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The Maturity related Physical Phenotypes of English, Elite Youth Soccer Players: Exploring the Elite Player Performance Plan

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by

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List of Published Works

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2) **Towlson, C**., Cobley, S., Midgley, A., Garrett, A., Parkin, G., & Lovell, R. (2017). Relative Age, Maturation and Physical Biases on Position Allocation in Elite-Youth Soccer. *International Journal of Sports Medicine*.

Conference proceedings:

1) **Towlson, C**., Midgley, A., Garrett, A., Parkin, G., & Lovell, R. (2015). Playing position characteristics of youth (13-18 years) academy soccer players in England. Paper presented at the 8th World Congress of Science and Football.

2) **Towlson, C**., Midgley, A., & Lovell, R. (2012). Acute match preparation strategies of professional football players: Practitioners' perspectives. 3rd World Conference on Science and Soccer, Abstract book, 247.

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List of Abbreviations

EPL	English Premier League
EPPP	Elite Player Performance Plan
UEFA	Union of European Football Associations
U	Under
3G	Third generation, synthetic playing surface
TD	Talent development
km	Kilometres
GK	Goalkeeper
CD	Central defender
LD	Lateral defender
CM	Central Midfielder
LM	Lateral Midfielder
FWD	Forward
$m.s^{-1}$	Meters per second
$km.h^{-1}$	Kilometres per hour
cm	Centimetre
m	Meter
min	Minute
CV	Coefficient of variation
%	Percent
CMJ	Vertical counter movement jump
MSS	Maximal sprint speed
s	Seconds
ISAK	International Standards for Anthropometric Assessment
$\dot{V}O_2$ max	Maximum oxygen uptake ($mL \cdot kg^{-1} \cdot min^{-1}$)
MAS	Maximum aerobic speed
MSFT	Multi-Stage Fitness Test
UMTT	The Université Montreal Track Test
YYIRT	Yo-Yo Intermittent Recovery Test (Level 1)
PHV	Estimated peak height velocity ($cm \cdot year^{-1}$)

*	Multiply
YPHV	Estimated number of years from achieving peak height velocity
PWV	Estimated peak weight velocity (kg·year^{-1})
FIFA	The Fédération Internationale de Football Association
n	Number
MRI	Magnetic resonance imaging
DEXA	Dual energy X-ray absorptiometry
PHV	Estimated age at peak Height velocity
RAE	Relative age effect
LTAD	Long term athletic development
YPD	Youth Physical Development
d	Cohens *d* effect size
SWC	Smallest worthwhile change
SD	Standard deviation
MD	Mean difference
TE	Typical error
ICC	Intraclass correlation
CI	95% confidence interval
ES	Standard effect size
Q	Quartile
RAd	Relative Age according to birth distribution in days
s/YPHV	Seconds per years to peak height velocity
m/year^{-1}	Meters per year
cm/year^{-1}	Centimetres per year
s/year^{-1}	Seconds per year
kg/year^{-1}	Kilograms per year
BASES	British Association of Sports and Exercise Sciences

Abstract

The aims of this thesis were to examine the relationships between relative age, maturity status, and physical phenotypes on the selection, playing position allocation, and development tempo of a broad sample of elite youth soccer players' that best represents UK development programs governed by the Elite Player Performance Plan (EPPP).

The first research study (**Chapter 4**) aimed to establish the short-term reliability (STR) and smallest worthwhile changes (SWC) for a battery of field tests commonly used to assess elite youth soccer players' physical and somatic phenotypes. On two occasions, the within-practitioner STR of three anthropometric measures (stature, seated height and body-mass) were assessed to estimate age at peak height velocity (APHV). In addition, within-player STR of the Multi-Stage Fitness Test (MSFT), 10 and 20 m sprints were assessed using 45 elite youth soccer players (age: 13.5 ± 1.5 years; body-mass: 49.2 ± 10.3 kg; stature: 177.7 ± 6.4 cm). In addition, within-player STR was established for T-Test and counter-movement jump (CMJ) performance using 21 senior amateur soccer players (age: 24 ± 5.3 years; body-mass: 84.3 ± 7.1 kg; stature: 177.7 ± 6.4 cm). The within-practitioner STR (coefficient of variance [CV], (95% confidence interval [CI])) and SWC were established for anthropometric measures (stature: CV = 0.4 % [CI = 0.3 to 0.5 %], SWC = 2.3 cm; seated height: CV = 1.1 % [0.9 to 1.4 %], SWC = 1.1 cm; body-mass: CV = 0.7 % [0.6 to 0.9 %], SWC = 2.3 kg) and APHV (CV = 0.8 % [0.7 to 1.0 %], SWC 0.1 year) respectively. Within-player physical fitness reliability and SWC were also established for CMJ (CV = 5.9 % [4.6 to 9.0 %], SWC = 0.6 cm), T-Test (CV = 1.7 % [1.3 to 2.4 %], SWC = 0.08 s), 10 m sprint (CV = 2.7 % [2.2 to 3.4 %], SWC = 0.03 s) and 20 m sprint (CV = 4.9 % [4.1 to 6.4 %], SWC = 0.06 s) performances. This battery of anthropometric and physical fitness field tests observed a high level STR and produced SWC values that will permit talent development (TD) practitioners to implement SWC % to assess changes in player growth, maturity and physical fitness.

Research study 2 (**Chapter 5**) aimed to quantify the relative-age effect (RAE) and examine differences in physical phenotypes owing to the RAE of 731 (U11 to 18) elite youth soccer players sampled from 17 UK soccer development centres. Chi-squared analysis identified a clear un-even birth distribution across all age groups, demonstrating an over-representation of players born in the first quartile (Q1) (U11 to 12: 39%; U13 to 14: 46%; U15 to 16: 57%; U17 to 18: 42%) in comparison to Q4 (U11 to 12: 13%; U13 to 14: 8%; U15 to 16: 8%; U17 to 18: 14%) of the selection year that significantly differed to the distribution expected from National census data (all ≤ 0.001). *Small* to *moderate* differences in player stature and body-mass were identified for U11 to 14 players, whereby players born in Q1 were both heavier (ES = 0.48 to 0.57) and taller (ES = 0.62 to 1.06) than players born in Q4. U11 to U12 and U17 to 18 players born in Q1 were generally (ES = 0.37 to 0.70) more mature than their relatively younger (Q4) counterparts. There were no significant differences in agility (P = 0.108 to 0.643), 10 m (P = 0.122 to 0.886) and 20 m (0.090 to 0.911) sprint times between Q1 and Q4 players. However, relatively younger (Q4) U15 to U16 players showed *small* to *moderate* (ES = 0.34 to 0.49) inferiority in MSFT performance that continued for Q2 (Q2 vs. Q4: P = 0.041, ES = 0.91). The obvious birth distribution bias identified within this chapter favours the selection of players who are born earlier in the selection year, who possess enhanced maturity related anthropometric and aerobic performance characteristics.

Study 3 (**Chapter 6**) assessed the contribution of relative age, maturity and physical phenotypes upon soccer playing position allocation (goalkeeper [GK], central-defender [CD], lateral-defender [LD], central-midfield [CM], lateral-midfielder [LM], and forward [FWD]) in 465 elite-youth soccer players (U13 to U18`s). U13 to 14 CD were identified as being relatively older than LD (ES = 0.72). CD and GK were generally taller (U13 to 14: ES = 0.49 to 1.19; U15 to 16: ES = 0.72 to 1.48; U17 to 18: ES = 0.96 to 1.58) and heavier (U13 to 14: ES = 0.64 to 1.40; U15 to 16: ES = 0.24 to 1.57; U17 to 18: ES = 0.51 to 1.32) than other players at each developmental stage and were advanced maturers at U13 to 14 (ES = 0.63 to 1.22). Position specific fitness characteristics were distinguished at U17 to 18, where LD and LM were faster than their central counterparts (10m: ES = 0.72 to 0.83; 20m: ES = 0.94 to 1.07). In summary, relative age, maturity and anthropometric characteristics appear to bias the allocation of players into key defensive roles from an early development stage, whereas position-specific physical attributes do not become apparent until the latter stages (U17 to 18) of talent development in outfield players.

