equation was based on white American children.

	Predicted adult stature = β0 + β1 stature + β2 weight + β3 mid-parent height.		
Mirwald et al. (2002)	Estimation equation that uses anthropometric measurements to identify the number of years away from reaching peak height velocity. Male Maturity Offset: Maturity offset (years) YPHV = -9.236 + (0.0002708 x (Leg Length x Sitting height)) + (-0.001663 x (Age x Leg length)) + (0.007216 x (Age x Seated height)) + (0.02292 x (Body mass/Stature)). Female Maturity Offset: Maturity Offset = -9.376 + (0.0001882 x (Leg length x Sitting height)) + (-0.0022 x (Age x Leg length)) +	Equations were creating using one sample then validated using a further two samples. Used a longitudinal study.	Used a Canadian sample to create the equation (fails to state the ethnicities). Large margins of error the further away a child was from peak hight velocity (Malina and Koziel 2013).

	(0.005841 x (Age x Seated height)) – (0.002658 x (Age x Body mass)) + (0.07693 x (Body mass/Stature)).		
Moore et al. (2014)	Adjusted the Mirwald et al. (2002) equation and used anthropometric measurements to identify the number of years away from reaching peak height velocity.	Reported to be more reliable than the Mirwald et al. (2002) equation (Malina and Koziel 2013).	Reported errors the further away a child was from peak height velocity (Malina and Koziel 2013).
Fransen et al. (2017)	An equation using anthropometrical measurements to identify a maturity ratio. = 6.986547255416 + (0.115802846632 x Age) + (0.001450825199 x Age^2) + (0.004518400406 x Body mass) – (0.000034086447 x Body $mass^2$) x (0.151951447289 x Stature) + (0.000932836659 x $Stature^2$) –	Equation was tested on two separate samples (one was a sample of soccer players). Equation is usable in both general and athletic populations.	Reported mathematical errors within the equation (Nevill and Burton 2017).

	(0.000001656585 x Stature^3) + 0.032198263733 x Leg length) − (0.000269025264 x Leg length^2) − 0.000760897942 x (Stature x Age)).

2.11 Influence of maturation on athletic performance

Soccer is a multifaceted sport that requires many physical capabilities and qualities in order for players to be successful e.g. speed, strength and aerobic capacity (Vázquez et al. 2019; Milanović et al. 2017). Research has identified that elite players possess greater physical capabilities than sub-elite players (Trajković et al. 2020; Philippaerts 2006). Therefore, the ability to train and improve physical capabilities are vital to aid player development and success (Ford et al. 2011). This training and development is a longitudinal process that often begins at a young age, hence why the EPPP has three phases (Foundation Phase, Youth Development Phase and Professional Development Phase) that players progress through as they develop in terms of maturation, physical ability, skills and knowledge (Premier League 2020). There is a significant amount of research that has highlighted how maturation impacts upon long-term athlete development (Abarghoueinejad et al. 2021; Williams, Ford and Drust 2020; Deprez et al. 2015a; Deprez et al. 2015b; Unnithan et al. 2012; Ford et al. 2011). Often long-term athlete development models refer to "windows of opportunity" where periods of improvement are most opportune and likely to occur (Balyi and Hamilton 2004). However, this has approach been critiqued as it suggests that outside of these instances no improvement can be made (Ford et al. 2011). Likewise, growth, development and maturation are highly individualised and cannot be categorised into "windows" when there are so many influencing factors (e.g., hormones, genetics, diet) (Ford et al. 2011). Despite this, there is research that suggests there are periods of enhanced improvement in relation to maturation (Towlson et al. 2020). Philippaerts et al. (2006) conducted a longitudinal study utilising elite youth soccer athletes and reported that athletes pre-PHV and circa-PHV had the greatest improvement and development in strength, power, speed and endurance. Peña-Gonzáles et al. (2019) reported that during an 8-week strength training programme pre-PHV and circa-PHV players had the greatest adaptations. Drury et al. (2019) likewise reported that pre-PHV players showed greater benefits following a 6-week Nordic hamstring exercise programme in comparison to circa-PHV and post-PHV players. Moran et al. (2018) conducted an 8-week sprint training programme and reported that pre-PHV players were able to make greater adaptations and improvements than circa-PHV players. This research shows that relationship between maturation and anthropometrics are linked, therefore the adaptations that have reported in less mature players are to be expected as the players are experiencing the greatest velocity of growth and development (see figure 1.) (Towlson et al. 2018). The fewer adaptations reported in more mature players are thus explained by the fact that the influence of maturation has been shown to taper post-PHV because growth velocity slows (Towlson et al. 2018). Practitioners need to be aware of the impact of maturation upon the body's ability to adapt and improve as gains occur through stressing and overtraining certain areas/muscles/systems (Towlson et al 2020; Ford et al, 2011).

Research has also suggested that the stage maturation impacts upon injury occurrence. Van der Sluis et al. (2014) reported that more mature players are most at risk of injury, whist Gall et al. (2006) suggested the opposite, that less mature players are more at risk. Bult, Barendrecht and Tak

(2018) go as far as to suggest that injury risk is highest in players 6 months after PHV is achieved. There are several factors that influence injury occurrence making it impossible to pinpoint the exact cause however, research does suggest that there is some link between maturation and injury (Towlson et al. 2018). Growth-related changes occur in various parts of the body (e.g., joint stability, tendon strength and length, bones density and length and muscle strength and density) during maturation which impact upon athlete performance (Radnor et al. 2018). During this period the body can grow between 7 to 12 centimetres a year with injury risk reported to be higher in those players that grew more than 6 centimetres in the previous month (Kemper et al. 2015; Mirwald et al. 2002). This development may impair movement as the player is not used to the changes in height, weight, strength and flexibility therefore leading to injury (Towlson et al. 2020; Van der Sluis et al. 2013). Additionally, as players progress through the EPPP the demand placed upon them increases, i.e., greater time committed to training and increased numbers of game participation and play time (Wrigley et al. 2012). Likewise, this may also lead to injury through overtraining and/or increased demand placed upon the body/systems that are unprepared and undertrained (Verheul et al. 2020). Consequently, it is important to monitor players as adaptation varies according to the stage of maturation which in turn may impact upon injury occurrence (Ford et al. 2011).

This section has highlighted the various impacts that maturation has upon player performance, improvement and injury risk as players develop and grow. Research has shown that less mature players have the greatest ability to adapt to training as the body is still growing and adjusting. However, more mature players have the advantage of possessing greater anthropometrical characteristics which ultimately lead to greater output and performance. For example, peak/maximal aerobic speed and greater distance covered at high speeds (Lovell et al. 2019). Practitioners should be aware of the differences in player ability and performance to adequately adapt training to suit the needs of individuals (Towlson et al. 2020; Ford et al 2011).

2.12 Maturation selection hypothesis

As the previous chapter has pointed out, less mature players are more likely to experience greater improvements in ability during maturation however, there are several advantages that more mature players possess in comparison to less mature players (Gil et al. 2014; Malina, Bouchard and Bar-Or 2003). As a consequence of these anthropometric and physiological advantages, more mature players are often recruited and/or retained by talent identification practitioners due to being perceived as "talented" or "gifted" (Kelly and Williams 2020; Gil et al. 2007). This bias towards more mature players is termed the maturation selection hypothesis (Towlson et al. 2020; Vaeyens et al. 2008). Research has shown that this favouritism concerning physical ability, results in less mature players being less likely to become professional players and are more likely to drop out or not be selected (Figueiredo et al. 2009a). Due to less mature players being unable to physically outperform their more mature peers, research has shown that players with delayed maturation possess greater technical and tactical abilities (Cumming et al. 2018; Zuber, Zibung and Conzelmann 2016). Abbott et al. (2019) compared the technical performance of youth players in chronological games and found that late and on time maturing players performed more technical actions than early maturing players. Vandendriessche et al. (2012) reported that following consistent opportunities being given to early maturing players and late maturing players missing out, the Royal Belgian Football Association created 2 national teams that contained on time and late maturing players, that would run alongside their normal under-16 and under-17's teams. There are several studies that point out the futility of selecting early maturing players based upon their physical ability as the benefits that they display ultimately peter out as the less mature players catch up (Kelly and Williams 2020; Kelly et al. 2019; Cumming et al. 2018; Bidaurrazaga-Letona et al. 2017). Consequently, at more senior levels of competition early maturing players become disadvantaged because they do not possess the technical and tactical insight needed and can no longer rely upon physical capability (Kelly and Williams 2020; Vaeyens et al. 2008). Ostojic et al. 2014 completed a longitudinal study of 48 elite soccer players and followed their journey into senior soccer competition, finding that as the level of performance increased, early maturing players became more excluded. Therefore, there needs to be attempts at reducing the maturation selection hypothesis effects, as late maturing players are missing out on opportunities and early maturing players are less successful later on in their career. One solution, similar to that used by the Royal Belgian Football Association, is to use bio-banding.

2.13 Bio-banding

The Premier League and the EPPP have attempted to reduce the impact of maturational-selection bias by implementing a strategy called bio-banding (Premier League 2020). Bio-banding is the grouping of players according to biological age rather than chronological age (Malina et al. 2019). Bio-banding can be used in training, strength and conditioning, injury prevention, competition and talent identification (Eisenmann, Till and Baker 2020; Cumming et al. 2017b). Identifying and calculating biological age for bio-banding can be achieved through a variety of methods, as this literature review has shown, however biological age that is used for bio-banding is often calculated using predictive equations (Kelly and Williams 2020; Towlson et al. 2019; Malina et al. 2019; Cumming et al. 2017b). Once biological age has been identified players can be organised into ‘bands’, often referred to as ‘early’, ‘circa’ (on time) and ‘late’, depending on their maturation stage and how far away they are from achieving maturity. The various predictive equations have different thresholds that qualify a player as being ‘early maturing’, ‘circa/on time maturing’ or ‘late maturing’. For example, the Khamis and Roche (1994) approach to bio-banding classifies early maturing as according to the threshold >90.1 % of EASA, circa as 85.0 to 90.0% of EASA and late and <84.9% EASA (Malina et al. 2019; Cumming et al. 2017). In comparison the Mirwald et al. (2002) approach to bio-banding uses six thresholds to categorise maturation, with the least mature threshold at -2.5 YPHV, then -1.5 YPHV, -0.5 YPHV, 0.5 YPHV, 1.5 YPHV and finally 2.5 YPHV as the most mature threshold, respectively (Till and Jones 2015). These particular thresholds were chosen as they cover the duration of the growth spurt associated with the growth curve of maturation (Malina et al. 2019; Malina, Bouchard and Bar-Or 2004). Longitudinal studies have found that PHV occurs at approximately 91 to 92% of adult stature with growth spurts lasting around 24 to 26 months (± 1 year), therefore the start of any growth spurt would occur approximately around 88 to 89% of adult stature (Malina et al. 2019). Validation studies compared somatic maturation in comparison to the stages of pubic hair development at the time of measurement and reported that PHV occurs between 88 and 96% of adult height (Malina et al. 2019). Specifically, stage 1 of pubic hair development related to <85% of predicted adult height, stage 2 to 85 to 90% of predicted adult height, stage 3 to 90 to 95% and stage 4 to 95 to 100%. Malina et al. (2019) stated that the bands proposed to organise players are “assumed” to cover the span of growth spurt, therefore they “are not fixed and may be modified as needed”.

2.13.1 Bio-banding in elite soccer

Research that has utilised maturity status bio-banding in elite soccer has primarily focused on player and coach perception and opinions of using maturity status bio-banding in tournaments and training. Bradley et al. (2019) analysed the opinions of 115 elite soccer players from three elite academies and found that overall opinions of bio-banding were positive. Similar findings were reported by Reeves et al. (2018) where researchers conducted interviews with staff and parents to investigate opinions and reported that maturity status bio-banding also fostered psychological benefits, due to increased opportunities for communication, leadership and friendship as the various chronological age groups mixed. Cumming et al. (2017a) reported numerous benefits for players when they competed in maturity status bio-banded competition. More mature players reported that they were challenged more tactically when playing against similarly mature opposition, whilst less mature players reported that they had more control over the ball and felt more composed when playing against similarly matched opposition, which suggests that maturity status bio-banding is beneficial to players of all maturation stages. Whilst the views and experiences of the different participants in maturity status bio-banded competition and training are important, there is limited objective evidence that supports these opinions (Williams, Ford and Drust 2020; Towlson et al. 2019). Romann, Lüdin and Born (2020) have conducted one of the few studies that investigated the impact of maturity status bio-banding from an objective and non-opinion-based perspective. The study compared the performance of 62 soccer players from two elite Swiss soccer academies, in which players competed in chronological age group and maturity status bio-banded group competitions. The study reported that during maturity status bio-banded competition players performed significantly less total running distance ($p < 0.001$, $d = 0.26$), total jogging distance ($p < 0.001$, $d = 0.25$) and high-speed running distance ($p = 0.035$, $d = 0.25$) when compared to performance during chronological age group competition. However, there was a significant increase in the number of duels ($p = 0.024$, $d = 0.89$) and set pieces ($p = 0.025$, $d = 1.0$) during bio-banded games in comparison to chronological age group games. Abbott et al. (2019) conducted a similar study comparing the performance of 25 soccer players in maturity status bio-banded games and chronological age grouped games and found that there was little difference in player performance, however there was significant difference in performance between the different bio-bands i.e., early, circa and late. Late maturing players covered greater total distance (8971.9 ± 329.5 metres), high speed running (813.5 ± 81.2 metres) and explosive distance (486.0 ± 40.3 metres) than early and circa maturing players, whilst early and circa maturing players completed more tackles (9.0 ± 3.3 and 8.0 ± 3.8, respectively) and crosses (2.0 ± 1.7 and 1.6 ± 1.6, respectively) than late maturing players. Consequently, late maturing players scored the rate of perceived exertion (RPE) of bio-banded games to be higher than early maturing players. The RPE is a scale that measures a player's subjective opinion of exercise and task intensity (Sanchez-Sanchez et al. 2017). However early maturing players rated the RPE of maturity status bio-banded games to be higher than chronological games, therefore showing that the perceived activity intensity of bio-banded games is higher for both early and late maturing players. Whilst this study has its merits it is limited as it only examines four KPI's and football is influenced by a multitude of KPI's, as exemplified by Sarmento et al. (2014). The study is also limited as it does not explore how different maturity status bio-banded groups/ players perform against other maturity status bio-banded groups/ players, for example how late maturing players perform against early maturing players. Greater insight into how players of different maturation perform against each other would provide useful insight when observing players in chronological age groups, especially as the maturation-selection bias is prevalent.

Therefore, the research of this thesis attempts to further the knowledge that exists within the field of bio-banding in elite soccer in relation to performance analysis.

2.14 Aims

The primary aims of this research are to investigate:

1) To identify if players of different biological maturity bands in matched, mis-matched and mixed matches perform differently according to performance analysis.
2) To identify if the method of identifying biological maturation impacts upon the performance analysis of players.

Chapter 3. Methods

3.1 Participants

The participants were 92 male, academy soccer players, aged 11-16 years old participating in the Youth Development Phase (U11 to U16) of the EPPP. The players were selected from three, category two soccer academies in the UK. Players were free from injury and were of the correct maturity to be placed within the bio-bands of this study (>90.1% and <84.9% maturation). Informed consent was collected from the players, their parents and the soccer academy they were associated with. Players and parents were informed of their right to withdraw from the study at any point, with no consequences, the subsequent data collected would be deleted. The age, stature (cm), seated height (cm), estimated leg length (cm) and body mass (kg) of the soccer players were collected so that their biological maturity could be calculated.

Table 3. Average anthropometric measurements for each age group.

Metrics	U12 N = 4	U13 N = 21	U14 N = 37	U15 N = 20	U16 N = 8	U17 N = 2
Age (year)	11.5 ± 0.3	12.5 ± 0.3	13.5 ± 0.3	14.5 ± 0.4	15.6 ± 0.1	16.1 ± 0.2
Body mass (kg)	37.5 ± 5.7	45.0 ± 6.4	47.9 ± 7.8	55.4 ± 9.5	58.7 ± 5.7	52.3 ± 9.3
Stature (cm)	152.1 ± 6.7	157.8 ± 6.5	161.5 ± 9.2	166.2 ± 9.1	174.8 ± 8.5	168.6 ± 9.8
Seated height (cm)	79.2 ± 2.0	81.0 ± 3.2	82.8 ± 5.1	86.5 ± 5.6	91.0 ± 4.9	88.1 ± 6.3
Estimated leg length (cm)	72.9 ± 4.7	76.8 ± 5.3	78.7 ± 5.9	79.6 ± 5.0	83.8 ± 5.3	80.5 ± 3.9
EASA	83.3 ± 0.3	86.2 ± 0.4	88.8 ± 0.7	92.2 ± 0.6	95.7 ± 0.5	96.7 ± 0.1
YPHV	-1.9 ± 0.1	-1.2 ± 0.1	-0.5 ± 0.2	0.4 ± 0.2	1.0 ± 0.1	1.5 ± 0.0

Key: Kg = Kilograms, Cm = Centimetres

3.2 Anthropometrical measurements

All measurements were taken according to International Society for the Advancement of Kinanthropometry (ISAK) guidelines (Stewart et al. 2011) by six ISAK accredited practitioners (level 1 - 2). If the measurements varied by more than 0.4 cm or 0.4 kg then a third measure was taken, the median calculated and the resulting value used. A portable stadiometer (seca 217, Chino, U.S.A) was used to measure player stature and seated height (an additional, standardised platform was used to assist in this measurement), expressed in centimetres, from which estimated leg length was identified by calculating player stature minus player seated height. Player body-mass was then established using digital scales (813, Chino, U.S.A) and expressed in kilograms. The relationship between estimated leg length, body mass and age were used to estimate player maturity status.

3.3 Maturity status and bio-banding

The Khamis and Roche (1994) method of estimating the players' maturity status is calculated using the players decimal age, stature, body-mass and the mid-parental stature, using the calculation, predicted adult height = $\beta_0 + \beta_1$ stature + β_2 weight + β_3 mid-parent stature (see equation 1). The stature of the players parents was collected through self-reports (with adjustment allowed for over-estimation) so that the players maturation status could be estimated (Epstein et al. 1995). To allow for similar terminology to be utilised, the 'bands' that were subsequently used to organise the players into teams were set at post-PHV (>92.0 % post-EASA), circa-PHV (87.0 - 92.0% circa-EASA) and pre-PHV (<87.0% pre-EASA).

The Fransen et al. (2017) maturity offset method utilises a predictive algorithm in which players stature, body mass and age are used to predict their age at peak height velocity (see equation 4). The players maturity offset is then identified by subtracting their decimal age in years from their age at peak height velocity (PHV). The bands by which to organise players into groups were then set as <-1.0 post-PHV, -1.0-0.0 circa-PHV and >0.0 pre-PHV.

3.4 Small-sided games (SSG)

Each player participated in five SSG fixtures, once a week for three weeks, on the same day each week (three days prior to match day). Each week a different method of maturity status bio-banding was used to organise the players into their teams. Weeks 1 used the Khamis and Roche method (1994), week 2 using the Fransen et al. (2017) method and week 3 using a mixed team's method (players within the study were randomly assigned into teams regardless of maturity status bio-banding or estimated biological age). For weeks 1 and 2 the teams were named after the bio-band that the players were placed in according to their maturity status i.e., Pre A, Pre B, Circa, A, Circa B, Post A and Post B. For week 3 the teams were named using a letter and number that had no significance other than to distinguish between the different teams i.e., A1, A2, B1, B2, C1 or C2.

Teams consisted of four players that were assigned to each team randomly by an individual who had no knowledge of the study or the participants. Each team was assigned a soccer bib colour that they were referred to by rather than their bio-band, to reduce bias when the players were being assessed during the notational analysis and the Game Technical Scoring Chart (see chapter 3.5.). To ensure the anonymity, the participants wore numbered bibs which they were identified by.