Study 4 (**Chapter 7**) assessed the development tempo of anthropometric and physical fitness characteristics according to players decimal age and maturity offset (YPHV) of 969 (U9 to U18) UK elite youth soccer players using battery of 7 field tests. Segmented regression analysis established that estimated stature increases were highest between 10.7 (CI = 10.2 to 11.2) to 15.2 (CI = 14.8 to 11.2) years, and between -3.2 (-3.5 to -2.9) to 0.8 (0.5 to 1.1) YPHV, with estimated annual growth rates of 7.5 (CI = 7.0 to 7.9) and 8.6 (CI = 8.3 to 9.0) cm·year^{-1} identified for decimal age and YPHV, respectively. Estimated rate of body-mass developmet was also increased (7.1 [CI = 6.6 to 7.6] kg·year^{-1}) between 11.9 (CI = 11.5 to 12.3) to 16.1 (CI = 15.5 to 16.7) years of age, whereas when modelled against somatic maturity, body-mass increases continued at 7.5 (CI = 7.2 to 7.7) kg·year^{-1} from -1.6 (CI = -2.1 to -1.1) to ~4.0 YPHV, without plataeu. Estimated CMJ development tempo decreased from 2.5 (CI = 2.2 to 2.8) to 1.3 (CI = 0.7 to 1.9) cm·year^{-1} circa- PHV (0.6 [-0.4 to 1.6] YPHV). Estimated T-Test performance gains ceased from 15.8 (CI = 15.2 to 16.4) years of age onwards, but when modelled against somatic maturity status, improvements slowed by ~43% at 0.4 (CI = -0.1 to 0.9) YPHV. Players estimated endurance capacity increased by 169 (CI = 158 to 179) and 185 (CI = 173 to 198) m·year^{-1}, until 16.4 (CI = 15.9 to 17.0) years and 2.1 (CI = 1.6 to 2.5) years post PHV, respectively. Estimated 10 and 20m sprint performance increased until 11.8 (CI = 11.2 to 12.5) years of age, or -1.8 (CI = -2.5 to -1.0) YPHV, before development tempo increased (31-43%) until 15.8 (CI = 15.3 to 16.3) years, or 1.2 (CI = 0.1 to 2.3) to 1.3 (CI = 0.8 to 1.8)YPHV. Findings identified that model strength for stature and body-mass was slightly higher in YPHV (r^2 = 0.89) versus decimal age (r^2 = 0.81). However these trends were not apparent for the development of physical fitness attributes. In addition, **Chapter 7** revealed that players estimated sprint performance development markedly increased (31 to 43%) between 11.8 years and 15.8 years, or 1.2 to 1.3 YPHV. This data will provide practitioners with a guide to help forecast players' rate of anthropometric and physical fitness characteristics development at an early stage of their development. Findings here's suggest that TD practitioners should systematically use estimates of maturity offset to reduce the premature deselection of equally talented but slower players who may reach the same sprint capacity in adulthood, but are slightly later maturers versus there team-mates

In summary, the standardised battery of field-tests used within this thesis observed high levels of STR. There was a clear birth distribution bias that favours the selection of players' for UK elite soccer development centres, who are born earlier in the selection year. It is likely that transient anthropometric advantages afforded to relatively older players within younger age categories act as a major contributory factor that bias the premature selection and role allocation of these players in to key defensive (GK and CD) roles, before the development of position-specific physical attributes become apparent during the latter stages (U17 to 18) of the EPPP in outfield players. Likely to be of particular importance to TD practitioners, players' estimated sprint performance development increased across decimal ages (11.8 to 15.8 years) spanning PHV (-1.8 to 1.3 YPHV), justifying research to further examine the intricacies between training prescription and maturity on sprint speed development.

Monitoring player maturity will enable a better understanding of maturity related anthropometric and performance gains, and is likely to improve sensitivity of training prescription and physical phenotype development forecasting. Emphasising the necessity for systematic and consistent monitoring of player growth and maturity that will likely inform talent identification and development processes, and reduce the biases associated with relative age and anthropometric advantages upon talent selection and positional role allocation.

Key words:

Talent Identification, Anthropometry, Physical Fitness, Relative Age Effect, Maturity

Chapter 1. General Introduction.

1.1 Introduction

Historically, professional soccer clubs competing in the English Premier League (EPL) have been reported to operate beyond their financial capacity, often leading to worsening financial deficits and net losses that in some extreme cases result in club administration. In 2014, it was reported that the net debt for clubs competing in the EPL and Football League soccer divisions was £2.4 and £1.0 billion respectively, with nine of the top ten debtors from the Championship having previously played in the EPL (Conn, 2014). In an attempt to combat such financial fragility, the governing body for soccer in Europe, the Union of European Soccer Associations (UEFA) introduced the Financial Fair Play (FFP) regulation (UEFA, 2012). The FFP regulation dictates that all European professional soccer clubs are to operate within their financial means or face competition or financial penalties (UEFA, 2012). In addition, UEFA also introduced squad size restrictions, limiting the number of players' per team to 25 players', with an unlimited number of players' under the age of 21 years (UEFA, 2012). EPL clubs also agreed upon the introduction of a 'home-grown' player quota that ensures 8 of the 25 player squad have been registered with a club affiliated to the Football Association or the Football Association of Wales for a period, continuous or not, of three entire seasons or 36 months prior to the players` 21st birthday (or the end of the Season during which he turns 21). Although, anecdotal evidence suggests that this ruling is somewhat undermined by clubs who buy and/or import young foreign players who are then classified as 'home-grown' after the aforementioned 36 months period has past. However, since the introduction of this quota, Greg Dyke (Football Association Chairman 2013-2016) proposed that there should be a reduction in the maximum number of 'non-home-grown' players' permitted in a soccer clubs' first team squad of 25 from 17 to 13, phased over four years from 2016. This would have the accumulative effect of ensuring that in a squad of 25, 12 players' would have to be 'home-grown' (The Football Association, 2014)

Such legislation has seemingly put emphasis on UK professional soccer clubs to unearth talented young players' from within their own academy systems, in an attempt to promote 'home-grown' talent to compete at a senior level soccer and reduce club financial outgoings on imported players'. Thus, emphasising the necessity for domestic professional soccer clubs to install adequate youth development centre facilities that support the vision and drive of the clubs senior teams.

In a timely response to UEFA`s legislation, the EPL introduced the Elite Player Performance Plan (EPPP) (The English Premier League, 2011). The EPPP was designed to independently audit each elite youth (players' aged 5 to 23 years) soccer development centre attached to an EPL or Football League club. The broad aim of the EPPP is to effectively monitor each elite youth soccer development centre (UK soccer academy or centre of excellence partaking within the EPPP) and assess if they meet the examined components that are considered as 'good practice' by the EPL. As part of the EPPP, each development centre is awarded a category rating from 1 to 3 (one being the most elite according to EPPP guidelines), accompanied with financial incentive that reflects the development centres grading (The English Premier League, 2011). Seemingly, the EPPP was introduced by the English soccer governing bodies to create a structured set of national guidelines that detail best practice for the discrete components of elite youth soccer player development that includes education, coaching, welfare, talent identification, sport science and medicine (The English Premier League, 2011). The EPPP legislation has provided focus for elite youth soccer development centres to install dedicated support frameworks that specialise in the physical, technical, psychological and social development of young elite soccer players' that will permit the advancement of a talent development (TD) philosophy.

Traditionally, TD frameworks and philosophy have focussed upon discrete aspects of player performance and development such as technical (Valente dos-Santos, Coelho-e-Silva, et al., 2012), physiological (Gonaus & Müller, 2012), psychological (Morris, 2000), sociological

(Mills, Butt, Maynard, & Harwood, 2012), cognitive (Davids, Lees, & Burwitz, 2000; Ljach, Witkowski, Gutnik, Samovarov, & Nash, 2012; Williams, 2000) and anthropometric (Reilly, Bangsbo, & Franks, 2000; Reilly, Williams, Nevill, & Franks, 2000). However, given the rise in club investment for specialised members of staff to work within development centres due to new legislation (such as the EPPP), elite youth soccer player practice and research has become increasingly more holistic in its approach to soccer TD (Reilly, Williams, et al., 2000; Unnithan, White, Georgiou, Iga, & Drust, 2012; Vaeyens et al., 2006; Vandendriessche et al., 2012). Soccer development programs now encompass a combination of the discrete components of player performance attributes (technique, physical fitness, anthropometry, and psycho-social) and are increasingly considerate of the interaction between these characteristics throughout the players' progression, encompassing biological maturity. The emergence of a holistic approach to soccer TD programmes has prompted much interest from researchers and soccer practitioners alike, examining the efficacy of monitoring player maturity status (Bouchard, Malina, Hollmann, & Leblanc, 1975; Deprez et al., 2013; Deprez, Fransen, et al., 2014; Deprez, Valente-dos-Santos, et al., 2014; Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004; Malina et al., 2000; Philippaerts et al., 2006; Vaeyens et al., 2006) and the impact that differences between player decimal age, maturity and birth date distribution across the selection year have on specific soccer performance attributes and selection criteria.

Consideration of player maturity during initial talent identification and continued talent development player assessment has been widely reported in the literature (Philippaerts et al., 2006; Vaeyens, Lenoir, Williams, & Philippaerts, 2008; Vaeyens et al., 2006). The literature suggests that the inclusion of a measure of maturity is justified, given that the early exposure to advanced normative growth curves are associated to performance related advantages attributed to early maturing players' which may impede the accurate assessment of equally talented but less mature young soccer players' (Buchheit, Mendez-Villanueva, Simpson, & Bourdon, 2010a; Mendez-Villanueva et al., 2010; Philippaerts et al., 2006). In addition, the advanced exposure to normative growth curves of early maturing soccer players' are considered as a primary contributing factor for the maturation-selection hypothesis (Cobley, Baker, Wattie, & McKenna, 2009; Helsen, Van Winckel, & Williams, 2005), that witnesses the selection phenomena of players' who possesses superior maturity related anthropometric and physical fitness characteristics for soccer talent development programs (Carling, Le Gall, Reilly, & Williams, 2009; Deprez, Fransen, et al., 2014; Malina et al., 2000).

Such selection biases are considered a large contributing factor of the relative age effect (RAE) phenomena (Cobley et al., 2009; Helsen et al., 2005) that systematically discriminates against the selection of relatively younger players who are born at the end of the selection year, when categorised in to chronological playing age groups. Consequently, the EPPP mandates soccer development centres to systematically monitor player anthropometric and physical fitness characteristics across the 'Foundation' (Under [U]5 to U11), 'Youth' (U12 to U16) and 'Professional' (U17 to U21) stages of development (The English Premier League, 2011), each trimester of the soccer season using a standardised battery of field-tests (The English Premier League, 2011). In addition, the EPPP directs that TD practitioners use a predicative equation that assesses the interaction between the somatic and anthropometric (stature, seated height, and leg length) characteristics of the players (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002) and serves as an indirect measure of assessing player maturity during the 'Youth' and 'Professional' development stages only. Such EPPP legislation allows development centres and league governing bodies to effectively track the development of their players' relative to their maturity status, decimal age groups and primary playing position against a national database (The English Premier League, 2011). That said, a second somatic based method for assessing player maturity exists which is capable of predicting a young players adult height using cumulative height velocity curves to an accuracy of ±5.35 cm (Sherar, Mirwald, Baxter-Jones, & Thomis, 2005). However, it might be postulated that the EPPP`s mandate to evaluate player maturity using the Mirwald et al. (2002) is justified given that the Sherar et al. (2005) predictive model might in fact encourage the premature and systematic discrimination of players for development programs based upon predicted adult height values rather than technical prowess *per se.*

Systematic monitoring of player somatic maturity and physical fitness attributes are integral to the successful development of a detailed portfolio documenting progress throughout the EPPP relative to their specific playing position. Given that playing positions such as goalkeeper and defenders have been shown to be characterised by specific anthropometric and maturity characteristics, and that midfield players' by specific physical fitness attributes (Deprez, Fransen, et al., 2014; Gil, Gil, Ruiz, Irazusta, & Irazusta, 2007), consideration of these traits by TD practitioners are of relevance in order to inform selection policy. However, only a limited number of studies have explicitly examined if enhancements in maturity related physical phenotypes of relatively older elite youth players' (Carling et al., 2009; Deprez, Vaeyens, Coutts, Lenoir, & Philippaerts, 2012; Malina, Ribeiro, Aroso, & Cumming, 2007) bias the selection (Vandendriessche et al., 2012), deselection (Helsen, Starkes, & Van Winckel, 1999) and role allocation (Romann & Fuchslocher, 2013) of these players', with no studies having examined such selection hypotheses using UK elite youth soccer players'. In addition, inferences made in many previous research studies are limited to reflect the talent identification philosophies of few (≤ 2) domestic (Deprez et al., 2013; Deprez, Fransen, et al., 2014; Hirose, 2009) and international development centres (Carling et al., 2009). Therefore, the extent of how the maturation-selection hypothesis and RAE might influence the selection and role allocation of young soccer players in the UK (and how this might compare to other countries) largely remains unresolved. Therefore, given the absence of such previous research, the general aim of this thesis was to examine the relationships between relative age, maturity status, physical phenotypes and playing position within a broad sample of elite youth soccer players' as they develop and navigate the EPPP that best represents UK development programs.

To achieve this, the test-retest reliability of a standardised battery of anthropometric and physical fitness field-tests in a program adopted by 20 English professional soccer development centres will need to be determined. Establishing the smallest worthwhile changes for each field test in order to accurately monitor player progression throughout the development pathway. In addition to this, this thesis sought to examine the presence and magnitude of the RAE discriminated by days and quartiles of the selection in each annual age group and to assess the relationships between relative age, maturity status, anthropometric and physical fitness characteristics. In the absence of published literature, this thesis will also monitor the evolution of positional specific differences of UK elite youth soccer players relative to decimal age and maturity throughout the EPPP pathway. This was achieved by assessing the differences in relative age, anthropometry, maturity status, and physical fitness attributes associated with positional role allocation throughout the EPPP 'Youth' and 'Professional' phases of development. Lastly, this thesis attempted to provide insight for elite youth soccer practitioners regarding the physical and anthropometric development trajectories of players' across the biological maturity continuum. This was achieved by assessing the development tempo of anthropometric and physical fitness characteristics relative to their chronological and biological maturity; providing insight for youth soccer practitioners regarding the future physical and anthropometric development trajectories of players' and permitting a more considered approach to current TD policies in elite youth soccer in the UK.

Chapter 2. Review of Literature.

2.1 The Elite Player Performance Plan

The following review of literature is 'narrative' in design (Boland, Cherry, & Dickson, 2013), whereby it has analysed pertinent literature relating to the physical and anthropometrical development of elite youth soccer players according to their relative age and maturity status in order to identify gaps within current player (de)selection and development knowledge.

The Financial Fair Play regulation (UEFA, 2012) introduced by the governing body for soccer in Europe (UEFA), dictates that all European professional soccer clubs operate within their financial means. To comply with this ruling, a number of professional domestic clubs and league governing bodies have invested in the improvement of TD processes of 'home-grown' talented young soccer players'. The English Premier League (EPL) introduced the EPPP (The English Premier League, 2011), seemingly with the broad aim to reduce financial expenditure on player imports at the domestic level, and to expand the pool of talented players' available for international representation. Designed as longitudinal development plan, the EPPP routinely audits each development centre associated within a professional soccer club, categorising them either 1 to 3 (1 being most elite) based upon the provision of coaching, training facilities, and medical resources (The English Premier League, 2011). The EPPP`s vision for youth development is centred on the ambition to enable English soccer to create a world leading academy system that serves to provide more and better 'home-grown' players' and increase the efficiency of youth development investment in the UK (The English Premier League, 2011).