As per Fenner et al. (2016) the games were organised so that every team played each other (round robin style) (see table 4.) but also had time to recover sufficiently before playing their next opponent (five minutes game time followed by fifteen minutes low-intensity, active recovery). During this recovery players performed a standardised technical drill in order to maintain match readiness. The games were performed following a 15-minute standardised warm up and were played on an outdoor 3G pitch to ensure similar pitch conditions each week. Games were played on a dry pitch to allow secure footing and when the weather was not too extreme to interfere with player performance (i.e., too hot or cold). The pitch dimensions used were 18 x 23 meters and two 2m x 1m goals were used (Fenner et al. 2016). The pitch was supplied with multiple balls so that the game could continue with as few stoppages as possible, for instance by ball retrieval. There was minimal referee or coach input in the games so that there were no outside influences on the participants or the game. The rules of the small-sided games were explained to the participants beforehand so each game was, for the majority, self-regulated. The rules of the SSG's were designed to facilitate the flow of the game and ensure few stoppages. There were no throw ins, any restarts following a goal were played from the goal line not from the middle of the pitch, free kicks were to be played immediately, there were no goal keepers and goals had to be scored from the opposition half and not their own half (this was to encourage players to demonstrate their skill and prevent players from scoring with one well-placed kick).

This particular SSG structure and pitch size were utilised due these procedures being accurately validated in relation to coach perceptions within a previous study by Fenner et al. (2016). As discussed within the literature review of this thesis (see chapter 2.4) the number of players within a team impact upon player performance within SSGs, with larger teams (5 v 5 or 6 v 6) resulting in fewer actions performed per player and smaller teams (2 v 2 or 3 v 3) resulting in more actions per player (Sannicandro and Cofano 2017; Almeida, Ferreira and Volossovitch 2013; Aguiar et al. 2012). Therefore, using a team structure such as 4 v 4 as a mid-point between the different team structures would potentially be able to investigate an average value for potential actions per player that may take place. Additionally, this thesis was limited in the sample size available, therefore teams of 4 v 4 were the most suitable.

Table 4. Schedule of matches in the small-sided ‘round-robin’ tournament.

Team bio-band		Team bio-band	Type of match
Post B	*Versus*	Post A	Matched
Pre B	*Versus*	Pre A	Matched
Circa A	*Versus*	Circa B	Matched
Post B	*Versus*	Pre B	Mis-matched
Post A	*Versus*	Circa B	Mis-matched
Pre A	*Versus*	Circa A	Mis-matched
Circa B	*Versus*	Post B	Mis-matched
Post A	*Versus*	Pre A	Mis-matched
Pre B	*Versus*	Circa A	Mis-matched
Pre A	*Versus*	Circa B	Mis-matched
Post A	*Versus*	Pre B	Mis-matched
Post B	*Versus*	Circa A	Mis-matched
Pre B	*Versus*	Circa B	Mis-matched
Pre A	*Versus*	Post B	Mis-matched
Circa B	*Versus*	Post A	Mis-matched

Where Pre refers to Pre-PHV, Circa refers to Circa-PHV, and Post refers to Post-PHV,
In week 1 the players were organised in teams according the Khamis and Roche (1994) approach and in week 2 the players were organised into teams according to the Fransen et al. (1994) approach.
In week 3 a similar format was used however the teams were random.

3.5 Game Technical Scoring Chart

Each player was assessed during each game using the valid and reliable Game Technical Scoring Chart (GTSC) which is a tool used by coaches and scouts that measures their perceptions of players (Fenner, Iga and Unnithan 2016; Unnithan et al. 2012). The chart is comprised of 10 elements ‘cover/support’, ‘communication’, ‘decision making’, ‘passing’, ‘first touch’, ‘control’, ‘one versus one’, ‘shooting’, ‘assists’, and ‘marking’. Each of these 10 elements were independently scored from 1 – 5 (1 being classed as ‘poor’ and 5 as ‘excellent’) by 12 qualified football practitioners (at least FA Level 2 qualified). The points awarded during each game were totalled together to give a total score, therefore the maximum number of points a player could score was 50.

3.6 Performance analysis

Full, SSG’s were filmed (Sony Handycam HD 9.2) using a tripod (Velbon DF-41) set to a standardised height (153 cm) and pitch position. The camera and tripod were positioned at the halfway line with enough distance away from pitch that the whole pitch could be viewed and recorded. The camera was set to record with the screen zoomed out at maximum so that the recording settings were replicable for every game. The games were analysed using industry standard video analysis software (SportsCode version 11.3.0). Footage was coded to identify the key performance indicators: possession (seconds), possession position on court, shots on target, shots off target, successful passes, unsuccessful passes, interceptions, fouls conceded, aerial challenges, ground challenges, dribbling (seconds), turning and x-factor using a coding window [see appendix 1.]. The coding window was tested by a performance analyst for its usability for the selected key performance indicators. During this process, several issues were identified and rectified, pertaining to possession and individual player observations. During the creation of the code window used to complete the performance analysis the players were labelled “Player 1”, “Player 2”, “Player 3” and “Player 4” according to the bib numbers that they wore. When selecting the buttons in the code window for the players this automatically initiated the collection of the possession data through an activation link. However, the code window failed to distinguish between players on

“Team 1” and players on “Team 2’ which resulted in data being collected for both players on both teams at the same time. For instance, when “Player 1” on “Team 1” was selected data was being collected for “Player 1” on “Team 2” as well because the initial player buttons were labelled the same i.e., “Player 1”. After realising this over sight, the player buttons were re-labelled to “Player 1, Team 1”, “Player 2, Team 1”, “Player 3, Team 1” and “Player 4, Team 1” for “Team 1” and “Player 1, Team 2”, “Player 2, Team 2”, “Player 3, Team 2” and “Player 4, Team 2” for “Team 2”. By using labels that distinguished between the players on each team this allowed for the correct possession data to be collected.

3.6.1 Key performance indicators and operational definitions

The operational definitions for the key performance indicators identified (see table 5.) were informed by the literature and validated by professionals working in the football industry to assess the suitability and usability.

The KPI “possession” was chosen as a metric due to previous literature identifying that possession was different between successful and unsuccessful teams in soccer therefore it may be able to indicate talented and less talented players (Hughes et al. 2012; McKenzie and Cushion 2012; Jones, James and Mellalieu 2004). “Position on pitch” was investigated to add additional insight into the “possession” metric and identify if different teams (i.e., different bio-bands) had different strategies (e.g., offensive and defensive tactics) when in possession of the ball. “Shots on target”, “shots off target” and “fouls conceded” were included as a KPI due to the popularity of those indicators investigated in previous research (see table 5.). The KPI’s “successful passes”, “unsuccessful passes”, “interception”, “ground challenges” and “dribbling” were included as technical metrics as research identified that more talented elite youth soccer players are able to perform more successful passes, tackles, interceptions and dribble for longer in comparison to less talented players elite youth soccer players (Forsman et al. 2016; Huijgen et al. 2009). The KPI "aerial challenge" was investigated in this thesis because it has been investigated in previous research and being able to complete aerial challenges requires lower body strength, which previous research has shown to differentiate between athletes of different maturation (Towlson et al. 2017; Liu et al. 2013; Malina et al. 2004). "Turning" was investigated as a KPI because it takes agility to be able to perform and studies have shown there is a difference between maturation and agility performance (Malina et al. 2007; Malina et al. 2004). Finally, the KPI "x-factor" was investigated to identify if it is possible to quantify a "gut feeling" and if it matches the gut feelings and impressions of coaches (Larkin and O'Connor 2017).

Choi (2008) proposed that KPI's operational definitions should be informed by coaches opinions as they are experts, however purely utilising KPI's influenced by opinions can lead to bias. Therefore, in order to incorporate both research and soccer experts the KPI's and operational definitions utilised in this thesis were informed in part by research and by those involved in soccer on a regular basis. A sample of football professionals (n = 8; coaches, performance analysts and sports scientists) working within the soccer academies, completed an anonymous, online, multiple choice questionnaire [see appendix 2.]. The questionnaire comprised of 12 questions that tested the suitability of the operational definitions that had been selected and created for the key performance indicators used in this analysis. On 10 of the questions the answers were unanimous in their agreement of which operational definitions best described the key performance indicators selected, however there was some disagreement over the definitions on two questions. After reviewing the answers given for the key performance indicator 'x-factor' and 'foul conceded' the operational definitions used in this study were changed to add more clarity. The operational definitions and the literature that influenced them can be found in table 5. below.

Table 5. The key performance indicators and operational definitions used for this study.

Key Performance Indicator	Operational Definitions
Possession	When a player has control of the ball to an extent that they can influence its direction. Possession ends when the ball in intercepted/influenced by an opposition player, the ball goes out of play and/or a referee stops play. Possession starts form a referee's whistle, from the ball being played onto the pitch, from an interception from the opposition, from a re-bound on the goal, from a free kick. Adapted from Jones et al. (2004)
Shots on target	When a player aims the ball towards the goal that results in a goal or a save from the opposition. Adapted from Scherschel (2014) and Opta (2018).
Shots off target	When a player aims the ball towards the goal that results in missing the goal or re-bounding off the goal posts. Adapted from Scherschel (2014) and Opta (2018).
Successful pass	When the ball is transferred from one player to another successfully without the ball being intercepted or going out of play. Adapted from Scherschel (2014) and Opta (2018).

Unsuccessful pass	When the ball is unsuccessfully transferred from one player to another i.e., the ball is intercepted or goes out of play. Adapted from Scherschel (2014) and Opta (2018).
Interception	The ball is won due to interrupting the oppositions possession of the ball whilst still keeping the ball in play. Interception can occur by recovering the ball from a ground or an aerial challenge but not through the gaining of the ball through the oppositions breaking the rules or the ball leaving the pitch. Interception is defined as winning the ball whilst game play continues and not through an event that causes a re-start of play. Adapted from Barreira et al. (2014).
Foul conceded	A deliberate breaking of the rules of the game that results in the ball being awarded to the non-offending team, does not include deliberately playing the ball out the field of play. When the referee stops play to award the ball to the non-offending team following the rules being broken. Adapted from The Football Association (2018).
Aerial challenge	When the ball is competed for the ball or the player is in the air. Adapted from Opta (2018).
Ground challenge	When the ball is competed for when the ball is on the ground.

	Adapted from Scherschel (2014).
Dribbling	When a player maintains possession of the ball and guides the ball in a certain direction using their feet. Adapted from Abbott et al. (2019).
Turning	A change of direction when the player has the ball in their possession. Adapted from Malina et al. (2005).
Position on court	Where the player is located on the court when they are in possession of the ball. These sections are spilt into offensive right side, offensive left side, defensive right side and defensive left side
x-factor	"Unpredictable; creativity; thinks outside the box; talent; gift". A gut feeling of impressiveness when observing a player/s. Larkin and O'Connor (2017).

3.6.2 Reliability

The reliability of the coding window and operational definitions was also analysed through intra-rater reliability methods (see table 6.). A sample (n = 18) of SSG's were re-coded, by the same analyst to identify the reliability of the code window utilised. These 18 games were selected so that each of the methods of maturity status bio-banding (Khamis and Roche = 6, Fransen = 6 and mixed = 6) and each maturity status bio-band (pre = 4, circa = 4, post = 4) could be re-tested. To reduce potential bias, a week-long wash out' period between the first and second analysis was carried out. To reduce fatigue when coding the games, a minimum five-minute break was carried out between each game.

Table 6. The intra-rater reliability of 18 matches (Khamis and Roche = 6, Fransen = 6 and mixed = 6), testing 12 key performance indicators (mean ± SD), with a week-long 'wash-out' period between the first and second analysis.

	First analysis (mean ± SD)	Second analysis (mean ± SD)	Mean difference	R^2 (confidence intervals)	R^2 qualitative relationship
Successful passes (*f*)	24.6 ± 6.7	24.7 ± 6.0	0.1 ± 1.8	0.96 (0.95 to 0.97)	Strong
Unsuccessful passes (*f*)	6.3 ± 2.6	6.3 ± 2.7	0.0 ± 0.8	0.84 (0.76 to 0.90)	Strong
Turning (*f*)	1.0 ± 1.2	0.6 ± 0.7	-0.4 ± 0.7	1.00 (0.88 to 1.00)	Strong
Goals (*f*)	1.6 ± 1.3	1.4 ± 1.5	-0.2 ± 0.4	0.94 (0.92 to 0.94)	Strong

Shots on target (*f*)	3.1 ± 1.9	3.1 ± 2.0	0.1 ± 0.9	0.91 (0.85 to 0.95)	Strong
Shots off target (*f*)	2.8 ± 1.8	3.0 ± 1.7	0.2 ± 0.5	0.96 (0.92 to 0.98)	Strong
Aerial challenge (*f*)	0.2 ± 0.4	0.5 ± 0.8	0.3 ± 0.8	0.34 (0.16 to 0.51)	Moderate
Ground challenge (*f*)	4.8 ± 2.3	5.4 ± 3.3	0.6 ± 3.0	0.65 (0.44 to 0.79)	Moderate
Interception (*f*)	4.6 ± 2.5	5.4 ± 3.4	0.8 ± 2.2	1.00 (0.88 to 1.00)	Strong
Penalty (*f*)	0.2 ± 0.4	0.0 ± 0.0	-0.2 ± 0.4	0.16 (-0.04 to 0.34)	Weak
X-factor (*f*)	0.6 ± 0.6	0.3 ± 0.6	-0.2 ± 0.6	0.26 (0.07 to 0.44)	Weak
Dribbling (s)	21.08 ± 12.89	25.77 ± 12.41	4.69 ± 4.21	0.94 (0.91 to 0.96)	Strong
Defensive left side (s)	28.21 ± 13.14	31.15 ± 11.11	2.94 ± 11.14	0.94 (0.91 to 0.96)	Strong
Defensive right side (s)	27.46 ± 11.91	26.81 ± 12.52	-1.45 ± 2.18	0.69 (0.57 to 0.78)	Moderate
Offensive left side (s)	15.80 ± 9.89	13.73 ± 8.79	-2.05 ± 2.97	0.96 (0.94 to 0.97)	Strong
Offensive right side (s)	17.76 ± 9.81	16.83 ± 9.07	-0.92 ± 1.87	0.98 (0.97 to 0.99)	Strong

f = frequency and s = seconds. Where the qualitative R^2 values are defined as Strong (<0.70), Moderate (0.30 to 0.50) and Weak as (0.00 to 0.30).

The coefficient of determination shows that there were several instances of high determination, in particular the turning ($R^2 = 1.00$) and interception ($R^2 = 1.00$). The lowest reported values of determination were reported for aerial challenge ($R^2 = 0.34$), penalties ($R^2 = 0.16$) and x-factor ($R^2 = 0.26$). These results may be influenced by the low, mean number of these KPI's being performed in each game and/or between each week of analysis.

3.7 Statistical analysis

Statistical analysis was completed using SPSS (Statistical Produce and Service Solutions) (version 27; IBM, Chicago, USA). Findings were analysed for normality using a Q-Q plot, following which general linear modelling was conducted to investigate the estimated marginal means for the anthropometrical measurements, GTSC total points, GTSC points scored and the KPI's identified in table 5. between the maturity matched (post-PHV v post-PHV, circa-PHV v circa-PHV and pre-PHV v pre-PHV), maturity mis-matched (post-PHV v pre-PHV, post-PHV v circa-PHV and circa-PHV v pre-PHV) bio-banded games and randomly assigned mixed games (A v A, B v B, C v C, A v B, A v C and B v C) with 95% confidence intervals. Two-tailed significance was set at $P < 0.05$.

Cohen's d effect size (ES) (Hopkins et al. 2009) was calculated to identify the magnitude of anthropometrical measurements, GTSC total points and GTSC points scored and the investigated KPI's between the different bio-bands (post-PHV, circa-PHV and pre-PHV). ES was categorised as trivial (< 0.2), small (0.201 to 0.6), moderate (0.601 to 1.2), large (1.201 to 2.0) and very large (2.001 to > 4.0) (Hopkins 2017).

Chapter 4. Results

4.1 Maturity matched bio-banded games

4.1.1 Anthropometric measurements

There were no statistical differences between the age (*P* = 1.000), stature (*P* = 1.000), seated height (*P* = 1.000), estimated leg length (*P* = 1.000) or body-mass (*P* = 1.000) of the players when compared according to bio-banded matched games (e.g., post-PHV versus post-PHV), this applied to both the Fransen et al. (2017) (see table 7.) and Khamis and Roche (1994) methods (see table 8.), respectively. Specific to the Fransen et al. (2017) method there was no statistical difference in the years from peak height velocity (*P* = 1.000) between maturity matched bio-banded games. Specific to the Khamis and Roche (1994) method there was no statistical difference in the estimated adult stature attainment (*P* = 0.4 to 1.000) between maturity matched bio-banded games.

Table 7. The anthropometric measurements and years from peak height velocity, with 95% confidence intervals, effect size and statistical significance, for maturity status bio-banded small-sided games using the Fransen et al. (2017) equation.

		Fransen et al. (2017)					
		Post-PHV v Post-PHV	***Circa-PHV v Circa-PHV***	***Pre-PHV v Pre-PHV***	***Post-PHV v Pre-PHV***	***Post-PHV v Circa-PHV***	***Circa-PHV v Pre-PHV***
Age (years)	Mean (95% Confidence Interval)	14.6 to 14.7 (1.1 to 1.6)	13.5 to 13.7 (-1.6 to 1.2)	12.7 to 13.0 (-1.3 to 1.4)	12.7 to 14.7 (-3.3 to -0.6)	13.5 to 14.7 (-2.3 to 0.9)	12.7 to 13.7 (2.9 to 1.7)
	Effect size	0.0 Trivial	0.0 Trivial	0.7 Moderate	-5.8 to 4.6 Very large	-2.9 to 2.9 Very large	-2.9 to 2.9 Very large
	P value	1.000	1.000	1.000	≤0.001 to 0.004	0.95 to 1.000	0.9 to 1.000
Years from peak height velocity (years)	Mean (95% Confidence Interval)	0.2 to 0.2 (-1.1 to 0.8)	-0.05 to 0.09 (-0.8 to 1.2)	-0.3 to -0.3 (-0.7 to 1.2)	-0.3 to 0.2 (-3.4 to 1.1)	-0.05 to 0.2 (-2.4 to 0.2)	0.09 to -0.3 (-2.3 to 0.1)
	Effect size	0.03 Trivial	0.7 Moderate	0.0 Trivial	-0.5 to 12.4 Small to very large	-0.3 to 4.6 Very large	-4.7 to 6.4 Very large
	P value	1.000	1.000	1.000	≤0.001	0.001 to 0.500	≤0.001 to 0.200
Stature (cm)	Mean (95% Confidence Interval)	171.1 to 172.4 (-9.2 to 11.7)	160.2 to 162.9 (7.8 to 13.2)	154.4 to 155.0 (-9.4 to 11.6)	154.4 to 172.4 (-28.4 to 7.4)	160.2 to 172.4 (-25.6 to 4.0)	154.4 to 162.9 (-18.9 to 5.1)
	Effect size	0.6 Small	0.9 Moderate	0.2 Small	-10.3 to 7.2 Very large	-4.2 to 3.1 Very large	-3.3 to 2.5 Very large
	P value	1.000	1.000	1.000	≤0.001	0.800 to 1.000	0.800 to 1.000
Seated height (cm)	Mean (95% Confidence Interval)	89.4 to 89.7 (-5.3 to 5.8)	82.8 to 84.1 (-4.3 to 6.9)	78.5 to 79.4 (-5.0 to 6.2)	78.5 to 89.7 (-16.8 to 5.6)	82.8 to 89.7 (-13.7 to 2.2)	78.5 to 84.1 (-11.2 to 2.2)
	Effect size	0.0 Trivial	0.7 Moderate	0.9 Moderate	-9.6 to 8.3 Very large	-5.4 to 4.7 Very large	-3.7 to 4.0 Very large
	P value	1.000	1.000	1.000	≤0.001	0.02 to 0.900	0.04 to 1.000
Estimated leg length (cm)	Mean (95% Confidence Interval)	81.5 to 83.0 (-6.7 to 9.7)	77.4 to 78.9 (-6.8 to 9.7)	75.6 to 75.9 (-7.8 to 8.7)	75.9 to 83.00 (-15.7 to 2.8)	77.4 to 83.0 (-16.8 to 6.5)	75.6 to 78.9 (-11.6 to 6.30)

	Effect size	0.9 Moderate	0.6 Small	0.3 Small	-4.3 to 3.5 Very large	-2.3 to 2.1 Very large	-2.0 to 1.7 Very large to large
	P value	1.000	1.000	1.000	0.400 to 1.000	1.000	1.000
Body-mass (kg)	Mean (95% Confidence intervals)	57.0 to 58.8 (-12.8 to 8.7)	49.2 to 49.7 (-10.1 to 10.9)	41.9 to 42.0 (-9.7 to 11.4)	41.9 to 58.8 (-27.2 to 6.2)	49.2 to 58.5 (-26.6 to 6.9)	41.9 to 49.7 (-18.3 to 3.1)
	Effect size	0.6 Small	0.1 Trivial	0.0 Trivial	-7.0 to 6.5 Very large	-2.9 to 2.3 Very large	-3.1 to 2.9 Very large
	P value	1.000	1.000	1.000	≤0.001	0.200 to 1.000	0.900 to 1.000

Maturity status: Where the estimated number of years to peak height velocity categorises pre-PHV (>0.0 YPHV), circa-PHV -1.0 to 0.0 YPHV) and post-PHV (<-1.0 YPHV). Effect size: Where observed effects are categorised as Trivial (<0.2), Small (0.201 to 0.6), Moderate (0.601 to 1.2), Large (1.201 to 2.0) and Very large (2.001 to >4.0). Statistical significance is denoted as $P \leq 0.05$.
cm = centimetres, kg = kilograms, *f* = frequency and seconds.

Table 8. The anthropometric measurements and estimated adult stature attainment, with 95% confidence intervals, effect size and statistical significance, for maturity status bio-banded small-sided games using the Khamis and Roche (1994) equation.

		Khamis and Roche (1994)					
		Post-PHV v Post-PHV	***Circa-PVH v Circa-PHV***	***Pre-PHV v Pre-PHV***	***Post-PHV v Pre-PHV***	***Post-PHV v Circa-PHV***	***Circa-PHV v Pre-PHV***
Age (years)	Mean (95% Confidence Interval)	14.19 to 14.83 (-2.1 to 0.8)	13.43 to 14.12 (-2.1 to 0.7)	12.88 to 12.97 (-1.7 to 0.7)	12.88 to 14.83 (-3.4 to 0.2)	13.43 to 14.83 (-2.8 to 1.4)	12.88 to 14.12 (-2.7 to 1.1)
	Effect size	2.3 Very large	1.4 Large	0.0 Trivial	-7.7 to 2.9 Very large	-5.8 to 1.4 Very large to large	-2.9 to 2.9 Very large
	P value	1.000	1.000	1.000	≤0.001 to 0.400	1.000	0.300 to 1.000
Estimated adult stature attainment (years)	Mean (95% Confidence Interval)	93.0 to 95.4 (-5.3 to 0.4)	89.1 to 90.4 (-4.2 to 1.6)	85.4 to 85.7 (-3.6 to 2.8)	85.4 to 95.3 (-12.6 to -4.6)	89.1 to 95.4 (-9.2 to 0.4)	85.4 to 90.4 (-7.9 to 0.1)
	Effect size	2.8 Very large	1.6 Large	0.5 Small	-11.9 to 12.4 Very large	-5.6 to 7.3 Very large	-5.8 to 6.0 Very large
	P value	0.4	1.000	1.000	≤0.001	≤0.001 to 0.300	≤0.001 to 0.07
Stature (cm)	Mean (95% Confidence Interval)	172.2 to 175.2 (-13.2 to 7.2)	159.8 to 161.8 (-8.2 to 12.2)	154.4 to 156.6 (-14.0 to 8.9)	154.4 to 175.2 (-31.0 to -5.4)	159.8 to 175.2 (-25.6 to -0.2)	154.4 to 161.8 (-19.7 to 7.0)
	Effect size	1.2 Moderate	0.8 Moderate	1.4 Large	-11.9 to 9.0 Very large	-5.8 to 5.0 Very large	-5.1 to 3.2 Very large
	P value	1.000	1.000	1.000	≤0.001	≤0.001 to 0.4	1.000
Seated height (cm)	Mean (95% Confidence Interval)	88.4 to 92.8 (-9.6 to 0.8)	82.3 to 82.5 (-5.6 to 5.0)	79.5 to 80.2 (4.4 to 7.3)	79.5 to 92.8 (-18.5 to -3.0)	82.3 to 92.8 (-15.8 to -0.7)	79.5 to 82.3 (-8.2 to 5.0)
	Effect size	3.3 Very large	0.0 Trivial	0.4 Small	-10.7 to 9.8 Very large	-7.6 to 7.1 Very large e	-2.9 to 2.6 Very large
	P value	0.4	1.000	1.000	≤0.001	≤0.001	1.000
Estimated leg length (cm)	Mean (95% Confidence Interval)	82.4 to 83.8 (-6.5 to 9.3)	77.3 to 79.5 (-5.6 to 10.1)	74.2 to 77.1 (-12.8 to 4.8)	74.2 to 83.8 (-17.5 to 2.6)	77.3 to 83.8 (-14.4 to 5.0)	74.2 to 79.5 (-15.4 to 7.7)

	Effect size	0.9 Moderate	1.2 Moderate	1.8 Large	-5.2 to 6.1 Very large	-5.5 to 4.6 Very large	-1.4 to 1.4 Large
	P value	1.000	1.000	1.000	≤0.001	1.000	1.000
Body-mass (kg)	Mean (95% Confidence Interval)	57.0 to 61.4 (-14.0 to 5.1)	45.5 to 50.5 (-4.4 to 14.7)	41.8 to 43.6 (-12.8 to 8.6)	41.8 to 61.4 (-29.2 to -3.8)	45.5 to 61.4 (-25.7 to 3.1)	41.8 to 50.5 (-20.9 to 7.8)
	Effect size	1.7 Large	1.9 Large	0.9 Moderate	-9.2 to 7.8 Very large	-4.6 to 4.4 Very large	-5.2 to 4.0 Very large
	P value	1.000	1.000	1.000	≤0.001	≤0.001 to 1.000	0.7 to 1.000

Maturity status: Where the estimated adult stature attainment categorises post-PHV (> 92.0%), circa-PHV (87.0 to 93.0%) and pre-PHV (<87.0%). Effect size: Where observed effects are categorised as Trivial (<0.2), Small (0.201 to 0.6), Moderate (0.601 to 1.2), Large (1.201 to 2.0) and Very large (2.001 to >4.0). Statistical significance is denoted as $P \leq 0.05$.
cm = centimetres, kg = kilograms, *f* = frequency and s = seconds.

4.1.2 Game technical scoring chart

There were no statistically significant results ($P \geq 0.05$) found in total GTSC for any of the maturity matched bio-banded games, which was true for both the Fransen et al. (2017) (see table 9.) and Khamis and Roche (1994) (see table 10.) methods, respectively. There were only two significant ($P < 0.05$) results found in GTSC points scored, the first was circa-PHV versus circa-PHV ($P = 0.002$, ES = 0.26, *small*) in the Fransen et al. (2017) method and the second was post-PHV versus post- PHV ($P \leq 0.001$, ES = 1.38, *large*) in the Khamis and Roche (1994) method.

Table 9. The game technical scoring chart measurements, with 95% confidence intervals, effect size and statistical significance, for maturity status b
banded small-sided games using the Fransen et al. (2017) equation.

		Fransen et al. (2017)					
		Post-PHV v Post-PHV	***Circa-PHV v Circa-PHV***	***Pre-PHV v Pre-PHV***	***Post-PHV v Pre-PHV***	***Post-PHV v Circa-PHV***	***Circa-P Pre-P***
Total GTSC	Mean (95% Confidence Interval)	23.3 to 23.6 (-13.6 to 14.2)	22.3 to 23.0 (-14.6 to 13.2)	22.8 to 23.3 (-18.1 to 8.8)	22.8 to 23.6 (-16.7 to 13.5)	22.3 to 23.6 (-21.9 to 27.9)	22.8 to (-17.4 to
	Effect size	0.02 Trivial	0.09 Trivial	0.06 Trivial	-0.10 to 0.07 Trivial	-0.15 to 0.07 Trivial	-0.12 to Trivi
	P value	1.000	1.000	1.000	1.000	1.000	1.00
GTSC points scored	Mean (95% Confidence Interval)	2.6 to 3.1 (-0.9 to 3.6)	1.9 to 2.3 (-4.9 to 0.4)	1.2 to 0.9 (-3.6 to 0.9)	0.9 to 3.1 (-4.9 to 0.9)	1.9 to 3.1 (-7.5 to 3.1)	0.9 to (-6.2 to
	Effect size	0.30 Small	0.26 Small	0.20 Trivial	-1.49 to 1.17 Large	-0.77 to 0.52 Moderate to small	-0.94 to Moder
	P value	1.000	0.002	1.000	0.002 to 0.004	≤0.001 to 1.000	≤0.001 to

Maturity status: Where the estimated number of years to peak height velocity categorises pre-PHV (>0.0 YPHV), circa-PHV -1.0 to 0.0 YPHV) and post-PHV (<-1.0 YPHV). Ef
Where observed effects are categorised as Trivial (<0.2), Small (0.201 to 0.6), Moderate (0.601 to 1.2), Large (1.201 to 2.0) and Very large (2.001 to >4.0). Statistical significa
denoted as P ≤ 0.05.
cm = centimetres, kg = kilograms, *f* = frequency and seconds.

Table 10. The game technical scoring chart measurements, with 95% confidence intervals, effect size and statistical significance, for maturity status banded small-sided games using the Khamis and Roche (1994) equation.

		Khamis and Roche (1994)					
		Post-PHV v Post-PHV	***Circa-PHV v Circa-PHV***	***Pre-PHV v Pre-PHV***	***Post-PHV v Pre-PHV***	***Post-PHV v Circa-PHV***	***Circa-PH[V] PH[V]***
Total GTSC	Mean (95% Confidence Interval)	23.4 to 24.1 (-10.7 to 12.9)	23.4 to 24.0 (-13.1 to 10.6)	21.8 to 23.6 (-10.2 to 16.2)	21.8 to 24.1 (-16.8 to 14.6)	23.4 to 24.0 (-14.0 to 13.7)	21.8 to (17.5 to
	Effect size	0.10 Trivial	0.09 Trivial	0.26 Small	-0.22 to 0.33 Trivial to small	-0.08 to 0.11 Trivial	-0.24 to Sma
	P value	1.000	1.000	1.000	1.000	1.000	1.00
GTSC points scored	Mean (95% Confidence Interval)	1.9. to 3.5 (-6.1 to -1.9)	2.0 to 2.6 (-0.8 to 3.5)	0.8 to 1.2 (-1.7 to 3.1)	0.8 to 3.5 (-6.1 to 0.8)	1.9 to 3.5 (-3.5 to 4.8)	0.8 to (-6.1 to
	Effect size	1.38 Large	0.39 Small	0.26 Small	-2.32 to 1.98 Very large to large	-1.29 to 0.77 Large to moderate	-0.90 to Moder
	P value	≤0.001	1.000	1.000	≤0.001 to 1.000	≤0.001 to 1.000	≤0.001 to

Maturity status: Where the estimated adult stature attainment categorises post-PHV (> 92.0%), circa-PHV (87.0 to 93.0%) and pre-PHV (<87.0%). Effect size: Where observed e[f] categorised as Trivial (<0.2), Small (0.201 to 0.6), Moderate (0.601 to 1.2), Large (1.201 to 2.0) and Very large (2.001 to >4.0). Statistical significance is denoted as P ≤ 0.[0] cm = centimetres, kg = kilograms, f = frequency and s = seconds.

4.1.3 Key performance indicators from match analysis

There were no statistical differences in any of the other KPI's investigated in the Fransen et al. (2017) method apart from defensive right side for pre-PHV versus pre-PHV (*P* = 0.001, ES = 0.59, *small*) (see table 11.). Likewise, there were no statistical differences found in any of the KPI's investigated in the Khamis and Roche (1994) method apart from defensive left side for circa-PHV versus circa- PHV (*P* = ≤0.001, ES = 0.72, *moderate*) and pre-PHV versus pre-PHV (*P* = ≤ 0.001, ES = 0.16, *trivial*) (see table 12).

Table 11. The key performance indicators, with 95% confidence intervals, effect size and statistical significance, for maturity status bio-banded small-sided games using the Fransen et al. (2017) equation.

		Fransen et al. (2017)					
		Post-PHV v Post-PHV	***Circa-PHV v Circa-PHV***	***Pre-PHV v Pre-PHV***	***Post-PHV v Pre-PHV***	***Post-PHV v Circa-PHV***	***Circa-PHV v Pre-PHV***
Successful passes (*f*)	Mean (95% Confidence Interval)	6.3 to 6.5 (-2.9 to 5.9)	5.4 to 6.2 (-4.3 to 4.6)	5.5 to 6.2 (-3.6 to 5.2)	5.5 to 6.5 (-6.7 to 5.4)	5.4 to 6.5 (-7.5 to 5.7)	5.5 to 6.2 (-6.6 to 4.6)
	Effect size	0.06 Trivial	0.34 Small	0.26 Small	-0.32 to 0.39 Small	-0.39 to 0.36 Small	-0.26 to 0.29 Small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Unsuccessful passes (*f*)	Mean (95% Confidence Interval)	1.8 to 2.0 (-1.8 to 2.8)	1.8 to 2.2 (-2.5 to 1.3)	2.0 to 2.0 (-1.9 to 1.9)	1.8 to 2.0 (-2.0 to 3.3)	1.8 to 2.2 (-3.3 to 2.1)	1.8 to 2.2 (-2.7 to 2.7)
	Effect size	0.13 Trivial	0.34 Small	0.00 Trivial	-0.13 to 0.13 Trivia	-0.17 to 0.26 Trivial to small	-0.17 to 0.13 Trivial
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Turning (*f*)	Mean (95% Confidence Interval)	1.1 to 1.3 (-1.8 to 2.7)	1.3 to 1.3 (N/A)	1.1 to 1.3 (-2.1 to 2.8)	1.1 to 1.3 (-2.8 to 2.1)	1.1 to 1.3 (-4.2 to 2.2)	1.1 to 1.3 (-3.8 to 4.2)
	Effect size	0.17 Trivial	0.00 Trivial	0.26 Small	-0.26 to 0.17 Small to trivial	-0.13 to 0.17 Trivial	-0.17 to 0.13 Trivial
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Goals (*f*)	Mean (95% Confidence Interval)	1.4 to 1.4 (-1.3 to 1.8)	1.3 to 1.4 (1.3 to 2.3)	1.1 to 1.1 (-1.9 to 1.4)	1.1 to 1.4 (-2.4 to 2.0)	1.3 to 1.4 (2.4 to 2.2)	1.1 to 1.4 (-3.2 to 1.9)
	Effect size	0.00 Trivial	0.13 Trivial	0.00 Trivial	-0.39 to 0.39 Small t	-0.13 to 0.13 Trivial	-0.39 to 0.39 Small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Shots on tar-get (*f*)	Mean (95% Confidence Interval)	1.8 to 1.8 (-2.2 to 1.4)	1.5 to 1.8 (-1.4 to 2.7)	1.3 to 1.5 (-2.7 to 2.1)	1.3 to 1.8 (-2.7 to 1.8)	1.5 to 1.8 (-4.1 to 1.6)	1.3 to 1.8 (-3.4 to 2.6)

	Effect size	0.00 Trivial	0.39 Small	0.09 Trivial	-0.64 to 0.43 Small	-0.26 to 0.39 Small	-0.26 to 0.64 Small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Shots off target (*f*)	Mean (95% Confidence Interval)	1.2 to 1.4 (-1.8 to 0.7)	1.1 to 1.5 (-0.8 to 1.7)	1.3 to 1.3 (-1.3 to 1.4)	1.2 to 1.3 (-1.9 to 1.9)	1.2 to 1.5 (-2.2 to 3.0)	1.1 to 1.3 (-1.4 to 1.9)
	Effect size	0.26 Small	0.65 Moderate	0.00 Trivial	-0.13 to 0.13 Trivial	-0.39 to 0.48 Small	-0.32 to 0.26 Small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Ground challenges (*f*)	Mean (95% Confidence Interval)	1.6 to 1.8 (-2.4 to 1.8)	2.1 to 2.2 (-2.6 to 2.0)	2.0 to 2.7 (-2.7 to 2.0)	1.6 to 2.7 (-1.8 to 4.8)	1.6 to 2.2 (-0.6 to 4.6)	2.1 to 2.7 (-3.1 to 3.5)
	Effect size	0.17 Trivial	0.06 Trivial	0.36 Small	-0.47 to 0.71 Small to moderate	-0.43 to 0.52 Small	-0.31 to 0.26 Trivial
	P value	1.000	1.000	1.000	0.8	1.000	1.000
Interceptions (*f*)	Mean (95% Confidence Interval)	1.8 to 1.9 (-1.5 to 3.2)	1.6 to 1.6 (-2.0 to 2.0)	1.4 to 1.5 (-2.1 to 1.6)	1.4 to 1.9 (-3.1 to 1.8)	1.6 to 1.9 (-3.8 to 2.9)	1.4 to 1.6 (-2.4 to 2.0)
	Effect size	0.09 Trivial	0.00 Trivial	0.13 Trivial	-0.39 to 0.51 Small	-0.26 to 0.26 Small	-0.26 to 0.26 Small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Dribbling (s)	Mean (95% Confidence Interval)	6.71 to 7.65 (-9.88 to 7.80)	6.70 to 7.42 (-9.37 to 8.77)	7.45 to 7.79 (-10.27 to 7.99)	6.71 to 7.79 (-11.29 to 12.86)	6.70 to 7.79 (-16.16 to 9.76)	6.70 to 7.79 (-11.06 to 10.74)
	Effect size	0.17 Trivial	0.13 Trivial	0.05 Trivial	-0.22 to 0.03 Trivial	-0.18 to 0.13 Trivial	-0.13 to 0.26 Trivial
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Defensive left side (s)	Mean (95% Confidence Interval)	19.28 to 26.64 (-0.52 to 29.18)	25.08 to 27.64 (-5.88 to 23.83)	27.74 to 28.19 (-15.19 to 15.19)	19.28 to 26.64 (-13.68 to 21.84)	19.28 to 27.64 (-27.80 to 30.17)	25.08 to 29.13 (-26.33 to 16.93)
	Effect size	0.83 Moderate	0.26 Small	0.12 Trivial		-0.86 to 0.62 Moderate	-0.35 to 0.27 Small

					-0.22 to 0.85 Trivial to moderate		
	P value	0.09	1.000	1.000	1.000	0.500 to 1.000	1.000
Defensive right side (s)	Mean (95% Confidence Interval)	29.53 to 31.72 (-7.76 to 28.61)	27.46 to 28.54 (-4.72 to 31.65)	24.49 to 33.17 (-41.50 to -4.32)	29.53 to 33.17 (-28.00 to 23.16)	27.46 to 33.17 (-38.22 to 15.89)	24.49 to 33.17 (-33.42 to 28.70)
	Effect size	0.18 Trivial	0.10 Trivial	0.59 Small	-0.55 to 0.46 Small;	-0.32 to 0.26 Small to trivial	-0.23 to 0.39 Small to trivial
	P value	1.000	0.9	0.001	1.000	1.000	1.000
Offensive left side (s)	Mean (95% Confidence Interval)	20.03 to 22.31 (-19.44 to 5.39)	18.62 to 19.36 (-19.74 to 5.10)	13.89 to 18.05 (-6.62 to 18.78)	13.89 to 22.31 (-31.25 to 19.88)	18.62 to 22.31 (-50.42 to 6.82)	13.89 to 19.36 (-27.08 to 14.79)
	Effect size	0.17 Trivial	0.09 Trivial	0.54 Small	-0.81 to 0.61 Moderate	-0.40 to 0.27 Small	-0.81 and 0.74 Moderate
	P value	1.000	1.000	1.000	≤0.001 to 1.0000	≤0.001 to 1.000	0.002 to 1.000
Offensive right side (s)	Mean (95% Confidence Interval)	22.45 to 28.52 (-17.89 to 6.88)	17.71 to 20.10 (-18.65 to 6.13)	13.22 to 16.58 (-7.51 to 17.81)	13.22 to 28.52 (-30.94 to 12.83)	17.71 to 28.52 (-62.16 to 1.55)	13.22 to 20.10 (-30.13 to 8.10)
	Effect size	0.49 Small	0.29 Small	0.40 Small	-1.79 to 1.08 Large to moderate	-1.21 to 0.72 Large to moderate	-0.89 to 0.89 Moderate
	P value	1.000	1.000	1.000	≤0.001 to 1.000	≤0.001 to 0.01	≤0.001 to 1.000

Maturity status: Where the estimated number of years to peak height velocity categorises pre-PHV (>0.0 YPHV), circa-PHV -1.0 to 0.0 YPHV) and post-PHV (<-1.0 YPHV). Effect size: Where observed effects are categorised as Trivial (<0.2), Small (0.201 to 0.6), Moderate (0.601 to 1.2), Large (1.201 to 2.0) and Very large (2.001 to >4.0). Statistical significance is denoted as $P \leq 0.05$.
cm = centimetres, kg = kilograms, *f* = frequency and s = seconds.