Largely based upon the Football Associations 'Four Corner Model' for long-term player development (The Football Association, 2010), the EPPP encourages soccer development centres to apply their own bespoke, multi-disciplinary approach to performance planning, largely based upon frameworks outlined for the coaching, education, games and player support programmes within the EPPP (The English Premier League, 2011). As part of the coaching programme, the sports science and medicine programmes are an inter-disciplinary frameworks comprised of sport science, medicine, physiotherapy and match analysis services (The English

Premier League, 2011). The programme contributes to the long-term development of players', creating an environment that nurtures talent and systematically converts development centre players' into professional players' capable of playing first team soccer at the club that develops them (The English Premier League, 2011). The Sports Science and Medicine programme of the EPPP mandates the systematic monitoring of player anthropometric, physical fitness and biological maturity development using a standardised battery of field-tests each trimester of the domestic soccer season (1st September to August 31st) as players' navigate the performance pathway through the 'Youth' (U12 to U16) and 'Professional' (U17 to U21) phases of development (The English Premier League, 2011). With the complex and multifaceted nature of elite youth soccer player physical development in mind, this thesis will now introduce the literature pertaining to the assessment of player maturity within an applied setting and will examine and discuss how such measures might influence the physical development and selection of players across the EPPP.

2.2 Introduction to Monitoring Elite Youth Soccer Player Development

The efficacy of the EPPP to provide more and better 'home-grown' soccer players' is in part reliant on the effectiveness of the Sports Science and Medicine programme to assist the identification and physical development of young talented soccer players'. Outlined in the Sports Science and Medicine Programme (The English Premier League, 2011), the EPPP dictates the systematic and controlled monitoring of players' anthropometric, physical fitness and biological maturity status using a standardised battery of field-tests each trimester of the domestic soccer season as players' navigate the performance pathway. It is assumed that the systematic assessment of player development will provide TD practitioners (and fitness coaches) with objective anthropometric and physical fitness data relative to each players' decimal age, maturity and playing position. However, to ensure that field test data accurately reflects the performance development or growth of each player, it is essential that the suitability, validity and reliability of each component of the implemented field test battery are considered.

The phrase ‘criterion test’ often refers to a test in which an individual’s score or performance is compared to a measure that has previously been established as being valid and reliable (Kent, 2006). However, growth, maturity and physical fitness criterion tests are often performed in controlled laboratory conditions that require use of specialised equipment that are costly and laborious within team-based sports, such as soccer. Therefore, given their ease of administration and enhanced ecological validity (Hopkins, Hawley, & Burke, 1999), TD practitioners in team sport (and the EPPP) often elect to administer field test equivalents of laboratory based testing protocols for the collection of player physical fitness, growth and maturity data within UK development centres (The English Premier League, 2011).

2.2.1 Monitoring the Physical Fitness Characteristics of Elite Youth Soccer Players’

Soccer match-play is characterized by players performing high intensity, intermittent match activity, interspersed by periods of low intensity exertion lasting 90-minutes that taxes both the aerobic and anaerobic energy systems (Di Salvo et al., 2007; Mohr, Krustrup, & Bangsbo, 2003). In addition to technical ability, it might be argued that player physical fitness attributes are also considered as a major contributory factor to soccer players’ ability to successfully compete at both recreationally and elite levels. Match-play time motion analysis data reports that senior elite level soccer players’ cover a mean ~11 km per match (Di Salvo et al., 2007), whilst their junior counterparts (U13 to U18) cover 7 to 9 km (Buchheit et al., 2010a). This provides evidence to support the notion that soccer match-play running performance is affected by age, throughout the youth phases of player development (Mendez-Villanueva, Buchheit, Simpson, & Bourdon, 2012). However, when discriminated by playing position, central (CM) and lateral midfield (LM) players’ cover the greatest distance in both senior (CM:

~12 km; LM; ~12 km (Di Salvo et al., 2007)) and youth (CM: ~9 km; LM:~8 km (Mendez-Villanueva et al., 2012)) cohorts, performing greater volumes of high intensity (>13 $km.h^{-1}$) running than any other playing position (Buchheit et al., 2010a; Di Salvo et al., 2007). That being said, of the senior outfield players', defenders perform a greater number of utility movements (lateral, diagonal and backwards) (Bloomfield, Polman, & O'Donoghue, 2007). These differences in match-play activities are possibly reflected within each individual players' physical fitness profile, with midfield players' having the greatest aerobic capacity, whilst attacking players' have a greater anaerobic capacity (Buchheit et al., 2010a; Deprez, Fransen, et al., 2014). Given the complex nature of physical performance coupled with the between playing position and age variability in match-play activity, it is natural that a carefully selected battery of physical fitness field-tests are necessary to accurately evaluate current soccer player physical fitness status, monitor development and inform athletic prescription to optimise gains to physical training. Therefore, this thesis will now introduce and discuss the various methods that can be used to evaluate the different components of player physical fitness and the purpose of each test in relation to the general aims if the thesis outlined in **Chapter 1, Section 1.1**.

2.2.2 Monitoring Lower Limb Power Output of Elite Youth Soccer Players'

A soccer player's ability to generate muscular power to jump vertically is of importance for players' to successfully compete with opponents in aerial duels during match-play and training (Stølen, Chamari, Castagna, & Wisløff, 2005). Although both the Wingate (Bar-Or, 1987; Inbar, Bar-Or, & Skinner, 1996) and standing broad-jump (Castro-Piñero et al., 2010) tests have been identified as valid and reliable measures of lower limb power, it might be argued that the vertical counter-movement jump (CMJ) is more representative of the jumping movement patterns typically performed within soccer match-play and therefore possesses superior ecological validity. The CMJ test is a well-established method for soccer practitioners to isolate and assess lower limb muscular power (Lees, Vanrenterghem, & De Clercq, 2004) (Stewart, 2002; Winter, Jones, Davison, Bromley, & Mercer, 2006). Jump heights using the CMJ method for Belgian (Deprez, Fransen, et al., 2014) (U9 to U19), English (U9 to 18) (Hulse et al., 2012), Qatari (U13 to 18) (Buchheit et al., 2010a), and Portuguese elite youth (U13 to U15) (Malina et al., 2000) soccer players' have been reported to be between 19.5 to 40.2 cm. Typically unavailable to many soccer practitioners due to cost and situational constraints, digital force plate technology that uses the impulse method (Street, McMillan, Board, Rasmussen, & Heneghan, 2001) for determining jump height is often considered as the criterion method for assessing CMJ performance. However, given its reliability (coefficient of variation [CV] = 12.9 to 14.5%) and validity (r = 0.63 to 0.83) (Lloyd, Oliver, Hughes, & Williams, 2009)), the application of digital contact mats are common place within both professional and development soccer environments (Boone, Vaeyens, Steyaert, Bossche, & Bourgois, 2012; Carling et al., 2009; Deprez, Fransen, et al., 2014; Deprez, Fransen, Lenoir, Philippaerts, & Vaeyens, 2015). Therefore, such evidence would imply that the inclusion of digital contact mat technology for the assessment of CMJ performance is appropriate for deployment within a national benchmarking scheme to quantify the physical development of a broad sample of elite youth soccer players residing in multiple soccer development centres across the UK.