Table 12. The key performance indicators, with 95% confidence intervals, effect size and statistical significance, for maturity status bio-banded small-sided games using the Khamis and Roche (1994) equation.

		Khamis and Roche (1994)					
		Post-PHV v Post-PHV	***Circa-PHV v Circa-PHV***	***Pre-PHV v Pre-PHV***	***Post-PHV v Pre-PHV***	***Post-PHV v Circa-PHV***	***Circa-PHV v Pre-PHV***
Successful passes (*f*)	Mean (95% Confidence Interval)	6.3 to 7.7 (-3.6 to 5.8)	5.1 to 6.5 (-1.9 to 8.0)	5.2 to 5.8 (-2.9 to 7.6)	5.2 to 7.7 (-9.0 to 4.3)	5.1 to 7.7 (-7.3 to 4.8)	5.2 to 6.5 (-6.0 to 7.0)
	Effect size	0.40 Trivial	0.25 Small	0.22 Small	-0.55 to 0.81 Small to moderate	-0.81 to 0.44 Moderate to small	-0.48 to 0.26 Small
	P value	1.000	1.000	1.000	0.200 to 1.000	1.000	1.000
Unsuccessful passes (*f*)	Mean (95% Confidence Interval)	2.0. to 2.2 (-3.6 to 5.8)	2.1 to 2.1 (-1.9 to 8.0)	2.4 to 2.6 (-2.6 to 3.3)	2.0 to 2.6 (-2.7 to 4.7)	2.0 to 2.2 (-3.4 to 2.6)	2.1 to 2.6 (-3.7 to 4.7)
	Effect size	0.13 Small	0.00 Trivial	0.10 Trivial	-0.26 to 0.31 Small	-0.06 to 0.06 Trivial	-0.26 to 0.26 Trivial to small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Turning (*f*)	Mean (95% Confidence Interval)	1.0 to 1.3 (-4.7 to 2.7)	1.1 to 1.5 (-4.1 to 1.1)	1.1 to 1.6 (-3.2 to 1.2)	1.0 to 1.6 (-2.7 to 4.7)	1.0 to 1.5 (-4.2 to 4.2)	1.1 to 1.6 (-3.8 to 3.7)
	Effect size	0.19 Trivial	0.26 Small	0.68 Moderate	0.26 to 0.52 Small	-0.13 to 0.32 Trivial to small	-0.36 to 0.43 Small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Goals (*f*)	Mean (95% Confidence Interval)	1.3 to 1.4 (-2.5 to 2.5)	1.2 to 1.6 (-4.1 to 1.1)	1.2 to 1.4 (-2.8 to 4.8)	1.2 to 1..4 (-3.2 to 2.6)	1.3 to 1.6 (-2.8 to 2.7)	1.2 to 1.6 (-3.7 to 3.4)

	Effect size	0.09 Trivial	0.34 Small	0.17 Trivial	-0.26 to 0.09 Small to trivial	-0.26 to 0.19 Small to trivial	-0.34 to 0.17 Small to trivial
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Shots on target (*f*)	Mean (95% Confidence Interval)	1.9 to 2.0 (-1.6 to 3.9)	1.7 to 1.8 (-1.4 to 2.8)	1.4 to 1.4 (-1.7 to 3.3)	1.4 to 2.0 (-3.9 to 2.3)	1.7 to 2.0 (-2.8 to 2.7)	1.4 to 1.8 (-3.8 to 2.4)
	Effect size	0.06 Trivial	0.06 Trivial	0.00 Trivial	-0.52 to -0.43 Small	-0.13 to -0.19 Trivial	-0.34 to -0.26 Small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Shots off target (*f*)	Mean (95% Confidence Interval)	1.3 to 1.5 (-1.9 to 1.8)	1.4 to 1.7 (-2.8 to 1.2)	1.3 to 1.3 (-2.4 to 2.1)	1.3 to 1.5 (-1.9 to 2.5)	1.3 to 1.7 (-2.6 to 2.2)	1.3 to 1.7 (-3.9 to 2.0)
	Effect size	0.26 Small	0.19 Trivial	0.00 Trivial	-0.17 to 0.17 Trivial	-0.17 to 0.34 Trivial to small	-0.26 to 0.26 Small to trivial
	P value	1.000	1.000	1.000	1.000	1.000	0.9 to 1.000
Ground challenges (*f*)	Mean (95% Confidence Interval)	1.9 to 2.2 (-3.1 to 2.2)	1.9 to 2.2 (-3.0 to 2.2)	2.2 to 2.2 (-3.1 to 1.7)	1.9 to 2.2 (-2.6 to 3.8)	1.9 to 2.2 (-2.8 to 3.0)	1.9 to 2.2 (-2.9 to 3.3)
	Effect size	0.19 Trivial	0.26 Small	0.00 Trivial	-0.19 to 0.19 Trivial	-0.19 to 0.26 Small to trivial	-0.26 to 0.26 Small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Interception (*f*)	Mean (95% Confidence Interval)	1.8 to 1.9 (-1.4 to 2.2)	1.5 to 2.0 (-3.1 to 1.1)	1.7 to 1.7 -2.3 to 1.7)	1.7 to 1.9 (-2.8 to 2.3)	1.5 to 2.0 (-2.2 to 3.1)	1.5 to 2.0 (-2.7 to 2.8)
	Effect size	0.13 Trivial	0.43 Small	0.00 Trivial	-0.17 to 0.26 Trivial to small	-0.39 to 0.52 Small	-0.26 to 0.26 Small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Dribbling (s)	Mean (95% Confidence Interval)	6.40 to 8.00 (-7.38 to 12.02)	7.84 to 8.23 (-8.70 to 11.87)	7.84 to 8.55 (-6..07 to 15.74)	6.40 to 8.55 (-10.93 to 12.21)	6.40 to 8.23 (-11.59 to 12.93)	7.84 to 8.55 (-14.75 to 11.46)
	Effect size	0.34 Small	0.06 Trivial	0.12 Trivial		-0.34 to 0.23 Small	-0.10 to 0.07 Trivial

					-0.40 to 0.29 Small		
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Defensive left side (s)	Mean (95% Confidence Interval)	26.62 to 27.79 (-6.73 to 21.70)	22.19 to 29.20 (10.36 to 38.80)	29.53 to 31.40 (6.31 to 38.10)	26.62 to 31.40 (-26.72 to 22.15)	22.19 to 29.20 (-18.59 to 27.27)	22.19 to 31.40 (-16.88 to 31.95)
	Effect size	0.12 Trivial	0.72 Moderate	0.16 Trivial	-0.43 to 0.32 Small	-0.42 to 0.54 Small	-0.65 to 0.79 Moderate
	P value	1.000	≤0.001	≤0.001	0.300 to 1.000	0.100 to 1.000	≤0.001 to 1.000
Defensive right side (s)	Mean (95% Confidence Interval)	26.10 to 29.10 (-1.99 to 27.16)	26.23 to 26.39 (-5.30 to 23.85)	27.00 to 27.32 (-4.83 to 27.75)	26.10 to 29.10 (-27.52 to 26.69)	26.10 to 26.23 (-25.68 to 17.41)	26.23 to 27.32 (-24.97 to 18.79)
	Effect size	0.29 Small	0.02 Trivial	0.04 Trivial	-0.18 to 0.18 Trivial	-0.24 to 0.24 Small	-0.12 to 0.11 Trivial
	P value	0.3	1.000	1.000	0.200 to 1.000	0.700 to 1.000	1.000
Offensive left side (s)	Mean (95% Confidence Interval)	19.47 to 22.09 (-10.21 to 12.48)	16.29 to 21.64 (-8.45 to 14.24)	12.41 to 14.30 (-7.31 to 18.06)	12.41 to 22.09 (-34.74 to 2.49)	16.29 to 22.09 (-22.18 to 12.12)	12.41 to 21.64 (-26.11 to 5.84)
	Effect size	0.32 Small	0.51 Small	0.26 Small	-1.19 to 1.01 Moderate	-0.75 to 0.43 Moderate to small	-0.70 to 0.85 Moderate
	P value	1.000	1.000	1.000	≤0.001 to 0.700	0.01 to 1.000	≤0.001 to 1.000
Offensive right side (s)	Mean (95% Confidence Interval)	20.53 to 21.41 (-15.21 to 7.45)	17.06 to 17.41 (-9.80 to 12.87)	13.32 to 15.47 (-10.95 to 14.39)	13.32 to 21.41 (-31.53 to 5.71)	17.06 to 21.41 (-22.05 to 3.37)	13.32 to 17.41 (-21.99 to 13.45)
	Effect size	0.10 Trivial	0.04 Trivial	0.24 Small	-1.10 to 0.89 Moderate	-0.56 to 0.49 Small	-0.51 to 0.53 Small
	P value	1.000	1.000	1.000	≤0.001 to 1.000	0.1 to 1.000	0.1 to 1.000

Maturity status: Where the estimated adult stature attainment categorises post-PHV (> 92.0%), circa-PVH (87.0 to 93.0%) and pre-PHV (<87.0%). Effect size: Where observed effects are categorised as Trivial (<0.2), Small (0.201 to 0.6), Moderate (0.601 to 1.2), Large (1.201 to 2.0) and Very large (2.001 to >4.0). Statistical significance is denoted as P ≤ 0.05. cm = centimetres, kg = kilograms, *f* = frequency and s = seconds.

4.2 Mis-matched bio-banded games

4.2.1 Anthropometric measurements

Statistical differences were reported within the Fransen et al. (2017) method for most of the anthropometrical measurements reported and for player age (see table 7.). Significant differences in player age were only reported for post-PHV versus pre-PHV (P ≤ 0.001 to 0.004, ES = 5.8 to 4.6, *very large*). Differences were found in years from peak height velocity for post-PHV versus pre-PHV (*P* = ≤0.001, ES = 0.5 to 12.4, *small to very large*), post-PHV versus circa-PHV (*P* = 0.001 to 0.5, ES = 0.3 to 4.6, *very large*) and circa-PHV versus pre-PHV (*P* = ≤0.001 to 0.2, ES = 4.7 to 6.4, *very large*). Difference was also reported in stature but only in the post-PHV versus pre-PHV SSG's (*P* = ≤0.001, ES = 10.3 to 7.2, *very large to very large*). Differences in seated height were reported for all of the different SSG's; post-PHV versus pre-PHV players (*P* = ≤0.001, ES = 9.6 to 8.3, *very large*), post-PHV versus circa-PHV players (*P* = ≤0.001 to 0.9, ES = 4.7 to 5.4, *very large*) and circa-PHV versus pre-PHV players (*P* = ≤0.001 to 1.000, ES = 3.7 to 4.0, *very large*). No statistical differences were reported for estimated leg length and differences in body-mass were only reported post-PHV versus pre-PHV bio-banded games (*P* = ≤0.001, ES = 6.5 to 7.0, *very large*).

Statistical differences were reported within the Khamis and Roche (1994) method for most of the anthropometrical measurements reported (see table 9.). Within the reported age there were statistical difference for the post-PHV versus pre-PHV matches (*P* = ≤0.001 to 0.4, ES = 2.9 to 7.7, *very large*) but not for post- PHV versus circa-PHV (*P* = 1.00, ES = 1.4 to 5.8, *large to very large*) or circa- PHV versus pre- PHV *P* = 1.00, ES = 2.9, *very large)*. Differences in estimated adult stature attainment was also reported for post-PHV versus pre-PHV (*P* = ≤0.001, ES = 11.9

to 12.4, *very large*), post-PHV versus circa-PHV (P = ≤0.001 to 0.3, ES = 5.6 to 7.3, *very large*) and circa- PHV versus pre-PHV (P = ≤0.001 to 0.07, ES = 3.2 to 5.1, *very large*). Statistical differences in stature were also reported between post-PHV versus pre-PHV players (P = ≤0.001, ES = 9.0 to 11.9, *very large*) and post-PHV versus circa-PHV players (P = ≤0.001 to 0.4, ES = 5.0 to 5.8, *very large*). Likewise, differences were also reported for seated height between post-PHV versus pre-PHV players (P = ≤0.001, ES = 9.8 to 10.7, *very large*) and post-PHV versus circa-PHV players (P = ≤0.001, ES = 7.1 to 7.6, *very large*). Differences in estimated leg length were only observed between post-PHV versus pre-PHV players (P = ≤0.001, ES = 5.2 to 6.1, *very large*). Large statistical differences in body-mass were shown in post-PHV versus pre-PHV players (P = ≤0.001, ES = 7.8 to 9.2, *very large*) and post-PHV versus circa-PHV players (P = ≤0.001 to 1.000, ES = 4.4 to 4.6, *very large*).

4.2.2 Game Technical Scoring Chart

Both the Fransen et al. (2017) method (see table 9.) and Khamis and Roche (1994) method (see table 10.) reported no statistical differences in the total GTSC points given out of 50 for the various mis-matched bio-banded games (P = 1.000), however there were reported difference in the GTSC points scored. The Fransen et al. (2017) method reported that there were differences between post-PHV versus pre-PHV players (P = ≤0.001, ES = 1.49 to 1.17, *large to large*), post-PHV versus circa-PHV players (P = ≤0.001 to 1.000, ES = 0.77 to 0.52, *moderate to small*), and circa-PHV versus pre-PHV players (P = ≤0.001 to 1.000, ES = 0.94 to 0.70, *moderate to moderate*) (see table 9.). The Khamis and Roche (1994) method also reported differences between all of the mis-matched bio-banded games, post-PHV versus pre-PHV players (P = ≤0.001 to 1.000, ES = 2.32 to 1.98, *very large to large*), post-PHV versus circa-PHV players (P = ≤0.001 to 1.000, ES =

1.29 to 0.77, *large to moderate*) and circa-PHV versus pre-PHV players (P = ≤0.001 to 1.000, ES = 0.90 to 1.16, *moderate to moderate*) (see table 10.).

4.2.3 Key performance indicators

The Fransen et al. (2017) method reported statistical differences in offensive left side between post-PHV versus pre-PHV players (P = ≤0.001 to 1.000, ES = 0.81 to 0.61, *moderate to moderate*), post-PHV versus circa-PHV players (P = ≤0.001 to 1.000, ES = 0.40 to 0.27, *small to small*) and circa-PHV versus pre-PHV players (P = ≤0.001. to 1.000, ES = 0.81 to 0.74, *moderate to moderate*) (see table 11.). Differences in offensive right side were also observed between post-PHV versus pre-PHV players (P = ≤0.001 to 1.000, ES = 1.79 to 1.08, *large to moderate*), post-PHV versus circa-PHV players (P = ≤0.001 to 0.01, ES = 1.21 to 0.72, *large to moderate*) and circa-PHV versus pre-PHV players (P = ≤0.001. to 1.000, ES = 0.89 to 0.89, *moderate to moderate*) (see table 11.).

The Khamis and Roche (1994) method reported differences in defensive left side for circa-PHV versus pre-PHV players (P = ≤0.001 to 1.000, ES = 0.65 to 0.79, *moderate to moderate*) (see table 12.). Differences in offensive left side were reported for post-PHV versus pre-PHV players (P = ≤0.001 to 0.7, ES = 1.19 to 1.01, *moderate to moderate*), post-PHV versus circa-PHV players (P = 0.01 to 1.000, ES = 0.75 to 0.43, *moderate to small*) and circa-PHV versus pre-PHV players (P = ≤0.001 to 1.000, ES = 0.70 to 0.85, *moderate to moderate*). Statistical differences for offensive right side were also observed for post-PHV versus pre-PHV players (P = ≤0.001 to 1.000, ES = 1.10 to 0.89, *moderate to moderate*) (see table 12.).

4.3 Mixed games

There were no statistical differences reported for the anthropometrical measurements taken in the mixed teams (*P* = 1.000) (see table 13.) . Statistical differences were reported for GTSC points scored between teams A versus B (*P* = 0.05 to 1.000, ES = 0.26 to 0.77, *small to moderate*), A versus C (*P* = 0.05 to 1.000, ES = 0.52 to 0.52, *small to small*) and B versus C (*P* = 0.05 to 1.000, ES = 0.26 to 0.77, *small to moderate*), respectively (see table 14.). Statistical differences were observed for defensive left side for B versus B (*P* = ≤0.001, ES = 0.19, *trivial*) and A versus B (*P* = ≤0.001 to 1.000, ES = 0.56 to 0.45, *moderate to small*) (see table 15.). Differences were also observed in defensive right side in teams A versus B (*P* = ≤0.001to 1.000, ES = 0.28 to 0.26, *small to small*) and A versus C (*P* = ≤0.001 to 1.000, ES = 0.26 to 0.26, *small to small*) (see table 15.). Further statistical differences in offensive right side were also reported in A v B (*P* = ≤0.001 to 1.000, ES = 0.37 to 0.43, *small to small*) (see table 15.).

Table 13. The anthropometrical measurements, with 95% confidence intervals, effect size and statistical significance, for randomly assigned teams.

		Mixed					
		A v A	**B V B**	**C v C**	**A v B**	**A v C**	**B v C**
Age (years)	Mean (95% Confidence Interval)	13.4 to 13.8 (-2.2 to 1.5)	13.6 to 13.7 (-1.7 to 2.0)	13.6 to 13.8 (-2.1 to 1.6)	13.4 to 13.7 (-2.1 to 2.1)	13.4 to 13.8 (-2.2 to 2.1)	13.6 to 13.8 (2.1 to 2.0)
	Effect size	0.3 Small	0.0 Trivial	0.0 Trivial	-0.0 to 0.0 Trivial	-0.3 to 0.1 Small to trivial	-0.0 to 0.0 Trivial
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Years from peak height velocity (years)	Mean (95% Confidence Interval)	-0.6 to -0.2 (-2.2 to 1.5)	-0.3 to -0.4 (-1.9 to 1.9)	-0.2 to -0.5 (-2.2 to 1.5)	-0.6 to -0.2 (-2.1 to 2.0)	-06 to -0.2 (-2.3 to 2.1)	-0.5 to -0.2 (-2.1 to 2.0)
	Effect size	0.5 Small	0.0 Trivial	0.4 Small	-0.2 to 0.3 Small	-0.4 to 0.5 Small	-0.2 to 0.2 Small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Estimated adult stature attainment (years)	Mean (95% Confidence Interval)	88.1 to 90.6 (-9.7 to 4.7)	89.2 to 89.7 (-7.7 to 6.6)	89.3 to 90.4 (-8.2 to 6.1)	88.1 to 90.6 (-8.9 to 8.6)	88.1 to 90.6 (-9.5 to 8.5)	89.2 to 90.4 (-8.3 to 7.6)
	Effect size	1.3 Large	0.3 Small	0.6 Small	-0.9 to 0.7 Moderate	-0.6 to 1.2 Moderate to large	-0.6 to 0.4 Moderate to small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Stature (cm)	Mean (95% Confidence Interval)	161.4 to 163.7 (-18.5 to 13.3)	163.6 to 164.5 (-17.1 to 15.3)	160.8 to 163.2 (-18.7 to 13.8)	161.4 to 164.5 (-19.3 to 16.4)	160.8 to 164.5 (-18.0 to 19.2)	160.8 to 164.5 (-15.9 to 19.9)
	Effect size	0.5 Small	0.2 Small	0.5 Small	-0.5 to 0.6 Small	-0.7 to 0.3 Moderate to small	-0.8 to 0.7 Moderate
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Seated height (cm)	Mean (95% Confidence Interval)	83.5 to 84.7 (-10.7 to 8.2)	84.1 to 84.2 (-9.6 to 9.4)	83.0 to 84.4 (-10.9 to 8.1)	83.0 to 84.7 (-10.2 to 10.1)	83.5 to 84.7 (-10.4 to 11.2)	83.0 to 84.4 (-9.8 to 10.7)
	Effect size	0.4 Small	0.0 Trivial	0.9 Moderate	-0.3 to 0.2	-0.9 to 0.4 Moderate to small	-0.6 to 0.4 Small

					Small to trivial		
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Estimate leg length (cm)	Mean (95% Confidence Interval)	77.0 to 77.9 (-10.5 to 8.3)	79.5 to 80.3 (10.2 to 8.6)	77.8 to 78.8 (-10.4 to 8.4)	77.0 to 78.8 (-11.8 to 9.0)	77.0 to 80.3 (-10.3 to 10.6)	77.8 to 80.3 (-8.8 to 11.9)
	Effect size	0.4 Small	0.7 Moderate	0.4 Small	-0.7 to 0.6 Moderate to small	-0.3 to 0.6 Small	-1.0 to 0.4 Moderate to small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Body-mass (kg)	Mean (95% Confidence Interval)	48.0 to 49.6 (-16.6 to 13.3)	50.8 to 52.1 (-16.3 to 13.6)	47.0 to 49.7 (-17.6 to 12.3)	48.0 to 49.7 (19.0 to 13.8)	47.0 to 49.7 (-16.6 to 17.6)	47.0 to 52.1 (-13.8 to 20.0)
	Effect size	0.4 Small	0.3 Small	0.7 Moderate	-0.9 to 0.7 Moderate	-00.7 to 0.4 Moderate to small	-1.2 to 1.4 Moderate to large
	P value	1.000	1.000	1.000	1.000	1.000	1.000

Effect size: Where observed effects are categorised as Trivial (<0.2), Small (0.201 to 0.6), Moderate (0.601 to 1.2), Large (1.201 to 2.0) and Very large (2.001 to >4.0).
Statistical significance is denoted as $P \leq 0.05$.
cm = centimetres, kg = kilograms, *f* = frequency and s = seconds.

Table 14. The game technical scoring chart measurements, with 95% confidence intervals, effect size and statistical significance, for randomly assigned teams.

		Mixed					
		A v A	**B V B**	**C v C**	**A v B**	**A v C**	**B v C**
Total GTSC	Mean (95% Confidence Interval)	24.8 to 25.1 (12.8 to 14.0)	23.7 to 23.8 (-14.3 to 12.5)	23.7 to 24.0 (-14.1 to 12.6)	23.7 to 25.1 (-14.0 to 15.8)	23.7 to 25.1 (-14.0 to 16.5)	23.7 to 24.0 (-16.5 to 15.1)
	Effect size	0.04 Trivial	0.01 Trivial	0.04 Trivial	-0.16 to 0.15 Trivial	-0.10 to 0.17 Trivial	-0.03 to 0.02 Trivial
	P value	1.000	1.000	1.000	1.000	1.000	1.000
GTSC points scored	Mean (95% Confidence Interval)	1.7 to 2.5 (-4.0 to 1.3)	1.3 to 2.1 (-2.7 to 2.7)	1.7 to 2.5 (-4.0 to 1.3)	1.3 to 2.5 (-2.7 to 5.1)	1.7 to 2.5 (-5.3 to 4.0)	1.3 to 2.5 (-4.0 to 5.3)
	Effect size	0.52 Small	0.52 Small	0.52 Small	-0.26 to 0.77 Small to moderate	-0.52 to 0.52 Small	-0.26 to 0.77 Small to moderate
	P value	1.000	1.000	1.000	0.05 to 1.000	0.05 to 1.000	0.05 to 1.000

Effect size: Where observed effects are categorised as Trivial (<0.2), Small (0.201 to 0.6), Moderate (0.601 to 1.2), Large (1.201 to 2.0) and Very large (2.001 to >4.0).
Statistical significance is denoted as $P \leq 0.05$.
cm = centimetres, kg = kilograms, f = frequency and s = seconds.

Table 15. The key performance indicators, with 95% confidence intervals, effect size and statistical significance, for randomly assigned teams.

		Mixed					
		A v A	**B V B**	**C v C**	**A v B**	**A v C**	**B v C**
Successful passes (*f*)	Mean (95% Confidence Interval)	5.8 to 6.8 (-4.5 to 5.2)	5.6 to 6.8 (-1.6 to 8.3)	5.3 to 6.1 (-5.0 to 4.5)	5.6 to 6.8 (-6.1 to 8.0)	5.3 to 6.8 (-7.8 to 6.2)	5.3 to 6.8 (-6.4 to 6.8)
	Effect size	0.29 Small	0.39 Small	0.30 Small	-0.32 to 0.34 Small	-0.20 to 0.48 Trivial to small	-0.23 to 0.55 Trivial to small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Unsuccessful passes (*f*)	Mean (95% Confidence Interval)	2.1 to 2.3 (-2.7 to 1.7)	2.1 to 2.2 (-2.0 to 2.4)	1.9 to 2.1 (-3.1 to 1.7)	2.1 to 2.3 (-2.6 to 3.2)	1.9 to 2.3 (-3.2 to 3.3)	1.9 to 2.2 (3.0 to 3.2)
	Effect size	0.13 Trivial	0.06 Trivial	0.13 Trivial	-0.13 to 0.13 Trivial	-0.13 to 0.26 Trivial	-0.19 to 0.19 Trivial
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Turning (*f*)	Mean (95% Confidence Interval)	1.1 to 1.4 (-1.8 to 1.8)	1.0. to 1.2 (N/A)	1.1 to 1.2 (-1.9. to 1.9)	1.0 to 1.4 (-2.2 to 2.2)	1.1 to 1.4 (-2.9 to 2.9)	1.0 to 1.2 (-2.9 to 0.9)
	Effect size	0.27 Small	0.26 Small	0.09 Trivial	-0.52 to 0.29 Small	-0.13 to 0.29 Trivial to small	-0.26 to 0.26 Small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Goals (*f*)	Mean (95% Confidence Interval)	1.1 to 1.5 (-1.6 to 3.1)	1.2 to 1.3 (-1.3 to 2.3)	1.6 to 1.6 (-2.2 to 1.6)	1.1 to 1.5 (-2.2 to 2.4)	1.1 to 1.6 (-3.2 to 2.2)	1.2 to 1.6 (3.6 to 2.6)
	Effect size	0.54 Small	0.09 Trivial	0.00 Trivial	-0.41 to 0.18 Small to trivial	-0.45 to 0.45 Small	-0.36 to 0.36 Small
	P value	1.000	1.000	1.000	1.000	1.000	1.000

Shots on target (*f*)	Mean (95% Confidence Interval)	1.4 to 1.8 (-1.6 to 2.9)	1.6 to 1.7 (-2.0 to 1.7)	1.7 to 2.0 (-2.0 to 2.3)	1.4 to 1.8 (-2.5 to 2.5)	1.4 to 2.0 (-3.2 to 3.1)	1.6 to 2.0 (-3.0 to 2.3)
	Effect size	0.34 Small	0.09 Trivial	0.19 Trivial	-0.26 to 0.26 Small	-0.26 to 0.52 Small	-0.19 to 0.34 Trivial to small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Shots off target (*f*)	Mean (95% Confidence Interval)	1.3 to 1.5 (-1.8 to 1.6)	1.1 to 1.3 (-2.8 to 1.8)	1.3 to 1.4 (-1.7 to 2.0)	1.1 to 1.5 (-1.7 to 2.8)	1.3 to 1.5 (-2.2 to 2.6)	1.1 to 1.4 (-2.0 to 2.3)
	Effect size	0.18 Trivial	0.29 Small	0.13 Trivial	-0.30 to 0.37 Small	-0.14 to 0.17 Trivial	-0.29 to 0.43 Small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Ground challenges (*f*)	Mean (95% Confidence Interval)	2.0 to 2.1 (-1.9 to 2.4)	1.4 to 1.9 (-3.3 to 2.1)	1.9 to 2.1 (-2.2 to 2.3)	1.4 to 2.1 (-2.8 to 3.5)	1.9 to 2.1 (-2.9 to 3.1)	1.4 to 2.1 (-3.9 to 2.7)
	Effect size	0.06 Trivial	0.43 Small	0.13 Trivial	-0.60 to 0.52 Moderate to small	-0.06 to 0.13 Trivial	-0.60 to 0.43 Moderate to small
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Interceptions (*f*)	Mean (95% Confidence Interval)	1.5 to 2.0 (-1.5 to 2.8)	1.6 to 1.8 (-1.3 to 3.6)	1.6 to 1.7 (-2.3 to 1.3)	1.5 to 2.0 (-2.1 to 3.0)	1.5 to 2.0 (-2.3 to 3.1)	1.6 to 1.8 (-2.3 to 2.6)
	Effect size	0.43 Small	0.17 Trivial	0.13 Trivial	-0.26 to 0.34 Small	-0.26 to 0.34 Small	-0.17 to 0.13 Trivial
	P value	1.000	1.000	1.000	1.000	1.000	1.000
Dribbling (s)	Mean (95% Confidence Interval)	8.12 to 8.34 (-12.78 to 7.46)	7.24 to 8.20 (-6.81 to 16.25)	6.31 to 7.73 (-12.25 to 9.84)	7.42 to 8.34 (-10.05 to 14.82)	6.31 to 8.34 (-10.92 to 15.09)	6.31 to 8.20 (-13.63 to 12.73)
	Effect size	0.03 Trivial	0.12 Trivial	0.23 Trivial	-0.15 to 0.16 Trivial	-0.36 to 0.33 Small	-0.33 to 0.17 Small to trivial
	P value	1.000	1.000	1.000	1.000	1.000	1.000

Defensive left side (s)	Mean (95% Confidence Interval)	24.16 to 34.14 (-28.46 to 4.38)	27.23 to 29.75 (10.99 to 43.83)	22.86 to 26.93 (-15.04 to 17.80)	24.16 to 34.14 (-33.90 to 41.85)	22.86 to 34.14 (-29.47 to 20.48)	22.86 to 29.75 (-17.11 to 28.26)
	Effect size	0.81 Moderate	0.19 Trivial	0.48 Small	-0.56 to 0.45 Small	-0.45 to 0.94 Moderate to small	-0.71 to 0.42 Moderate to small
	P value	0.900	≤0.001	1.000	≤0.001 to 1.000	0.600 to 1.000	0.900 to 1.000
Defensive right side (s)	Mean (95% Confidence Interval)	32.20 to 33.12 (-16.39 to 18.45)	23.71 to 31.21 (-3.15 to 31.69)	24.28 to 29.45 (-20.05 to 14.79)	23.71 to 33.12 (-16.38 to 43.73)	24.28 to 33.12 (-35.83 to 40.32)	23.71 to 31.21 (-23.40 to 32.28)
	Effect size	0.03 Trivial	0.23 Trivial	0.15 Trivial	-0.28 to 0.26 Small	-0.26 to 0.26 Small	-0.18 to 0.23 Small to trivial
	P value	1.000	0.500	1.000	≤0.001 to 1.000	≤0.001 to 1.000	0.3 to 1.000
Offensive left side (s)	Mean (95% Confidence Interval)	16.56 to 20.09 (-9.15 to 14.23)	12.06 to 18.05 (-0.45 to 21.97)	18.67 to 19.70 (-8.84 to 13.59)	12.06 to 20.09 (-13.47 to 19.48)	16.56 to 20.09 (-16.99 to 21.24)	12.06 to 19.70 (-20.99 to 3.72)
	Effect size	0.46 Small	0.77 Moderate	0.14 Trivial	-0.99 to 0.55 Moderate	-0.39 to 0.41 Small	-0.85 to 0.94 Moderate
	P value	1.000	0.900	1.000	0.800 to 1.000	0.200 to 1.000	0.600 to 1.000
Offensive right side (s)	Mean (95% Confidence Interval)	18.34 to 20.50 (-13.34 to 12.75)	16.80 to 17.19 (-15.18 to 10.91)	14.68 to 22.22 (-18.99 to 7.10)	16.80 to 20.50 (-29.44 to 28.87)	14.68 to 22.22 (-23.79 to 23.23)	14.68 to 22.22 (-22.47 to 17.74)
	Effect size	0.24 Trivial	0.04 Trivial	0.81 Moderate	0.37 to 0.43 Small	-0.79 to 0.47 Moderate to small	-0.46 to 0.52 Small
	P value	1.000	1.000	1.000	≤0.001 to 1.000	0.4 to 0.7	0.9 to 1.000

Effect size: Where observed effects are categorised as Trivial (<0.2), Small (0.201 to 0.6), Moderate (0.601 to 1.2), Large (1.201 to 2.0) and Very large (2.001 to >4.0).
Statistical significance is denoted as $P \leq 0.05$.
cm = centimetres, kg = kilograms, *f* = frequency and s = seconds.

Chapter 5. Discussion

5.1 Discussion

The aims of this thesis were to investigate the effects that maturity status bio-banding had upon the technical performance of elite youth players, with further implications potentially impacting upon talent identification and the maturation-selection hypothesis. The main findings identified were: 1) the maturity matched bio-banded SSG's showed very few differences in the variables investigated (only 4 statistical differences reported in the 21 variables investigated across both methods), which was consistent for both the Fransen (2017) and Khamis and Roche (1994) methods; 2) more differences in KPI's were observed in mis-matched bio-banded games for both the Fransen (2017) and Khamis and Roche (1994) methods, in relation to anthropometric measurements, GTSC points scored, pitch possession and particularly when the maturation between players was large (i.e. pre-PHV versus post-PHV); 3) there were consistent differences in GTSC points scored and pitch possession regardless of whether the games were matched, mis-matched or mixed (randomly assigned).

5.2 Maturity matched bio-banded games

Findings showed that when players competed in maturity matched bio-banded games there were very few statistical differences observed in anthropometrical measurements and KPI's, which was consistent for both the Fransen et al. (2017) method and the Khamis and Roche (1994) method. The lack of statistical differences (P = 1.000) within the bio-banded matched games anthropometrical measurements (see tables 7. and 8.), show that the players were evenly matched against each other. Several researchers have identified that more mature athletes have greater physical and anthropometric advantages which affords them greater physical abilities, such as greater lower limb strength and aerobic capacity (Parr et al. 2020, Goto et al. 2019; Rommers et al. 2018; Cumming et al. 2018). Consequently, the fewer physical and anthropometrical advantages that less mature players possess, have resulted in less mature players developing greater technical and tactical ability to be able to succeed when competing against more mature players who have greater physical dominance (Parr et al. 2020, Goto et al. 2019; Rommers et al. 2018; Cumming et al. 2018). However, when the opposition likewise possess the same characteristics, any qualities associated with a certain bio-band become less advantageous for players. This may explain the lack of statistical differences that occurred in KPI performance between the matched bio-bands (tables 11. and 12.).

Tables 11. and 12. show that there were no statistical differences (P = 1.000) observed between players when performing technical skills when players compete in bio-banded matched games, which is true for both the Fransen et al. (2017) approach and the Khamis and Roche (1994) approach. The lack of statistical difference may be due to an overall lack of performance of the KPI's, which is similar to the findings reported by Abbott et al. (2019) who stated that during bio-banded competition early maturing players performed less dribbles and both on time and late maturing players performed fewer long passes. Romann, Lüdin and Born (2020) also reported lower instances of ball possession and fewer successful passes in their study during bio-banded competition. Romann, Lüdin and Born (2020) theorised that this lower performance rate was due to the limitations of playing in SSG's and performing on a smaller pitch (reduced pitch length and width), as this resulted in a change in the style of play that was needed to suit the parameters of the games. In comparison to full sized pitch dimensions of 105 x 68 metres, the pitch dimensions used by Romann, Lüdin and Born (2020) (55 x 58 metres) and the pitch dimensions utilised in this thesis of (18 x 23 metres) are both markedly smaller resulting in adaptations in player performance. For example, dribbling time, and consequent possession time, were lower because there was less pitch for players to dribble on, additionally the small pitch size allowed for the speed of the game to be increased as there was less distance to cover when performing actions, therefore allowing less time to perform actions resulting in fewer being performed. This differs to previous findings of other researchers that has reported increased performance of KPI's in SSG's. Several researchers (Hodgson, Akenhead and Thomas 2014; Almeida, Ferreira and Volossovitch 2013; Aguiar et al. 2012; Da Silva et al. 2011; Katis and Kellis 2009) reported that dribbling, shots on goal, crosses, passes and tackles were all performed significantly more in SSG's, however this research was not conducted with maturity status bio-banding in mind and therefore the results may not be entirely applicable. Additionally, there were several variations of SSG and number of players used within each of the studies that may also have led to the differing results. For instance, Katis and Kellis (2009) used teams containing three players and Almeida, Ferreira and Volossovitch (2013) used a larger pitch (46 x 31 metres), therefore each player had a larger amount of space in which to perform. This thesis utilised a pitch size of 18 x 23 metres which is almost half the size of the pitch used in Almeida, Ferreira and Volossovitch (2013) study, therefore differences in reported findings are to be expected. Pitch size in relation to the number of players has shown to impact upon player performance as the greater the space available the greater the opportunity players have to perform (Aguiar et al. 2012). The team size and pitch size utilised in this study are different from those used in previous research which impacts upon the comparisons that can be made. The justification behind using a four player team in this thesis stems, in part, from limitations in available participants when recruiting players, whereby it was easier to facilitate teams of four than other team sizes. The team size selected in this thesis was also influenced by previous research. There no set standard of proceedings used in SSG's and a range of formats can be used, with teams sizes ranging from two versus two to six versus six (Clemente and Sarmento 2020; Hodgson, Akenhead and

Thomas 2014; Almeida, Ferreira and Volossovitch 2013; Aguiar et al. 2012; Katis and Kellis 2009). Therefore, a four versus four format was selected as a midpoint between the extremes of team sizes used within previous literature. Additionally, the team size selected was particularly influenced by the research completed by Fenner, Iga and Unnithan (2016). The study was able to validate the use of SSG's as a means of identifying talented players and as it was able to successfully differentiate between different player ability, therefore the methods used within the study influenced the proceedings of this thesis. For similar reasons the research by Fenner, Iga and Unnithan (2016) also effected the pitch sizes used within this thesis. Previous research (Sannicandro and Cofano 2017; Hill-Haas et al. 2011; Rampinini et al. 2007; Williams and Owen 2007; Owen, Twist and Ford 2004) has used a variety of different pitch sizes with different results and conclusions reported, however as Fenner, Iga and Unnithan (2016) was successful in giving insight into player performance and ability, the pitch sizes used were also mirrored in this thesis. Despite the success that Fenner, Iga and Unnithan (2016) report, the pitch dimensions utilised in this thesis have shown to be too small to allow to any effects of maturity status bio-banding to be displayed.