2.2.3 Monitoring Maximum Sprint Speed of Elite Youth Soccer Players'

The ability to accelerate and perform maximal sprint speeds (MSS) are often considered as fundamental fitness attributes to succeed in significant passages of competitive match-play, such as goal scoring opportunities and match saving tackles. Therefore it is unsurprising that, attacking forward (FWD) players' are typically the fastest players' in senior elite (Di Salvo, Pigozzi, González-Haro, Laughlin, & De Witt, 2013) and youth (Mendez-Villanueva et al., 2012) soccer. With such between playing position, discriminatory characteristics in mind, it is intuitive for the EPPP and TD practitioners to include a measure of acceleration and estimated MSS within their TD criteria and long-term athletic development portfolios. Although elite soccer players' are unlikely to sprint distances greater than 20 m (Andrzejewski, Chmura, Pluta, Strzelczyk, & Kasprzak, 2013), it is common place for athletic practitioners (Stewart, 2002; Winter et al., 2006) and researchers (Hulse et al., 2012; Mendez-Villanueva et al., 2010; Mendez-Villanueva et al., 2012; Strudwick & Doran, 2002) to estimate MSS over longer distances (20 to 50 m) than typically performed in match-play. This is likely to ensure that the information provided during the test reflects the players' true MSS rather than short distance sprint speed (or acceleration). Estimated acceleration and MSS are often established using digital timing lights placed at 0, 5, 10, 20, 30 and 40m splits in order to ascertain players' mean acceleration and sprint times across a known distance (Stewart, 2002; Winter et al., 2006). Such procedures have returned good test-retest reliability for 10 m (CV: 1.7 to 1.9 %; r = 0.86 to 0.96) and 20 m (CV: 1.5 to 1.6%; r = 0.90 to 0.95), and have been used to estimate MSS (10 m: 5.10 to 6.00 $m.s^{-1}$; 20 m: 5.64 to 6.84 $m.s^{-1}$) for elite youth (U9 to U18) soccer players' (Hulse et al., 2012). However, older (U14 to U18) elite youth soccer players are likely to achieve their MSS between 30 to 40 m in comparison to their younger (U12 to U13) counterparts (Buchheit, Simpson, Peltola, & Mendez-Villanueva, 2012). In light of this, short distance (20 m) maximal sprint tests outlined within the EPPP (The English Premier League, 2011) are likely justified given the situational constraints (i.e. size of indoor facilities) within many UK soccer academies, subsequently restricting the evaluation of sprint performance according to sprint time rather that speed *per se*. Therefore, although reliable and easy to administer, such field-tests are likely to be appropriate for use within in multiple elite youth soccer development centres to assess player acceleration and maximal sprint time only over shorter distances typically available within UK elite youth soccer academies.

2.2.4 Monitoring Agility of Elite Youth Soccer Players'

Agility can be defined as the ability to change body position rapidly and accurately without losing balance (Kent, 2006). A soccer players' ability to change direction at speed can be considered a crucial attribute in order for them to successfully compete at an elite level during offensive and defensive soccer match-play scenarios, often characterising forward and midfield playing positions (Gil et al., 2007). In addition, motor coordination characteristics might discriminate between players who are selected for talent development programs versus those who are deselected (Deprez, Fransen, et al., 2015). However, such discriminatory qualities are transient, fading as players reach the professional stage of their development (~ U17 to 18) (Deprez, Fransen, et al., 2015). Although there is no recognised criterion measure for assessing player agility, agility field-tests (Balsom, 1994; Semenick, 1990; Stewart, 2002) are often included within elite youth soccer TD criteria (Deprez, Fransen, et al., 2014; Reilly, Williams, et al., 2000; Vaeyens et al., 2006). The T-Test (Semenick, 1990) measures a players' ability to change direction at speed, requiring the player to navigate a 'T' shaped course under timed conditions. Using digital timing gates, the T-Test has reported good test-retest reliability (r = 0.94 to 0.98) among collegiate men (Pauole, Madole, Garhammer, Lacourse, & Rozenek, 2000) and has frequently been implemented to monitor agility performance within elite youth soccer populations (Deprez, Fransen, et al., 2014; Vaeyens et al., 2006). That being said, there are many other field-tests such as the modified 'Balsom Run' (Balsom, 1994), the 'M' run (Winter et al., 2006) and the 5-0-5 Test (Draper & Lancaster, 1985) that might also be considered appropriate to measure a players' agility.

The 'Balsom Run' (Balsom, 1994), requires players to perform a timed 23 m course which demands that players' perform a number of short accelerations and decelerations around a slalom of 5 cones that involves two recovery sprints whilst the athlete navigates the course. Similarly, the 'M' run is a timed slalom course in the shape of an 'M' (Winter et al., 2006), with cones placed at 15 and 11 m apart at an angle of 60° to form the 'M' shape. Although both the 'Balsom Run' (Balsom, 1994) and 'M' run (Winter et al., 2006) tax an athletes ability to accelerate, decelerate and change direction at speed, the tests seemingly neglects to assess utility movement patterns such as side shuffling and backwards running typically performed during soccer match-play (Bloomfield et al., 2007). In addition, to the authors' best knowledge there is no available data examining the short-term reliability of these tests. The 5-0-5 tests is a timed linear sprint course which measures a players ability to perform a 15 m sprint, decelerate and perform a return sprint, back toward the start point across the finish line situated 5 m away from the turning point. Given that the reliability of the 5-0-5 test to measure an athletes ability to decelerate and change direction (established during the turning phase of the test) is questionable (TE = 0.08 s, ICC = 0.05, CV = 39%), in comparison to the reliability data for the 5-0-5 in its entirety (SD = 0.15 s, TE = 0.07, ICC = 0.81, CV 2.8 %), it remains somewhat uncertain whether the 5-0-5 is reliable measure of agility or straight line running speed (Sayers & Kilip, 2010).

Considering its reliability and the required element for players' to perform straight-line accelerations accompanied by utility movement patterns (backwards running and side-stepping) commonly utilised within soccer match-play (Bloomfield et al., 2007), the T-Test has been selected by some UK academies to measure players' agility and will therefore be administered within this thesis.

2.2.5 Monitoring Endurance Capacity of Elite Youth Soccer Players'

It is well established that physical fitness characteristics of elite senior (Boone et al., 2012; Di Salvo et al., 2007) and youth (Deprez, Fransen, et al., 2014; Mendez-Villanueva et al., 2012) soccer players' are often regarded as a function of playing position. Therefore, given their tactical roles, midfield players' are often required to run the length of the soccer pitch multiple times, subsequently performing the greatest total distance during match-play (Mendez-Villanueva et al., 2012). With this in mind, it is of interest for TD practitioners to use fitness tests to identify players' who have the potential to succeed in such playing positions. Therefore, it is pertinent for TD practitioners to examine a players' maximal aerobic capacity ($\dot{V}O_2$ max), defined as the maximum amount of oxygen that a person can extract from the atmosphere and then transport and use in tissues in one minute (Kent, 2006). This is often established during treadmill or cycle ergometer exercise modalities, using open-circuit indirect calorimetry. The $\dot{V}O_2$ max test measures the pulmonary ventilation of a subject and compares the oxygen and carbon dioxide concentrations of both inspired and expired air as the primary indicator of aerobic metabolism (Stewart, 2002; Winter et al., 2006). Using indirect colorimetry, a comprehensive review article by Stølen et al. (2005), showed that $\dot{V}O_2$ max values determined for senior, elite male out-field soccer players' ranged from 51 to 74 $mL \cdot kg^{-1} \cdot min^{-1}$. Whist their junior counterparts (U8 to U19) tended to have lower range of criterion values (52 to 63 $mL \cdot kg^{-1} \cdot min^{-1}$ (Stølen et al., 2005)). Although, online indirect calorimetry has been shown to have excellent reproducibility (< 1.4 $mL \cdot kg^{-1} \cdot min^{-1}$), reporting low measurement error (± 2.95 $mL \cdot kg^{-1} \cdot min^{-1}$) (Weltman et al., 1990), the criteria set for the determination of $\dot{V}O_2$ max (Midgley, McNaughton, Polman, & Marchant, 2007) requires costly, specialist laboratory equipment that isn't feasible for many elite youth soccer development centres. Therefore, alternatives such as field based incremental running field-tests (Krustrup et al., 2003; Leger & Lambert, 1982; Uger & Boucher, 1980) have been used to estimate intermittent endurance capacity (Krustrup et al., 2003) and estimated running velocity of the last completed, one minute stage, commonly known as maximum aerobic speed (MAS) (Berthoin et al., 1994; Leger & Lambert, 1982; Mendez-Villanueva et al., 2010).