When further examining the anthropometrical measurements there were several instances where the effect size reported indicated an effect whilst the statistical testing did not for example, in table 7. pre-PHV versus pre-PHV age reported a 1.4 *large* effect size whilst $P = 1.000$. In table 10. there were also several effect sizes that reported significant effect sizes but not in statistical testing for example, in age, estimated adult stature, seated height, estimated leg length and body-mass. Closer examination of the participants revealed that there are several players that are younger (≥12.0 years old) and older (age = ≤16 years old) than their peers in the same bio-banded group. This may explain the unusual effect sizes as there are several measurements that are influencing the consistency of the outcomes, consequently this is a limitation within this thesis. As previous research has shown (see figure 1.), prior to 12 years old (but after initial growth phase from 0- to 2-years-old) height and weight gain velocity gradually increases, whereas post 12 years old the height and weight gain velocity increases rapidly (Tanner et al. 1966). The unusual effect sizes reported may be influenced by the oldest and youngest players in this sample as they are at opposite ends of the growth curve and therefore the anthropometrical measurements are varied. However, the lack of statistical differences (P = 1.000) in all of the anthropometrical measurements implies that these factors are not enough to truly have an impact. The lack of differences suggests that when players compete against competitors of a similar biological age then any advantages and/or disadvantages associated with being early (post), on time (circa) or late (pre) maturing are negated as the opposition likewise possess similar attributes. However, as there is a lack of statistical differences also reported in the mis-matched bio-banded games then this indicates that maturity status bio-banding has no impact upon player performance regardless of whether the teams are matched or mis-matched.

Another explanation as to the lack of statistical differences between the overall KPI performance may be due to players being more evenly matched. As tables 7. and 8. show, there were no anthropometrical differences between the matched teams, therefore indicating that players were evenly matched against each other in terms of physiological ability. Therefore, performance of KPI's (successful passes, unsuccessful passes, turning, goals, shots on target, shots off target, ground challenges, interceptions and dribbling) may also be matched as any attributes associated with each of the bands are reduced as the opposition likewise possess the same traits. For example, previous research has shown that more mature players have greater lower limb strength due to greater anthropometrical measurements (Cumming et al. 2017b). Therefore, players are able to complete more passes, in particular long passes, due to greater strength and endurance (Malina et al. 2007). Consequently, when the opposition have the same lower leg strength and likewise are able to complete similar passes, this results in similar performance between the two teams and a lack of statistical differences. This thesis did not collect data relating to the physical fitness capabilities of the players therefore these statements cannot be made conclusively. However, this is supported by the findings of Cumming et al. (2017a) whereby players were forced to change their playing style because the opposition possessed the same traits as themselves. For instance, older players could not rely on physical ability because the opposition possessed similar physical ability, therefore, to try and beat the opposition players had to use other skills such as tactics. The findings of this thesis suggest that games that match players according to similar biological age are able to overcome the traits and advantages that are associated with each band, consequently training and competition that is organised in this manner may result in players becoming more well-rounded (Cumming et al. 2017b). Therefore, should players reach a professional level then they are less likely to be deselected, as exemplified by Figueiredo et al. (2009a), as they possess a wider skill set. Additionally, in terms of talent identification, maturity status bio-banding is potentially able reduce the effects of the maturation-selection hypothesis when athletes are matched according to similar biological age (Malina et al. 2019).

5.3 Maturity mis-matched bio-banded games

Considering the lack of statistical differences in the maturity matched bio-banded games the opposite should be observed in mis-matched bio-banded games where the traits (e.g., greater physical ability or tactical ability) that each bio-band possesses are more prominent, however this was not the case. Within the anthropometric measurements recorded there were statistical differences ($P = \leq 0.001$) but this is to be expected considering that differences in biological age coincide with anthropometrical development (Figueiredo et al. 2019; Mujika et al. 2009; Malina et al. 2007; Malina et al. 2004). The results showed that more mature players have the greatest anthropometrical measurements in comparison to less mature players, e.g., pre-PHV versus post-PHV stature = 154.4 to 172.2 (see tables 7. and 8.). This shows that regardless of the adjusted bands used (post-PHV = >92.0%, circa-PHV = 87.0 to 92.0% EASA, pre-PHV = <87.0% EASA and post-PHV = <-1.0, circa-PHV = -1.0 to 0.0 and pre-PHV = >0.0)) there were still statistical differences in anthropometrical measurements, therefore investigating player performance between the different bands may be useful in providing insight into talented players whilst taking different biological ages into account. However, within the remaining investigated variables there were no statistical differences ($P = 1.000$) reported, apart from GTSC points scored and pitch possession, which was true for both the Fransen et al. (2017) and Khamis and Roche (1994) methods. This differs to previous research such as Romann, Lüdin and Born (2020) who reported that during bio-banded competition early and on-time developers performed more short passes in comparison to late developers. They theorise that this is due to the reduced physical maturation of the opposition and therefore the more physically challenging long passes are no longer required. The authors also speculate that during bio-banded competition teammates are less familiar with each other and therefore opt to perform the less challenging, shorter pass to maintain possession as there is a lack of trust and relationship needed to successfully complete the more challenging longer passes. Therefore, in order to move the ball towards the goal shorter passes are needed. The lack of statistical differences reported in passes in this thesis may in part be because the variables fail to make the distinction between the types of passes, i.e., long and short. Therefore, should this research mimic that of Romann, Lüdin and Born (2020) whereby there is no statistical significance reported in long passes but there is statistical significance reported in short passes, then by combining the two passes together into one variable, the overall reported statistical significance influenced by the lack of relationship in long passes performed.

The differences in the findings of this thesis and those of Abbott et al. (2019) may also be explained by differences in game procedures. Romann, Lüdin and Born utilised full-sized games on a 100 x 64 metre pitch, with each team containing 11 players and each game lasting 1 hour and 20 minutes (comprising of four 20-minute quarters). Therefore, the differences game duration, pitch size and number of teammates may explain the differences in findings as previous research has shown that all of these factors can have an impact upon athlete performance. However, the lack of reported statistical differences reported by Abbott et al. (2019) in shots performed are similar to those reported in this thesis. Abbott et al. (2019) theorise that the lack of shots performed was due to the influence of player position, as different playing positions have different skills that are required, for example goal keepers have a unique role within soccer and have unique skills to match (Saward et al. 2018; Towlson et al. 2017; Hughes et al. 2012; Hughes and Frank 2008). Therefore, a lack of statistical findings is due to the range of playing positions that are present within the sample as oppose to the lack of impact that maturity status bio-banding can have. Similar limitations exist within this thesis as midfielders were the predominant playing position of the players within the sample. The results of this study may be influenced by the traits commonly observed in midfield (e.g., receiving the ball and dribbling) players and therefore may not be applicable to all players (Towlson et al. 2018; Hughes et al. 2012; Hughes and Franks 2008; Di Salvo et al. 2007).

On the other hand, the findings of this thesis do compare with those of Malina et al. (2005) who reported that biological age has little impact upon the performance of soccer specific skills. There are several studies that reported similar findings; that biological age has little to no impact upon soccer skill, but it does impact upon fitness and functional movement skills (Gouvea et al. 2016; Borges et al. 2018; Matta et al. 2014; Vandendriessche et al. 2012; Figueiredo et al. 2010; Figueiredo et al. 2009a; Gall et al. 2008; Malina et al. 2004). Malina et al. (2005) further stated that any observed differences that do occur in performance, are due to physiological differences that players of different biological age possess i.e., more mature players have greater aerobic capacity and therefore are able to perform more repeated sprints or dribbling. The lack of statistical differences in the results may be explained by the short duration and limited pitch size utilised in each of these games, consequently any fitness characteristics that may have impacted upon athlete performance are less likely to be observed due to less opportunity for these characteristics to occur. For example, long passes require good lower limb strength, greater lower limb strength is often attributed to more mature players because of their greater anthropometrical measurements (Kelly and Williams 2020; Parr et al. 2020; Malina et al. 2019). However, this thesis failed to collect data that would give insight into physiological ability and the differences that exist between players of different maturity stages, e.g., VO^2 max tests, vertical jump tests and repeated sprint tests, that would be able to explain differences in player ability and performance. A further explanation may be due to the less frequent opportunity to display lower limb strength through long passes when a smaller pitch is utilised as the distance between players and goals is reduced thus long passes are not needed. Therefore, one of the fitness characteristics that differentiates between maturational status cannot be observed/performed, leading to a lack of statistical differentiation between player performance. However, this is only a supposition as this thesis failed to measure factors relating to fitness. On the other hand, this differs to the findings of Fenner, Iga and Unnithan (2016), Aguiar et al. (2012) and Rampinini et al. (2007) who stated that SSG's are able to mimic the intensity and demand of 'normal', full sized games, however none of the three studies were conducted using maturity status bio-banding, therefore the findings may not be applicable as the games were focussed on chronological age.

Further differences between this thesis and that of Malina et al. (2005) are the methods of identifying biological age, as Malina et al. (2005) used sexual characteristics to identify biological age whereas the current thesis used somatic equations, therefore this may lead to further differences in results. However, Borges et al. (2017) identified biological maturity according to somatic equations and reported similar findings to those of Malina et al. (2005), whereby level of maturity had little impact upon the technical ability of players. The findings of Malina et al. (2005) and Borges et al. (2017) may be criticised however, as their studies utilised testing methods that were removed from an in-game scenario i.e., technical skill tests that were performed in isolation.

Abbott et al. (2019) used a much more applied approach and used KPI's to analyse in game actions of bio-banded players, reporting that there were differences in performance between different bio-bands. For example, late developing players covered greater total distance (9027.8 ± 287.9m) and with higher explosive distance (530.8 ± 52.2m) than on time (total distance = 8620.0 ± 248.9m, explosive distance = 471.4 ± 28.1m) and early maturing players (total distance = 8098.7

± 351.1m, explosive distance = 438.6 ± 35.1m). Additionally, the research identified that early maturing and on time players completed more short passes ($P < 0.05$) than late maturing players. However, the study failed to state the specific differences when these different bio-bands performed against each other, therefore the findings are less useful to compare to the mis-matched competition used in this thesis. Additionally, whilst Abbott et al. (2019) did use the Khamis and Roche (1994) method of estimating maturation, the current thesis did not use the same thresholds to organise the different bio-bands, which consequently may have affected the results and comparisons that can be made. Previous literature using the Khamis and Roche (1994) method has typically set bands at >90.1 % EASA for early maturation, 85.0 to 90.0% EASA for circa maturation and <84.0% EASA for late maturation, whilst the current thesis utilised bands set at 92.0% EASA for early maturation, 87.0 to 92.0% EASA for circa maturation and <87.0% EASA for late maturation (Malina et al. 2019; Cumming et al. 2017). Previous literature using the Fransen et al. (2017) method has typically set bands at -2.5 YPHV for least mature (late maturation), then -1.5 YPHV, -0.5 YPHV, 0.5 YPHV, 1.5 YPHV and finally 2.5 YPHV as the most mature (early maturation), whilst the current thesis utilised bands set as <-1.0 for post-PHV, -1.0 to 0.0 for circa-PHV and >0.0 for pre-PHV (Till and Jones 2015). The differences in the thresholds may have resulted in players being organised into different bands, which may have resulted in teams more/less mature than those comparable to previous research. Consequently, this may have impacted upon the results as research has shown that athletes of different maturity possess different traits that impact upon performance (Kelly and Williams 2020; Parr et al. 2020; Malina et al. 2019). However, the reported statistical differences and effect sizes between the different bio-bands shows that there are still significant differences in anthropometrical measurements (see tables 7. and 8.), thus the impact of using different maturity thresholds may be limited, but caution should still be used when making direct comparisons to other research. The lack of reported differences in this thesis may mirror the findings of other researchers, in that there are no differences between performance of players in different bio-bands, consequently when players of different bio-bands compete against each other their performance also mimics this. However, the overall limitations and weaknesses that exist within this thesis make the reliability and applicability of the reported results weak, therefore limiting the conclusions that can be made.

A further explanation for the absence of statistical differences in the KPI's investigated between mis-matched bio-banded games may also be due to a small number of instances performed overall by each of the bio-banded teams. This was certainly the case for fouls conceded and aerial challenges, which were performed so infrequently they could not be included within the results of this study. Fouls conceded were included within this thesis as a variable due to previous research stating that penalties are a relevant factor that can differentiate between winning and losing teams (Castallano, Casamichana and Lago 2012; Lago-Penas, Lago-Ballesteros and Rey 2011). However, the procedures that were utilised during the SSG's meant that games rarely stopped and penalties were often not awarded following foul play so that the SSG's could 'flow' as much as possible. Similar SSG procedures may have also impacted upon the performance or lack of performance of aerial challenges. Aerial challenges were included in this thesis due to the skill being perceived as significant by soccer coaches and practitioners, requiring ability and lower limb strength to be able to perform successfully (Towlson et al. 2019; Cumming et al. 2017). As previous research has shown that players of different maturation have different levels of strength and stature this should be reflected in the performance of aerial challenges (Kelly and Williams 2020; Parr et al. 2020; Malina et al. 2019). However, as previously mentioned the small pitch size and short duration of the SSG's limited the display of certain characteristics such as strength and power, as players were in much closer proximity to each other, therefore more complicated skills requiring greater ability were not needed. This explanation is supported by investigations previously conducted by Abbott et al. (2019) and Romann, Lüdin and Born (2020) who both conducted research comparing the performance of soccer athletes in teams organised by chronological age and biological age, in which both articles reported that there was a difference in technical performance between the two approaches to organising teams/games. For instance, both studies reported that late maturing players completed more tackles than on time and early maturing players in bio-banded competition. The authors theorised that this was because the opposition, in some instances, were less mature than in chronological age competition and therefore posed less of a physical challenge to performance. This differs to the findings of this thesis as less instances of variables, like ground challenges (tackles) and passes, were performed. As previously discussed, this may be a result of the small pitch dimensions that limit player ability to fully showcase their skills.

Further findings between this thesis and Abbott et al. (2019) and Romann, Lüdin and Born (2020) also do not entirely agree. Whilst both studies report lower performance rates of dribbling, passes and possession during bio-banded games they also report higher instances of duels, tackles, set plays, unsuccessful passes and short passes being performed. The lower occurrence of the KPI's (total GTSC, successful passes, unsuccessful passes, turning, goals, shots on target, shots off target, ground challenges, interceptions and dribbling) reported in this research can only be partially explained and linked with previous research due to the limitations of this thesis. Furthermore, as a result of the low occurrence rates of the investigated KPI's in this thesis, the statistical tests performed are unable to show if there is a true difference in performance between the different bio-bands or not. The lack of statistical differences may mirror a lack of data as opposed to a lack of impact of bio-banded competition. In conclusion, the technical insight from this research cannot fully explain the differences or lack of differences in performance between the mis-matched bio-bands due to small number of KPI instances occurring and a larger sample of games/players would be needed in order to make more accurate observations.

5.4 Pitch possession

5.4.1 Maturity matched bio-banded games

The findings of the pitch possession overall, are much more irregular than those reported for the KPI's. Statistical differences were found on all areas of the pitch (i.e., defensive left side, defensive right side, offensive left side and offensive right side) during the matched and mis-matched bio-banded games, for both the Fransen et al. (2017) and Khamis and Roche (1994) methods, and the mixed games. Within the Fransen et al. (2017) maturity matched bio-banded games, there was only one pitch possession difference reported (P = 0.001, ES = 0.59, *small*) which was in the defensive right side between pre-PHV versus pre-PHV players. Statistical differences with the Khamis and Roche (1994) bio-banded matched games were also reported for the defensive half of the pitch however these findings were reported in the defensive left side for pre-PHV versus pre-PHV (P = ≤0.001, ES = 0.16, *trivial*) and circa-PHV versus circa-PHV (P = ≤0.001, ES = 0.72, *moderate*). As both the Fransen et al. (2017) and Khamis and Roche (1994) methods report similar statistical differences (P = ≤0.001) within the defensive pitch possession of the bio-banded matched games, this perhaps indicates that less mature players (i.e., pre-PHV) play more defensively when paired against opposition of the same biological age. This may be a tactical decision or the result of one team playing more offensively than the other, resulting in higher defensive possession in response, but there is a lack of offensive statistical differences reported within the findings to support this.

Another explanation for less mature players performing more defensively may be due the fact that less mature players have slower decision-making skills in comparison to more mature players (Gonçalves et al. 2016). This may result in players responding more defensively as they are too slow to identify the relevant cues when more mature players are attacking, however this research is limited in its ability to fully explore this. A further explanation for these results may be the impact of match-to-match variation. Factors such as goal difference, opposition strength and match context (position in competition) all change from one game to the next and impact upon the player performance (Liu et al. 2015; Gregson et al. 2010). It is impossible to completely replicate each game perfectly and to be able to account for the variability that these factors produce, a considerable sample would be needed that this thesis did not have access to (Liu et al. 2015; Gregson et al. 2010). The results of the pitch possession may be also have been influenced by the limitations of SSG's, as the short duration and limited pitch size force the players to compete in closer proximity to each other. As a consequence, the players have less space to compete and move around the pitch resulting in possession findings that do not necessarily represent true performance. This is supported by unusual findings reported during the randomly assigned mixed teams implying that the possession information collected during the bio-banded matched games may be influenced by other, external factors (see table 15.). The mixed teams were used as a surrogate control sample and the lack of statistical significance (P = 1.000) reported in the anthropometrical measurements shows that the biological age of the teams, in terms of both PHV and EASA, are random (see table 13.). There should be little to no statistical significance shown within the variables investigated within the mixed teams and this is true for all variables apart from GTSC points scored and pitch possession. Despite the random assignment of players into teams there is still statistical significance shown within pitch possession which is unexpected, therefore the findings relating to pitch possession during the bio-banded matched games may potentially have been influenced by other factors beyond biological age (see chapter 5.7). These results may be due to the influence of SSG's on tactics and possession, which research has shown to be an influential factor, however a limitation of this research is that it is unable to provide full explanation or insight into the tactics utilised by the players (Sarmento et al. 2018b).

A further argument supporting the fact that the results from the defensive pitch possession may not be the most accurate or insightful, can be found when examining the confidence intervals of the various possession results. For instance, whilst the pre-PHV versus pre-PHV matched game in the Fransen et al. (2017) approach has a significant statistical difference (P = 0.001) for the defensive right side, the confidence intervals sit within the range of -41.50 to -4.32 seconds, which is arguably quite wide. Whilst the reported statistical values for pre-PHV versus pre-PHV and circa-PHV versus circa-PHV defensive left side within the Khamis and Roche (1994) method were both $P = \leq 0.001$ their confidence intervals varied greatly. The pre-PHV versus pre-PHV match reported confidence intervals of 6.31 to 38.10 seconds and the circa-PHV versus circa-PHV match reported confidence intervals of 10.36 to 38.80 seconds. As the confidence intervals for all of these variables are wide it is challenging to be able to make an accurate conclusion, therefore limiting the trustworthiness that the statistical insight indicates a true effect of maturity status bio-banding. The effect size identified for the matched pre-PHV defensive right side (ES = 0.59, *small)*, the matched pre-PHV defensive left side (ES = 0.16, *trivial)* and matched circa-PHV defensive left side (ES = 0.72, *moderate)* do not exceed 1.2 (*moderate*). This implies that the effect of maturity status bio-banding within bio-banded matched games for both of the approaches does not exceed that of a moderate effect. The overall conclusions that can be made about the impact of maturity status bio-banding upon the possession that occurred during bio-banded matched games within both the Fransen et al. (2017) and Khamis and Roche (1994) are limited.

5.4.2 Maturity mis-matched bio-banded games

The statistical differences reported for the pitch possession within the bio-banded mis-matched games were more varied than those reported within the bio-banded matched games. The mis-matched bio-banded games reported more statistical differences within the offensive pitch possession for all of the bio-banded matches, in both methods, and only one defensive pitch possession difference. Within the Fransen et al. (2017) mis-matched bio-banded games there were statistical differences reported within the offensive left side and offensive right side for all mis-matched bio-banded games (see table 11.). The lack of reported differences in the defensive half of the pitch suggests that during the Fransen et al. (2017) bio-banded mis-matched games that the tactics are more offensive which may be an influence of more mature players being more physically capable and therefore are able to play more offensively (Cumming et al. 2018). However, as this discussion previously pointed out, the limitations of SSG have prevented such characteristics from being displayed due to limited pitch size and duration. Likewise, this thesis failed to collect data relevant to physical capabilities and therefore these statements cannot be made conclusively. A further explanation to the differences in offensive pitch statistics may be due to more mature players being able to make decisions more quickly than less mature players which allows for more offensive pitch possession (Gonçalves et al. 2016). However, the limitations of this study fail to provide the information to explore necessary to investigate this fully.

Statistical differences were also reported within Khamis and Roche (1994) bio-banded mis-matched games within the offensive left side for in all mis-matched bio-banded games (see table 12.). Only one difference was reported in the offensive right side, which was during the post-PHV versus pre-PHV (P = ≤0.001 to 1.000, ES = 1.10 to 0.89, *moderate to moderate*) matches and only one statistical difference reported in the defensive left side, which was during the circa-PHV versus pre-PHV (P = ≤0.001 to 1.000, ES = 0.65 to 0.79, *moderate to moderate*) matches (see table 12.). These results may again be explained by more mature athletes being able to make decisions more efficiently than less mature athletes resulting in more offensive play as they are able to react more quickly (Gonçalves et al. 2016). Hence why the reported findings in the offensive half of the pitch are for more mature players (post-PHV and circa-PHV players against pre-PHV players) and why the one defensive finding is reported for less mature players (pre-PHV). However, as previously stated this study lacks the ability to examine such information in further detail and there are several limitations to this study that may have impacted upon the accuracy of these results, therefore the conclusions that can be made are limited (see chapter 5.7).

When comparing the overall performance of possession there are a number of studies that analyse the impact of SSG's on possession, however there are very few that look at SSG's in relation to maturity status bio-banding and biological age (Malina et al. 2019; Sarmento et al. 2018b). One of the few studies that does, is research by Romann, Lüdin and Born (2020) who reported that in comparison to chronologically organised games, that bio-banded competition reported lower possession rates. The authors suggest that this is due to the pace of the games being much quicker, thus actions are performed more swiftly resulting in lower possession rates. The lack of statistical results reported for possession within some of the games in this thesis may be mirroring the results of Romann, Lüdin and Born (2020). The comparisons that can be made about pitch possession in relation to the Romann, Lüdin and Born (2020) study is limited as their matches were 20 minutes long, as opposed to the 5 minutes used within this thesis. The additional game time in the Romann, Lüdin and Born (2020) study may have afforded players more opportunity to display fitness characteristics that in turn may have affected performance, for example greater opportunity to observe aerobic capacity can be observed through dribbling over an extended period of time (Kelly and Williams 2020; Parr et al. 2020; Malina et al. 2019). The primary aim of Romann, Lüdin and Born's (2020) research was to compare player performance in maturity status bio-banded competition in relation to chronological age competition and therefore the study failed to specify any differences in performance between the different maturity status bio-bands when performing against each other. Abbott et al. (2019) analysed possession in their study and concludes that the high rate of dribbling that they observed in some of the maturity status bio-bands was due to players being unable to pass to a teammate and therefore were forced to maintain the ball. This may also explain some of the unusual results that have been reported in this thesis, whereby players are unable to perform an action therefore they have stayed in the same position or part of the pitch as a result, however the limitations of this thesis are unable to support this claim.

When directly comparing the Fransen et al. (2017) approach and the Khamis and Roche (1994) approach, the pitch possession findings do not mirror each other when, all other variables do. For instance, both approaches reported differences between the bio-banded games for anthropometrics, GTSC points scored and a lack of differences in the general KPI's investigated and total GTSC. Pitch possession is the only variable that does not report equivalent differences across both methods of maturity status bio-banding, which is true for both the matched and mis-match bio-banded games, however the match-to-match variability of soccer makes it highly difficult to compare equivalent performances of a factor as influenceable as pitch possession (Olthof, Frencken and Lemmink 2015). Limitations within this thesis mean that the reported findings of the pitch possession, for both the Fransen et al. (2017) and Khamis and Roche (1994) approaches, are less likely to show the impact of maturity status bio-banding and are more likely to be the result of other factors. For instance, despite attempts to reduce coach interference, there was still some intervention during some of the games (see chapter 5.7). Sarmento et al. (2018b) reported that coach encouragement can impact result in higher heart rate, blood lactate levels and RPE, which in turn may affect physical, technical and tactical performance during games. Additionally, when completing the reliability testing the pitch possession data reported some unusual coefficients of determination, particularly defensive right side (see table 6.). This in part is due to the nature of time-motion analysis data being more challenging to code accurately but also because the KPI's and operational definitions created failed to specify areas of the pitch exactly (Hughes and Franks 2007; O'Donoghue 2007). Whilst O'Donoghue (2007) said that agreed understanding is enough to ensure good reliability and accuracy that was not the case for this thesis. The pitch was not marked out to identify the four different pitch areas, therefore when an action occurred on the border of two areas it was often difficult to know where to mark the correct possession. Therefore, the pitch possession results from the mixed games, the bio-banded matched games and the bio-banded mis-matched games, for both the Fransen et al. (2017) and Khamis and Roche (1994) approaches, are not reliable and therefore limit the conclusions that can be made about the impact of maturity status bio-banding. Consequently, the likelihood that the pitch possession results show a true impact of maturity status bio-banding is doubtful due to low reliability and a lack of trend in the overall data.

5.5 Game technical scoring chart

Fenner, Iga and Unnithan (2016) reported that there was a very large relationship ($r = 0.758$, $P < 0.001$) between total GTSC and GTSC points scored and argued that this relationship existed due to the impact that multiple factors have upon talent. The study further stated that success in GTSC points scored is due to the technical ability of the players and specifies that 57% of the variability in GTSC points scored can be explained by GTSC total points, which differs to the findings of this research. This thesis reported that whilst there were significant differences found in GTSC points scored, there were no statistical differences reported in GTSC total points ($P = 1.000$), which was true for the Fransen et al. (2017), Khamis and Roche (1994) and mixed methods of organising teams. These findings are more similar to those found by Unnithan et al. (2012) who reported a moderate but non-significant relationship ($r = 0.39$, $P = 0.07$) between GTSC total points and GTSC points scored. The authors theorised that this was due to the effects of long-term training upon the sample, whereby players were of similar ability and skill having trained together for so many years. The sample used by Fenner, Iga and Unnithan (2016), whilst highly trained, were less experienced, which may explain the difference in results reported in their study and in this thesis. Additionally, Fenner, Iga and Unnithan (2016) did not conduct their research with teams organised according to maturity status bio-banding which may further explain the lack of agreement between findings.

5.5.1 Maturity matched bio-banded games

Overall, there were fewer statistical differences reported in GTSC points scored for the matched bio-banded games than there were for the mis-matched bio-banded games (see tables 9. and 10.). Within the Fransen et al. (2017) matched bio-banded games there was only one statistical difference (P = 0.002) reported in the circa-PHV versus circa-PHV matches. Whilst the effect size reported for this result was small (ES = 0.26), the confidence interval range reported was also small (-4.9 to 0.4), therefore suggesting that this is accurate, despite it being the only statistically significant result within the Fransen et al. (1994) matched bio-banded games. The reasoning for this result may be the influence of individual players differences. Fenner, Iga and Unnithan (2016) stated that the GTSC points scored are able to indicate talented players because these players are able to accrue points over a number of games, regardless of who the opponent is. The result of the circa-PHV versus circa-PHV bio-banded games may be due to the influence of one individual being particularly talented rather than the influence of matched bio-banded games. An additional explanation for this result may be due to the thresholds that were used to categorise players in this thesis. The threshold used to define each band were not typical of those used in previous research, therefore players within the circa-PHV band are more mature than the bands are indicative of (Till and Jones 2015). Consequently, there may be some players that are more/less mature than their peers within the same band, which may give them an advantage or put them at a disadvantage, in turn this could have impacted upon the results/performance of the players.

Within the Khamis and Roche (1994) matched bio-banded games there was also only one statistical difference reported (P = ≤0.001) which was in the post-PHV versus post-PHV matches. The effect size for this result is large (ES = 1.38) and the confidence intervals are small (6.1 to

1.9), like the matched circa-PHV bio-banded games reported in the Fransen et al. (2017) approach. These statistical differences may again be explained by the influence of one individual being particularly talented or due to the influence of playing position, as each player equates to 25% of the team. This thesis failed to identify the playing positions of each player within the sample, so there were an unknown number of forwards and strikers included, which may have impacted upon the results as their positions are focussed on goal scoring (Harkness-Armstrong et al. 2020; Di Salvo et al. 2007). As GTSC points scored are calculated as an accumulation of team match outcome, the influence of a particular player performing well impacts upon the outcome listed for the rest of the team. These differences in performance may not be indicative of the influence of bio-banded matched games but instead the influence of individual players. There are also significant results shown within the randomly assigned mixed teams (see table 14.), and whilst the significance of these results is moderate (P = 0.05), it supports the theory that GTSC total points are influenced by individual players.

In conclusion, the GTSC points scored, should be used with caution when making conclusions about maturity status bio-banding as they may indicate talented individuals as opposed the impact of maturity status bio-banding, particularly in matched bio-banded teams. In terms of talent identification this is a useful tool to have if it can specifically pinpoint talented players within a cohort of similar biological aged players, however talent extends beyond the ability to win games and multiple factors can have an influence, hence why the more multifaceted total GTSC is also used.

5.5.2 Maturity mis-matched bio-banded games

In contrast to the matched bio-banded games, statistical differences were reported in the all of mis-matched bio-banded games in GTSC points scored, for both the Fransen et al. (2017) approach and the Khamis and Roche (1994) approach, respectively. As both methods have reported differences in all of the different games this implies that GTSC points scored are impacted by maturity status bio-banding. The largest impact was observed between players with the largest gap between biological age, e.g., post-PHV verses pre-PHV (ES = 1.49 to 1.17, *large to large*) in the Fransen et al. (2017) approach and post-PHV versus pre-PHV (ES = 2.32 to 1.98, *very large to large*) in the Khamis and Roache (1994) approach (see tables 9. and 10.). For both the Fransen et al. (2017) and Khamis and Roche (1994) approaches the more mature players scored more GTSC points scored than the less mature players. This mirrored results within both methods, implying that the differences seen are a true representation of the impact of maturity status bio-banding on performance and are not the result of individual influences, as is more likely to be the case in the matched bio-banded games.

It is interesting to note that there were no matching statistical differences reported in goals scored in the KPI's investigated, when there should be some relationship. The GTSC points scored were awarded according to the outcome of each game i.e., winning scored 4 points, drawing scored 2 points and losing scored 0 points. Therefore, the number of goals, which directly influences game outcome, should reflect similar statistical differences, however in this research it does not. Therefore, when analysing performance according to KPI's and GTSC in relation to each other, caution should be used as the two factors, whilst linked, do not necessarily show similar outcomes.

Consequently, this may impact upon the conclusions that can be made about players in different maturity status bio-bands when they are analysed from different perspectives and using different tools.

5.6 Fouls conceded, aerial duels and x-factor

Instances of fouls conceded, aerial duels and x-factor were performed so infrequently that they could not be analysed for statistical significance. Previous research has reported that the number of fouls committed by winning and losing teams differ, however the current research failed to find similar results (Castallano, Casamichana and Lago 2012; Lago-Penas, Lago-Ballesteros and Rey 2011). This may be due to the short duration, reduced pitch size and reduced number of players that are utilised in the SSG's, therefore making the findings of previous research less applicable to the findings of this research. Previous research has also reported that aerial skill is perceived as an important skill by coaches and other multidisciplinary staff, however there were few instances reported during this research (Towlson et al. 2019). Similar to the previous point made, this may be due to the influence of the short duration, reduced pitch size and reduced number of players used during SSG's. Coaches and technical directors also identified x-factor being perceived as moderately important (Larkin and O'Connor 2017). Previous studies have identified that 'gut instinct' is often used by coaches and talent identification practitioners to inform decisions about players i.e., players that have an x-factor (Roberts et al. 2020). However, trying to objectively identify this is difficult to quantify, partly due to the small number of this KPI being identified but also because x-factor is so subjective. This can be seen in the reliability testing (see table 6.) where x-factor was the KPI with one of the largest differences in coefficients of determination, therefore even the same person cannot re-identify x-factor correctly.

In conclusion fouls conceded, aerial duels and x-factor are not able to provide insight into the impacts of maturity status bio-banding on player performance in this research due to low instances.

5.7 Limitations

There were several limitations identified in this study which may have impacted upon the findings and therefore the conclusions of this research. These limitations can be identified as factors relating to the participants, the method of calculating maturity and consequent bio-banding, the reliability of the results, the methods of collecting footage, the procedures during the games, the performance analysis and the tactics which will all be discussed below.

Limitations in participants occurred due to the sample that was available for selection in this thesis. This thesis failed to identify the playing positions of the players in this sample, therefore the findings may be biased towards particular playing position traits. Different playing positions have skills that are unique to each role and therefore training will focus on developing those skills to be successful (Saward et al. 2018; Hughes et al. 2012; Di Salvo et al. 2007). For example, previous research has highlighted that midfielders should be able to pass, dribble and head the ball in comparison to full backs that should be able to tackle, head the ball defensively and clear the ball (Hughes et al. 2012). Additionally, research has shown that playing position is influenced by maturation, with early maturing players typically occupying defensive roles and late maturing players occupying offensive roles (Towlson et al. 2017). The findings of this research may not be relevant to all players as it fails to identify player position which in turn is influenced by maturation.

In order to make the research more applicable, further research should include a wider variety of playing positions (Saward et al. 2018; Towlson et al. 2019; Hughes et al. 2012; Hughes and Franks 2008; Unnithan et al. 2012; Di Salvo et al. 2007).

There were several limitations within the methods of estimating maturation. As discussed within the literature review (see chapter 2) each approach to estimating maturation has strengths and weaknesses that impact upon the accuracy. For instance, the Khamis and Roche (1994) method of estimating maturation has reported instances of inaccuracy, particularly pertaining to the use of parental height and the reported instances of under estimation in early maturing players and over estimation in late maturing players (Baxter-Jones et al. 2020; Fragoso et al. 2014; Malina et al. 2012; Braziuniene et al. 2007). Similar concerns can be seen within the Fransen et al. (2017) method of estimating maturation, as the accuracy of the equation and accuracy regarding error for early and late maturing players have been questioned (Towlson et al. 2020 Nevill and Burton 2017). The limitations of both approaches may have impacted upon the accuracy of estimating players maturation within this thesis and therefore the maturity status bio-bands may contain players that are more mature or less mature than intended. This may have impacted upon the findings in this thesis as more mature- and less-mature players have different characteristics that impact upon performance (Gouvea et al. 2016; Borges et al. 2018; Matta et al. 2014; Vandendriessche et al. 2012; Figueiredo et al. 2010; Figueiredo et al. 2009a; Gall et al. 2008; Malina et al. 2005; Malina et al. 2004).

Further limitations also existed within the thresholds used to organise players into maturity status bio-bands. As previously discussed, the thresholds used in this thesis differ to those in previous research in order to overcome the restrictions of the sample available (post-PHV = >92.0%, circa-PHV = 87.0 to 92.0% EASA, pre-PHV = <87.0% EASA and post-PHV = <-1.0, circa-PHV

= -1.0 to 0.0 and pre-PHV = >0.0). The effects of this are limited as players still showed significant statistical differences (P = ≤0.001) in anthropometrical measurements when maturity status bio-bands were compared (see tables 7. and 8.). However, caution should be used when making direct comparisons between this thesis with previous research as the maturity status bio-bands were not exactly alike.

When analysing the matches from the different bio-banded methods, this thesis failed to consider the coefficient of variations. Therefore, the conclusions that can be made from these results are limited as it cannot be certain that the findings were due to the influence of different bio-banding methods rather than the influence of observations made (Trewin et al. 2018). Future research should take match to match variability into consideration when comparing match performance to allow for stronger conclusions to be made.

Likewise, this thesis also failed to calculate the reliability of the GTSC which limits the conclusions that can be made from the findings. The GTSC incorporated the opinions of four experienced coaches in relation to player ability in an attempt to identify if there was a link between coach opinions of players and the physical performance of players. This thesis however, neglected to identify the reliability of the GTSC, therefore it cannot be certain that the results were implicitly due to the effects of bio-banding. Consequently, this impacts upon the conclusions that can be made between coach opinions and performance analysis in relation to talented players and the impact of bio-banding. Future research should take steps to account for the reliability of coaches opinions so as to make more reliable conclusions.

Throughout the discussion section it has become apparent that a further limitation of this thesis is that it fails to collect data pertaining to physiological ability of players, such as aerobic capacity (VO2 max tests), lower body strength (vertical jump test) and endurance (yo-yo test).

Therefore, the conclusions that can be made from the findings when comparing the performance of athletes in different bio-bands are limited because they cannot be supported by empirical evidence. For example, an explanation for the differences reported in pitch possession between bio-bands was theorised to be due to the differences in endurance and aerobic capacity between players of different bio-bands. More mature players possess physical characteristics that allow them to have greater endurance and aerobic capacity than less mature players therefore giving them greater ability to play more offensively. However, this conclusion cannot be fully supported as this thesis did not measure whether the players do in fact possess differing endurance and aerobic capacity. In order to make more conclusive statements about bio-banding and player ability, future research should consider collecting a wider selection of data that incorporates physiological testing as well anthropometrical measurements and KPI performance.

The procedures of the SSG in terms of pitch size also resulted in various limitations. The small pitch size meant that there were several KPI's that were not performed because there was no need or adequate space for certain actions to be performed. For example, previous research has pointed out how small pitch size, limited the number of long passes made, because there was less distance to cover and short passes were more ideal to perform (Romann, Lüdin and Born 2020; Abbott et al; 2019; Drummond et al. 2019). The number of players on a small pitch resulted in less surface area per player which in turn impacted upon player performance (Sarmento et al. 2018; Goncalves et al. 2017). The impact of SSG's pitch size impacted upon the findings of this thesis therefore affecting the conclusions that can be made about maturity status bio-banding in relation to athlete performance.

Limitations during the procedures of the games included the goals accidentally being moved during the games by the players (i.e., by particularly forceful shots off target moving the goal posts or by players bumping into the goals). In most instances the goals were returned to their original position with no consequences however there were some cases in which there was an attempt made to score and the goal posts had not been returned, meaning that the shot was off target. Had the goal been in its original position then it would have been on target and potentially a goal, however the nature of the operational definitions utilised meant that this occurrence had to be coded as being ‘off target’. This is a limitation of the game proceedings and of the operational definitions used, as this was not an incident that had been anticipated. The implications of this limitation are that the resulting goals scored within the games may not be an accurate representation of the actual score. This may have led to disagreements between the KPI’s recorded and what the coaches as part of the GTSC recorded. The lack of agreement between the two may have affected the conclusions that can be made about the link between performance analysis and the GTSC.