The Université Montreal Track Test (UMTT) (Uger & Boucher, 1980) is a continuous, multistage, maximal running field test used to estimate $\dot{V}O_2$ max and MAS based on walking and running energy cost assumptions (Shephard, 1969). The UMTT requires the use of a standardised, continuous running track (typically 400 m), where markers are placed at each quarter sections (100 m increments) of the track (Uger & Boucher, 1980). Emitted sound signals act as a pacer for players' to travel around the track, passing through the quarter sections in time with an emitted sound signal. The frequency of the sound signals are increased, commencing at the equivalent pacing of 8 $km.h^{-1}$ and increasing by 0.5 $km.h^{-1}$ each minute until exhaustion. The UMTT requires players' to continue running until volitional exhaustion, whereby the total distance travelled by each player is used as an index for predicting $\dot{V}O_2$ max (Uger & Boucher, 1980) and MAS. Previous literature that has sampled elite youth soccer player's (11.5 to 17.8 years) has shown that players' typically cover ~2140 to 2340 m (MAS: ~14.5 $km.h^{-1}$) during the UMTT (Mendez-Villanueva et al., 2010). The UMTT has also demonstrated good reliability ($r = 0.66$; ± 4.53 $mL \cdot kg^{-1} \cdot min^{-1}$) (Uger & Boucher, 1980) and is a valid predictor of $\dot{V}O_2$ max, reporting similar $\dot{V}O_2$ max values to criterion treadmill protocols (UMTT: 56.8 ± 5.8 $ml/kg.min^{-1}$; treadmill $\dot{V}O_2$ max: 56.8 ± 7.1 $ml/kg.min^{-1}$). The robustness of the UMTT has offered researchers opportunity to modify the test (VAMEVAL Mendez-Villanueva et al. (2010)) for use with specific athletic populations, such as soccer players' (Mendez-Villanueva et al., 2010; Mendez-Villanueva et al., 2012). Although a valid and reliable predictor of $\dot{V}O_2$ max, the UMTT (and VAMEVAL) field test may not be suitable for use within multiple, elite youth soccer development centres given that many development centres will not have access to a suitable (400 m) running track to perform the test on.

Designed to reflect the intermittent nature of physical activity during soccer match-play, the Yo-Yo Intermittent Recovery Test (YYIRT) Level 1 (Krustrup et al., 2003), is an incremental running field test, interspersed by short periods of passive recovery that can be used to estimate $\dot{V}O_2$ max and determine an athlete's ability to recover from repeated bouts of exercise (Bangsbo, Iaia, & Krustrup, 2008; Stewart, 2002). The YYIRT requires players' to perform repeated 20 m shuttles, paced by an emitted audio signal that becomes progressively more frequent as the test continues (Krustrup et al., 2003; Stewart, 2002). The test is stopped when the tested players can no longer maintain the pace set by the audio signals and then total distance covered during the test can be used as an index for the estimation of $\dot{V}O_2$ max (Krustrup et al., 2003; Stewart, 2002). However, given that the composite nature of the YYIRT (demonstrated by its moderate association: *r* = 0.57; *P*= 0.003 to CMJ (Castagna, Impellizzeri, Chamari, Carlomagno, & Rampinini, 2006)) to be representative of the intermittent nature of soccer match-play activity (Bangsbo et al., 2008), players' are required to perform a 10 s active recovery by jogging a 5 m shuttle during each repetition and therefore taxing both aerobic and anaerobic energy systems. This may contribute to MAS being under-estimated (~3.0 $km.h^{-1}$) in comparison to the UMTT (VAMEVAL) during higher speeds (>16.3 $km.h^{-1}$) and vice versa during lower speeds (<16.3 $km.h^{-1}$) (Dupont et al., 2010) and further demonstrating that the YYIRT measures intermittent exercise capacity rather than MAS *per se.* Normative YYIRT test data reports that U17 national level soccer players' typically cover 2,327 m (Stewart, 2002), whilst their elite youth club counterparts cover 2064, 1649, 1199, 802, 596m at U17, U15, U13, U11 and U9 levels of representation respectively (Deprez, Fransen, et al., 2014). The YYIRT has also reported excellent reliability (r = 0.98; CV = 4.9 %) and moderate criterion-validity, correlating (r = 0.71) with incremental treadmill $\dot{V}O_2$ max values (Krustrup et al., 2003). Such evidence might justify fitness coaches' use of the YYIRT to determine soccer specific estimations of player endurance capacity. However, although the YYIRT is specific to soccer in its design (Bangsbo et al., 2008), it might be argued that the main outcome measure (total distance covered) of the YYIRT is in fact related to a number physical fitness (lower-limb power (Castagna et al., 2006) maximal oxygen uptake (Bangsbo et al., 2008)) and metabolic characteristics (Rampinini et al., 2010)) and fails to provide a clear measure of endurance capacity (Dupont et al., 2010). The multifaceted outcome of the YYIRT somewhat restricts the inferences that can be specifically made pertaining to players endurance capacity and subsequent training recommendations that can be made by soccer practitioners (Mendez-

Villanueva & Buchheit, 2013), limiting its effectiveness as a field test to evaluate absolute endurance capacity of players.

The Multi-Stage Fitness Test (MSFT) (Leger & Lambert, 1982) (commonly referred to as the 'bleep test') is a 20 m incremental running shuttle test that has been used to assess soccer player endurance capacity in the form of total distance covered during the MSFT (Lovell et al., 2015). Like other tests (YYIRT and 5-0-5), the MSFT permits multiple groups (10 to 20) of players' to complete the test at any one time, demanding that players' perform 20 m shuttles with all players' touching each base-line in unison signified by an emitted 'bleep' from an audio CD (Leger & Lambert, 1982). Unlike the YYIRT, there are no rest periods between shuttles and therefore, MSFT exercise is more continuous in nature. The frequency of the emitted 'bleep' is increased so that player running speed increases by approximately ~3 $km.h^{-1}$ every 2 minutes, commencing at 6.0 $km.h^{-1}$ (Leger & Lambert, 1982). The test stops when the player fails to complete the shuttle in the allotted time and the last fully completed shuttle (or MAS and total distance covered) is used as an index for predicting $\dot{V}O_2$ max. Previous literature reveals that elite soccer players' have established estimated $\dot{V}O_2$ max of 56.4 to 61.4 $ml/kg.min^{-1}$ (Davis, Brewer, & Atkin, 1992; Strudwick & Doran, 2002) with the total distance covered in the test being 1,653 ± 367 m (Castagna, Manzi, Impellizzeri, Weston, & Alvarez, 2010). Early MSFT literature has returned good reproducibility for children (intraclass correlation coefficients (ICC) = 0.89) and adults (ICC = 0.95), showing that the MSFT to be a reliable measure of $\dot{V}O_2$ max (± 4.4 $mL \cdot kg^{-1} \cdot min^{-1}$).

There are some limitations for the practical application of the MSFT to assess endurance capacity of players. Research literature has established that using MAS as the primary outcome measure to assess endurance capacity may indeed underestimate MAS by ~3 $km.h^{-1}$ during the MSFT (Berthoin et al., 1994). This is likely caused by the additional metabolic cost due to the multiple accelerations, decelerations and changes of direction required for 20 m shuttle running. Therefore, alternative outcome measures, such as total distance might be considered as an index of endurance capacity (Lovell et al., 2015). Therefore, given its reliability and ability to estimate the endurance capacity of an entire squad of soccer players' simultaneously in the absence of expensive equipment and facilities, the MSFT is seemingly an appropriate field test to administer within many elite youth soccer development centres on the proviso that its limitations are considered when deliberating player data.

Although laboratory based measures for the determination $\dot{V}O_2$ max have been successfully implemented in applied soccer environments (Hunter et al., 2014; Lovell & Abt, 2012), many elite youth soccer development centres do not have access to such specialised testing equipment and qualified test administrators. Therefore, given that the UMTT requires the use of a 400 m running track (largely unavailable too many UK soccer academies) and that the YYIRT likely measures both a combination of soccer specific fitness attributes (anaerobic, acceleration, leg strength (Castagna et al., 2006) and underestimates MAS (Dupont et al., 2010) (similarly to the MSFT (Berthoin et al., 1994)), this thesis elected to use the MSFT given that it exclusively estimates the aerobic capacity of multiple players ($n \leq 10$), using facilities (20 m track) typically available to all UK soccer academies.

2.4 Monitoring Anthropometric Characteristics of Elite Youth Soccer Players'

Anthropometry refers to the measurement of the size and proportions of the human body and is employed to monitor postnatal growth and development (Kent, 2006). Postnatal human growth can be summarised by dividing the growth of tissues and systems in to four categories (lymphoid, neural, genital and general) using Scammons curves of systematic growth (see **Figure 1** (Malina, Bouchard, & Bar-Or, 2004)). The 'genital' and 'lymphoid' traces describe the growth of sex characteristics and glands, whilst the 'neural' trace depicts the development of the brain and nervous system. The 'general' trace shows the development of the body as a whole, comprising of stature, body-mass, skeletal, muscular, respiratory and vascular system development (Malina, Bouchard, et al., 2004). Given that the over selection of relatively older elite youth soccer players for talent development programs has been attributed to such players' possessing superior physical and anthropometric characteristics (Carling et al., 2009; Deprez, Fransen, et al., 2014; Malina, Eisenmann, et al., 2004; Malina, Ribeiro, et al., 2007; Vaeyens et al., 2006), the 'general' development pathway might be of particular interest to soccer TD practitioners.

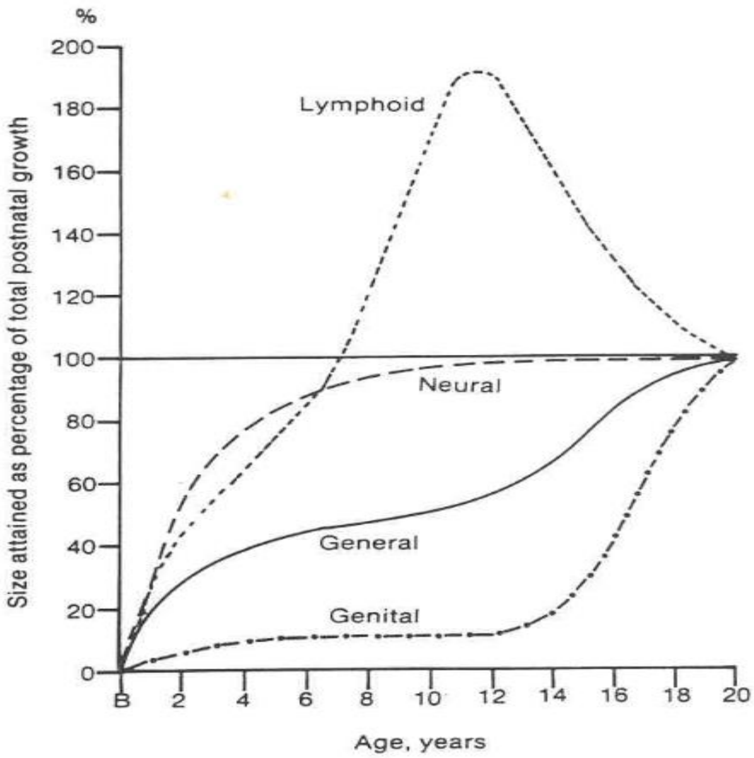


Figure 1. Scammons curves of systematic growth. Growth of each structure is expressed as a percentage of the total gain between birth and 20 years. Size at age 20 equals 100% on the vertical scale (Taken from Malina, Bouchard, et al. (2004)).

The sigmoid shape of the 'general' trace depicted in **Figure 1** shows four distinct phases of growth. 'Phase 1' during infancy and early childhood shows a period of rapid growth followed by 'Phase two' that shows steady and consistent growth during mid childhood to circa adolescence. 'Phase three' is depicted by rapid growth during adolescence and slowing thereafter during post adolescence until cessation in adulthood. Although Phase 1 of Scammons curve for general growth depicts rapid development, growth velocity curves for stature (cm·year^{-1}) and body-mass (kg·year^{-1}) in boys (see **Figure 2**) depict a deceleration phase across infancy (1 to 9 years) reaching its slowest rate of development before initiating peak height and weight velocities (PHV; PWV) across ages (~ 13 to 14 years) associated to adolescence (Tanner, Whitehouse, & Takaishi, 1966).

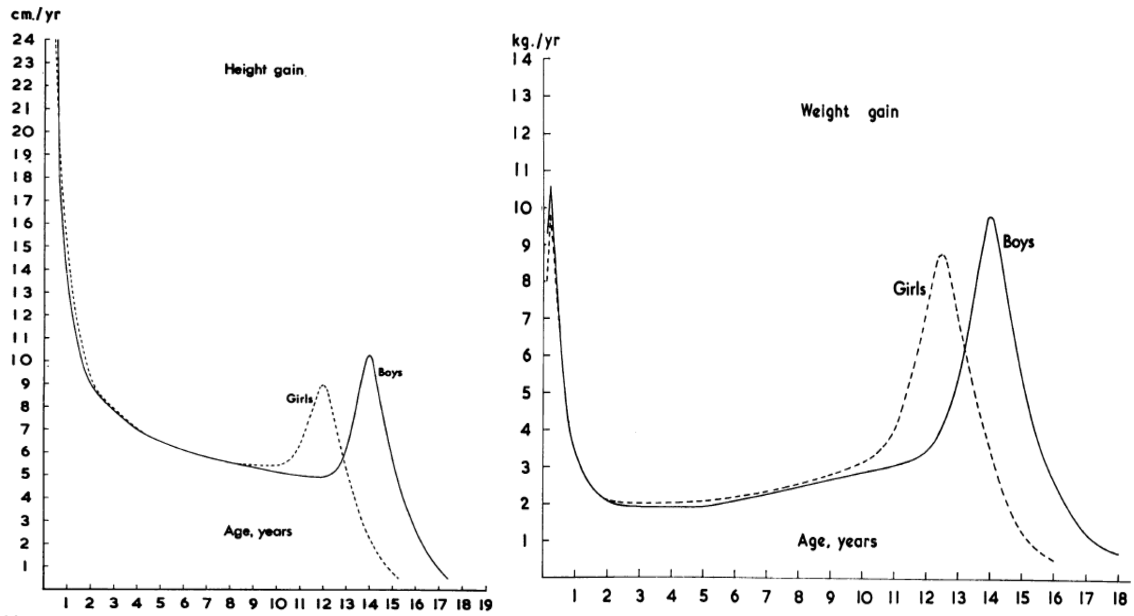


Figure 2. Typical individual velocity curves for supine stature (left) and body-mass (right) in boys and girls. These curves represent the velocity of the typical boy and girl at any given instant (Taken from Tanner et al. (1966))

Given that the anthropometric characteristics of elite youth soccer players' have been attributed to characterise the selection (Deprez, Fransen, et al., 2015) and playing position (Boone et al., 2012; Deprez, Fransen, et al., 2014) criteria of many professional soccer clubs, continuous monitoring of elite youth soccer players' growth is an obvious consideration. The ease of administration, permits soccer TD practitioners to regularly (weekly/monthly) monitor player stature and body-mass development using simple anthropometric tests that can be administered in field settings to track the tempo of player growth. According to guidelines outlined by the International Standards for Anthropometric Assessment (ISAK) (Stewart, Marfell-Jones, Olds, & Ridder, 2011), commonly regarded to as the “gold standard” for anthropometry, stature is defined as the perpendicular distance between the transverse planes of the vertex and the inferior aspect of the feet. Human stature is typically measured using a calibrated stadiometer, with the players’ shoeless feet together and heels touching the scale, whilst the head is positioned in the Frankfort plane to perform the stretch stature method of measurement to an accuracy of 0.1 cm (Stewart, 2002; Stewart et al., 2011; Winter et al., 2006). Dependent on the time of day the measurement is taken, circadian rhythm is responsible for up to a 1.1% (19.3 mm) fluctuation in overall stature across a 24 hour period, with 80% of overall stature loss occurring within the first 3 hours wakening (Reilly, Tyrell, & Troup, 1984). The reliability of such measures by a trained anthropometrist within a World Health Organisation study on measurement and standardization protocols reports that technical error in measurement to be 0.34 cm, with competent observers displaying 0.35 to 0.48 cm (de Onis, Onyango, Van den Broeck, Chumlea, & Martorell, 2004).