A further limitation that occurred during the games is that in some instances there was external influence from the referee or the coaches that impacted upon player intensity. The games were designed so that they were influenced by the players themselves, therefore the games were a direct result of their own performance (Fenner, Iga and Unnithan 2016). The influence of the coaches and referees, where they encouraged players or attempted to influence the intensity of the game occurring, may have impacted upon the players’ performance and outcome of the games. Previous research by Sarmento et al. (2018b) has shown that coach encouragement can impact on player performance in terms of increased heart rate and work rate. Cushion, Ford and Williams (2012) identified that coach behaviours can have a large impact upon athlete talent development due to the impact factors such as communication and coaching style can have upon an athlete’s ability to learn. Even coach body language was shown to impact upon athletes as the non-verbal cues give insight into a coach's emotional state. A more direct action such as yelling encouragement will have a more immediate effect, like those shown in Sarmento et al. (2018b). Thus, the results of this thesis may not have been an accurate representation of performance therefore limiting the conclusions that can be made about maturity status bio-banding from this research. The findings of the possession on the pitch were influenced by the proximity of the referee or the coaches. The players were prone to playing on the pitch in a manner in which they were closest to whichever external person was closest to the pitch, therefore the possession findings and pitch position findings were biased.

There were no operational definitions given for the 'areas' of the pitch when coding the possession on court data, in hindsight this may have led to the differences reported in the coefficient of determination due to a lack of clarity. Consequently, any replicability of this section of the study is limited due to a lack of operational definitions. Whilst O'Donoghue (2007) argued that agreed understanding regarding KPI's and operational definitions is enough, the lack of definitions in this research limits the potential replicability. Additionally, the areas of the pitch during the game were not clearly defined or marked, therefore the coding of the pitch possession are subject to individual coder interpretation and consequent bias. Had clear operational definitions been used then this would have improved the reliability and reduced bias.

Similar difficulties arose when it was challenging to ascertain what a player intended to do with a certain skill, from which the outcome of the skill was unsuccessful. For example, a player is standing by the opposition goal and a teammate kicks the ball towards the goal but the kick is intercepted or blocked by the opposition. This can be interpreted in a number of ways, for example the kick was an unsuccessful pass to the teammate who was stood by the goal or that the kick was a shot on goal that was blocked. Instances where a player would head the ball but it would not reach a member of the same team, could be coded as an unsuccessful pass and as an interception for the opposition. Similar occurrences were identified by Liu et al. (2013) where actions could be identified as more than one KPI. The lack of agreement that occurred in this thesis during the reliability testing may therefore be explained by this lack of clarity and crossover in KPI's. Therefore, the results of this study may not be an accurate representation of the occurrences that transpired in the games due to ambiguous coding and KPI's and operational definitions that failed to account for crossover of KPI's. An additional limitation of the KPI's and operational definitions created were that they failed to account for the occurrences of own goals. Whilst the number of these occurrences is limited it may have impacted upon the results of this study, as goal difference would affect the GTSC points given. Consequently, the success of the teams shown in the results may not always a representation of their own efforts and ability, therefore the findings of this study are limited in their application. Limitations can also be seen in the performance indicator 'x-factor' that showed a variety of different results during reliability testing and was a highly subjective indicator. Its usefulness and accuracy in this study is limited therefore affecting the applicability of the findings of this study.

This study was unable to give insight into the tactics that players used during the games however the tactics may have impacted upon the results of this thesis. For instance, during the matches, some of the teams would post a teammate by the opposition goal so that player was in a more opportunistic position to score. According to the rules of the small sided games this is legal and a legitimate tactic that can be used. In 'real life' football and in full sized games this tactic would be an offense and is against the football laws, as a player would be deemed as offside resulting in a penalty kick to the opposition. Whilst it could be argued that this is an insight into player creativity and tactical awareness, which is an aspect of player talent identification, this tactic does not always show a players' best abilities if they are stood by the goal for the duration of the game. For instance, the qualities often shown by strikers in talent identification research are that players quick, agile and have good accuracy, qualities that may not be shown by using this tactic in SSG's (Towlson et al. 2019).

5.8 Future research recommendations

In order to make more decisive and accurate conclusions, this thesis and future research should use a much larger sample of players, that includes a wider range of playing positions and biological ages so that the conclusions are more applicable to a wider audience. This thesis was limited by the sample available therefore the bio-bands that were utilised were adjusted to suit the players that had been recruited. The bands created were more able to distinguish between the maturation of the players in the sample the than the bands that had been used within previous literature. As mentioned in chapter 5.7 the effects of this were limited as there were still differences in anthropometrical measurements between the players in different bio-bands. However, the comparisons that can be made between the findings of this thesis and those in previously literature should be done so cautiously. Future research should recruit a larger sample of players so that the bands applied need not be adjusted and findings can be more directly compared to previous literature. Likewise, a larger sample size would allow for more accurate conclusions to be made as there were several occurrences in this thesis where this impacted upon the results. For example, there were some instances where the GTSC was affected by the performance of one particularly gifted player which in turn impacted upon the overall GTSC results for that group. If the sample within this study had been larger, the impact of such 'outlier players' would have been reduced therefore allowing for more accurate insight. Likewise, there were some instances where the KPI's investigated were also influenced by the small sample size, resulting in the confidence intervals and effect sizes showing weak relationships between several variables when the P values indicated otherwise. This disagreement between the different calculations brings doubt to the trustworthiness of whether that the results are truly showing an impact of bio-banding or not. Therefore, future research should recruit a larger sample to also allow for more accurate conclusions to be made. Additionally, a larger sample size that includes a larger sample of maturation and playing positions would also allow for the results to apply to a wider population for soccer players. Towlson et al. (2017) highlighted that player position is influenced by maturation whereby more mature players are predominantly selected for goal keeper and central defender positions. The majority of players within this study were midfielders and therefore the results of this study may be influenced by the characteristics displayed by midfield positions players, in terms of technical ability and maturation (Towlson et al. 2019; Saward et al. 2018; Towlson et al. 2017; Di Salvo et al. 2007). Consequently, the conclusions made aren't widely applicable to all players. Therefore, it is suggested that future research should aim to investigate the direct impact of bio-banding according to playing position as this would provide greater insight that is more relevant to a wider selection of players.

This thesis utilised a male sample and as previous research has shown that there are several anthropometrical differences between males and females that ultimately lead to difference in ability and physical performance, the results of this thesis are not useful to female soccer players (Harkness-Armstrong et al. 2020; Malina, Bouchard and Bar-Or 2004). Figure 1. shows that female and male growth velocity differs, which impacts upon the talent and identification and bio-banding of female athletes as they reach maturity earlier than male athletes (Tanner et al. 1966). This different in male and female maturation can also be observed within the various maturation estimation equations as separate equations were calculated for males and females due the differences in maturation that occur and difference rates (Fransen et al. 2017; Khamis and Roche 1994). These differences in anthropometrics, physical ability, maturation and consequent ability between genders means that most of the research that has been conducted is not relevant for female soccer players as the majority of research published utilises a sample of male soccer players. Therefore, in order to address the gap in research future research needs to be conducted using female soccer players and female youth soccer players as there is a considerably small amount of research in comparison to male soccer and male youth soccer research. This information would allow for practitioners to more accurately monitor female maturation and adjust training to better suit individual female player needs (Harkness-Armstrong et al. 2020; Malina, Bouchard and Bar-Or 2004).

Future research should also make further investigations into the impact of SSG's on maturity status bio-banding. Previous research has shown that SSG's can be altered and adapted in various ways for various purposes, however this research only utilised one SSG approach due to limitations in sample size (Clemente and Sarmento 2020; Akenhead and Thomas 2014; Aguiar et al. 2012). Larger pitch sizes and smaller team sizes have shown to produce greater physiological demand of players with the opposite found for smaller pitch sizes and larger teams sizes (Sarmento et al. 2018b). This thesis found that the pitch size (18 x 23 meters) utilised was too small and limited the investigation of bio-banding upon maturation as the effects that are typically associated with different maturation could not be displayed. For example, previous maturation studies have shown that more mature players have greater physiological abilities than less mature players (Cumming et al. 2018; Zuber, Zibung and Conzelmann 2016; Gil et al. 2014; Malina, Bouchard and Bar-Or 2003). Therefore, it is suggested that future research investigate bio-banding and maturation in relation to larger pitch sizes as this will enhance the differences between different stages of maturation and provide greater insight.

Finally, in order to fully monitor the impact and effects of maturity status bio-banding and SSG's, longitudinal studies should be conducted that are able to report player success in the future in relation to maturity status bio-banding. For instance, Saward et al. (2018) completed a longitudinal retrospective study that identified the performance between players differed if they were maintained or released from academies and if they became professionals or not. Research has also shown that the maturation selection-hypothesis favours more mature players, however they ultimately go on to be less successful because they lack the technical and tactical skill needed at more elite levels of competition (Cumming et al. 2018). Conversely, less mature players go on to become more successful because they eventually catch up to their more mature peers in terms of anthropometrical measurements and possess greater technical and tactical skills (i.e., become professional players) (Kelly and Williams 2020; Kelly et al. 2019; Bidaurrazaga-Letona et al. 2017). Therefore, future research should consider investigating the long-term impact of bio-banding and whether it can potentially overcome these biases and create equal opportunities for all players, regardless of maturation and biological age, as this information may lead to a greater quantity and quality of talented players.

5.9 Conclusions

In conclusion, the findings of this research suggest that maturity status bio-banding has little impact upon the technical ability of players, which was true for both matched and mis-matched bio-banded games in both the Fransen et al. (2017) and the Khamis and Roche (1994) approaches. When comparing the results from the Fransen et al. (2017) method and the Khamis and Roche (1994) method, there were few differences reported in the anthropometrical measurements, GTSC and performance of players, therefore suggesting that there is not a single method that is better than the other in providing insight in biological age. The selection of which approach to utilise is more likely to be influenced by the resources and information that soccer academies have available.

The results of this research show that maturity status bio-banding has a limited impact when examining players from a technical and tactical perspective. In part this is due to the limitations of this thesis that may have impacted upon the results, however the conclusions that can be made are that bio-banded matched competition results in few differences between player performance. The findings of the matched competition show that players with similar biological age possess similar attributes (for example height and weight), which leads to similar technical performance. Consequently, there is less opportunity for the maturation-selection biases to occur because players are anthropometrically similar. In terms of talent identification, it may be easier to identify players that are more gifted when competition is organised in this way because talented players are able to showcase their abilities more easily in a less biased environment.

The impact of mis-matched bio-banded competition is a little more difficult to conclude as the limitations present in this thesis have likely impacted upon the results. As the anthropometrical measurements have shown the maturity status bio-bands in this study were different from each other, player performance of technical and tactical factors when mis-matched should likewise be different. As such, the attributes that are afforded to each maturity status bio-band should be prevalent during mis-matched competition and more mature players should be more physically capable and less mature players should be more tactically capable. These attributes are likely to have been negated by the small pitch size and short duration that was utilised during the SSG’s, therefore player performance was influenced as they had to meet the new demands of restricted games. To summarise, this research cannot make a definitive statement about the impact of maturity status bio-banding upon the performance of players and more research is needed in order to make a more decisive conclusion.

5.10 Practical applications

To further assist the fair and equal identification, monitoring and development of talented players from a young age, this thesis proposes three practical recommendations for coaches, sports scientists and talent identification practitioners to consider. These recommendations hope to reduce the effects of the maturation-selection hypothesis therefore creating a larger selection of players that can developed from a young age and go on to play at senior levels.

1. Practitioners should consider using maturation testing and monitoring to allow highlight individual differences and allow for training to be adjusted to suit individual needs. Whilst there is no 'gold standard' or particular method that is deemed the best at identifying maturation and biological age, practitioner should still incorporate some method of identification.
2. Practitioners should be aware of the maturation-selection hypothesis and how more mature players possess greater anthropometrics and consequently display greater physiological ability. Therefore, initiatives such as bio-banding can help to reduce this bias particularly when players are matched according to their biological age as opposed to their chronological age.
3. Practitioners should be mindful of the fact that different methods of assessing player performance and ability may not necessarily show the same result and therefore

conclusions about player ability should be open to interpretation when comparing results. Within this thesis the insight provided from the GTSC and the KPI's investigated did not reveal similar results. As soccer and/or soccer academies use a variety of tools to gather information, such as GPS, RPE, heart rate monitors etc., practitioners should be aware that different methods reveal different insight and there is not one method that is able to indicate player ability as soccer and players are multifaceted.

Chapter 6. References

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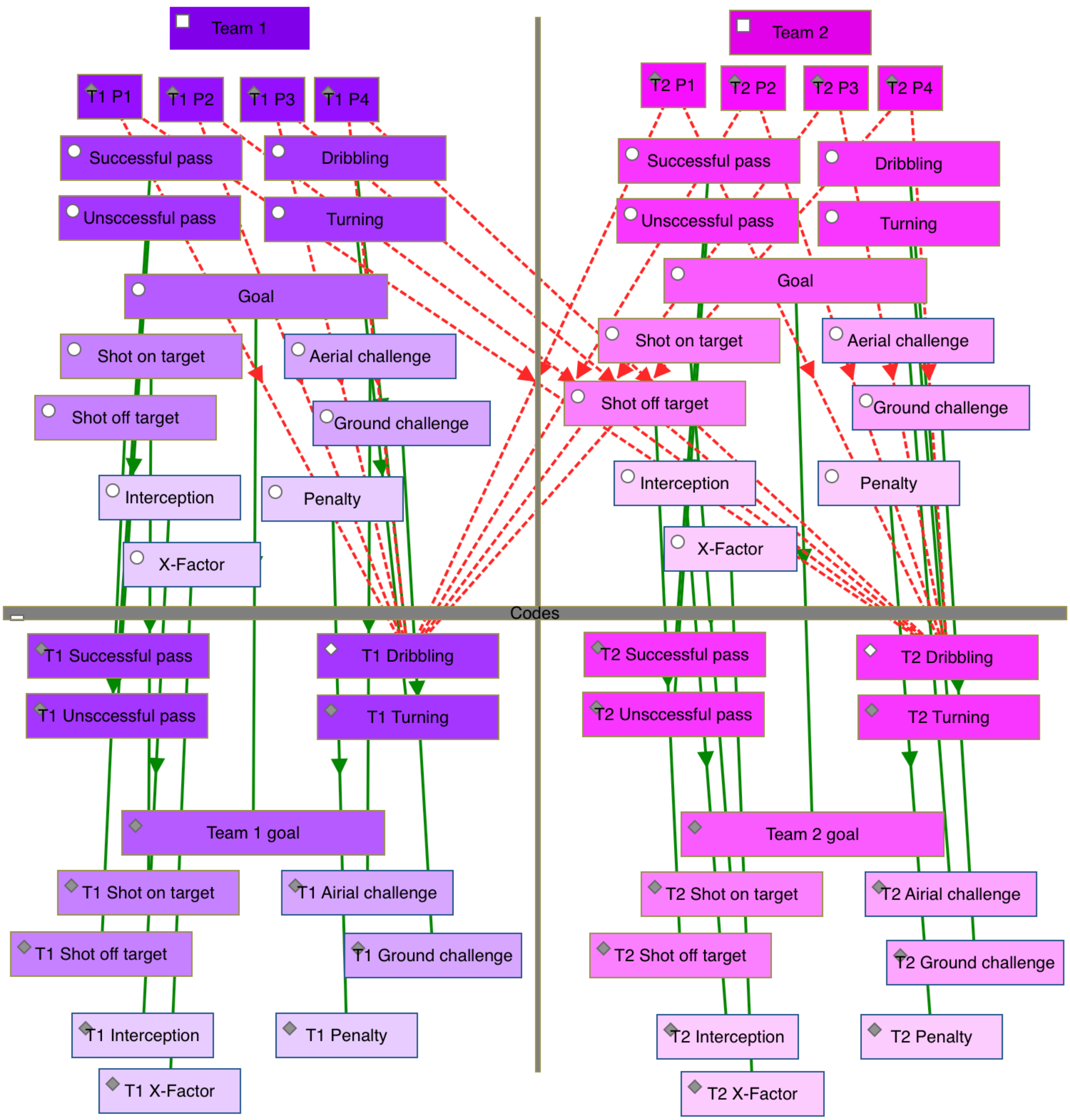
Chapter 7. Appendix

7.1 Appendix 1. Code window created to code KPI's that occurred during the games.



7.2 Appendix 2. Questionnaire given to inform the selection of the operational definitions for the KPI's, with answers.

1. How would you define possession?	Frequency
When a player has control of the ball to an extent they can influence its direction.	8
When a player competes for the ball.	0
When a player is able to shoot at the goal.	0
None of the above	0

2. How would you define shot off target?	Frequency
When a player aims the ball towards the goal that results in a goal or a save from the opposition.	0
When a player shoots towards the attacking third.	8
When a player aims the ball towards the goal that results in missing the goal or re-bounding off the goal posts.	0
None of the above	0

3. How would you define an unsuccessful pass?	Frequency
When the ball is unsuccessfully transferred from one player to another I.e. if the ball is intercepted or going out of play.	8
When the ball is transferred from one player to another successfully without the ball being intercepted or going out of play.	0
When the ball is transferred from one team to the opposition team.	0
None of the above	0

4. How would you define an interception?	Frequency
When a loose ball is picked up by the team or the opposition.	0
The ball is won due to interrupting the oppositions possession of the ball whilst still keeping the ball in play.	8
When the ball is awarded to the opposition after a foul or a restart of play.	0
None of the above	0

5. **How would you define a successful pass?**	**Frequency**
When the ball is transferred from one team to the opposition team.	0
When the ball is transferred from one player to another without the ball being intercepted or going out of play.	8
When the ball is unsuccessfully transferred from one player to another I.e. if the ball is intercepted or going out of play.	0
None of the above	0

6. **How would you define shot on target?**	**Frequency**
When a player aims the ball towards the goal that results in missing the goal or re-bounding off the goal posts.	0
When a player shoots towards the attacking third.	0
When a player aims the ball towards the goal that results in a goal or a save from the opposition.	8
None of the above	0

7. **How would you define foul conceded?**	**Frequency**
When the opposition break the rules of the game that results in the ball being awarded to the opposition team, does not include deliberately playing the ball out of play.	2
A deliberate breaking of the rules of the game that results in the ball being awarded to the to the opposition, does not include deliberately playing the ball out of the field of play.	4
When the referee stops play and awards the ball to the opposition.	2
None of the above	0

8. **How would you define aerial challenge?**	**Frequency**
When the ball is completed for whilst the ball is in the air.	8
When the ball is thrown into play from the side-line.	0
When a player makes contact with the ball whilst the ball is in the air.	0
None of the above	0

9. **How would you define a ground challenge?**	**Frequency**
When the ball is competed for whilst the ball is on the ground.	8

When a player maintains possession of the ball.	0
When a player is able to intercept the ball.	0
None of the above	0

10. How would you define dribbling?	**Frequency**
When a player is able to maintain possession of the ball.	0
When a player maintains possession of the ball and guides the ball in a certain direction using their feet.	0
When the ball is passed from one team member to another team member.	8
None of the above	0

11. How would you define turning?	**Frequency**
Moving from the attacking third to the defending third.	0
When a player plays the ball in a different direction.	0
A change of direction when the player has the ball in their possession.	8
None of the above	0

12. How would you define x-factor?	**Frequency**
Unpredictable; creativity; thinks outside the box; talent; gift.	6
When the player is taller, faster and stronger than the others.	0
A singing competition.	0
None of the above	2