Similarly to stature, body-mass also exhibits diurnal variation of about 1 kg in children and 2 kg in adults, with the most stable measure being obtained in the morning having eaten 12 hours previously (Stewart et al., 2011). Wearing light clothes and without shoes, measures of body-mass are simply performed by weighing the player on calibrated counter-balance (if available) or digital scales to an accuracy of 0.1kg. In addition to monitoring the tempo of player growth, such anthropometric measures can be used in combination with players’ decimal age to estimate player somatic maturity (Mirwald et al., 2002).

2.5 Monitoring Maturity Status of Elite Youth Soccer Players'

Biological maturation is only achieved when complete development of all tissues, organs, and organ systems has been attained (Malina, Bouchard, et al., 2004). However, when working with children and adolescent populations in athletic development environments, the expression 'maturity' often refers to the stage of development that the athlete has attained in relation to their final adulthood status (Malina, Bouchard, et al., 2004; Malina et al., 2000). Children mature at a tempo that is individual to them and independent of the calendar and of decimal age groupings (U10`s, 11`s etc.) that are often used in sport (Malina, Bouchard, et al., 2004). As established in ice-hockey (Sherar, Baxter-Jones, Faulkner, & Russell, 2007), rugby, (Till, Cobley, O'Hara, Cooke, & Chapman, 2014; Till et al., 2011), gymnastics (Baxter-Jones, Helms, Maffulli, Baines-Preece, & Preece, 1995) and soccer (Malina et al., 2000), this can result in groups of young athletes having been categorised by decimal age displaying a range of biological maturity attainment established using skeletal (Greulich & Pyle, 1959; Tanner & Whitehouse, 1962), sexual (Leone & Comtois, 2007; Roche, Wellens, Attie, & Siervogel, 1995), and somatic maturity (Mirwald et al., 2002; Sherar et al., 2005) methods. Given that early maturing, elite youth soccer players are typically beneficiaries of anthropometric and performance related advantages associated to early exposures to normative growth curves (Buchheit et al., 2010a; Mendez-Villanueva et al., 2010; Philippaerts et al., 2006), national soccer directives (such as the EPPP (The English Premier League, 2011)) mandate the collection of player maturity data in order to effectively interpret and benchmark player development. In consideration of this, this thesis will now introduce and discuss the various methods of establishing player maturity.

2.5.1 Skeletal Maturity

Stages of skeletal maturity are primarily determined by assessing an X-ray or radiograph image of the wrist to assess bone development from initial ossification to adult formation (Malina, Bouchard, et al., 2004). Indicators of skeletal maturity provide three types of information: the initial formation of bone centres that indicate the replacement of cartilage to bone; the formation of bone shape and structure that are reflective of the adult form of the assessed bone; and the fusion of the epiphyses (end portion of the bone) with their diaphyses (mid-portion of the bone often referred to as the shaft) and the attainment of adult bone contours (Malina, Bouchard, et al., 2004). The Greulich-Pyle (Greulich & Pyle, 1959), Tanner-Whitehouse (Tanner, Healy, Goldstein, & Cameron, 2001) and the Fels methods (Roche, Chumlea, & Thissen, 1988) are the three most frequently implemented direct measures of assessing skeletal maturity via wrist X-rays because of the number of different types (carpals, scaphoid, ulna and radius) of bone available to view in the wrist (Bowden, 1976) (**Figure 4**). Each method ultimately provides an estimation of skeletal maturity in the form of skeletal age that is often presented relative to the child's decimal age. For instance, if a child who has a chronological age of 10.1 years but has a skeletal age of 12.1 years, this child will be considered to have a maturity offset (skeletal age – chronological age) of + 2.1 years and is advanced in terms of skeletal maturity (Malina, Bouchard, et al., 2004). However, conversely, if the child has a chronological age of 12.1 years but possesses a skeletal age of 10.1 years, this child will deemed as having a -2.1 years maturity offset and considered as having a delayed skeletal maturity status (Malina, Bouchard, et al., 2004).

2.5.2 Greulich-Pyle Assessment of Skeletal Maturity

Sometimes referred to as the Atlas or Inspectional method (Todd, 1937), the Greulich-Pyle method (Greulich & Pyle, 1959) demands the matching of a child's hand-wrist X-ray to a predetermined standardised plate of known child skeletal maturity at a specified decimal age (see **Figure 3**). The skeletal age of each bone visible in the hand-wrist X-ray is assessed and the median value is used to determine the child's overall skeletal age. Therefore, if a 9 year old child's hand-wrist X-ray closely represents the standardised plate of a 10 year old, then there skeletal age is classified as 10 years (Greulich & Pyle, 1959). This method for the determination of skeletal age has been shown to be reliable, reporting that the skeletal age for 654 children to be 2.2 months less (male: -1.5; female: -3.7 months) than children's decimal age and not subject to significant inter and intra-observer difference (Paxton, Lamont, & Stillwell, 2013). Although repeatable and quicker than other methods (King et al., 1994), research suggests that there is a large amount of variability when using Greulich-Pyle method to assess skeletal ages of children circa-adolescence, likely due to the atlas being developed for clinical practice, and reference values were based upon White American population in the1930s. Therefore, it might be considered that the atlas used within this method is no longer a representative comparison for the accurate assessment of skeletal age of children within diverse demographics of modern society (Tisè et al., 2011).

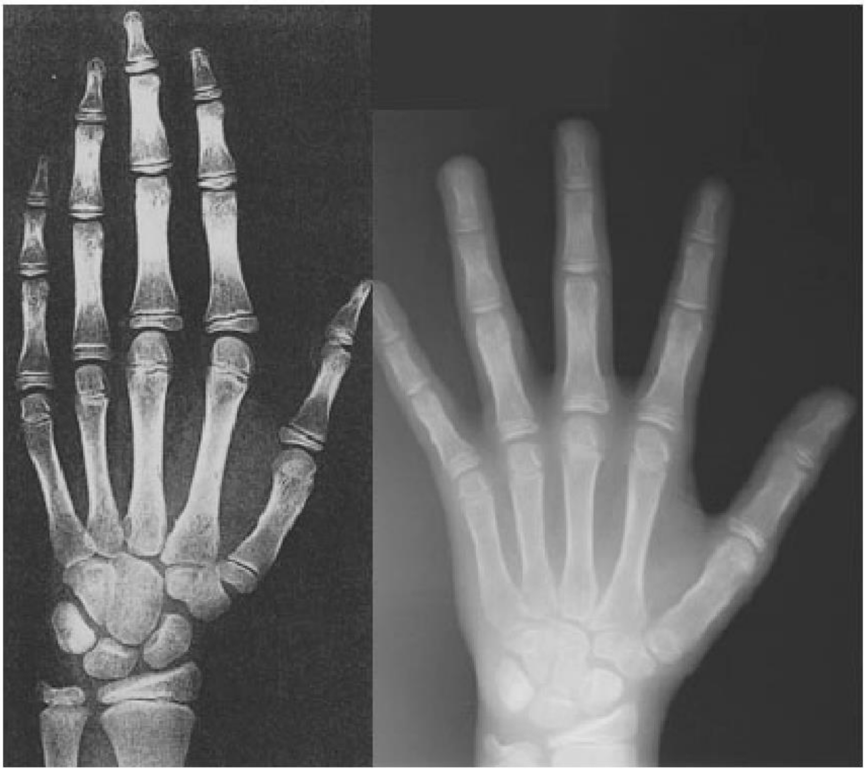


Figure 3. Comparison of a hand and wrist radiograph of a 10 year old girl (right) and the corresponding standardised plate (left) in the Greulich-Pyle atlas (Greulich & Pyle, 1959).

2.5.3 Tanner-Whitehouse Assessment of Skeletal Maturity

The Tanner-Whitehouse method was first established in 1966 (Tanner & Whitehouse, 1962) before being modified (TW2) in 1975 (Tanner et al., 1975), and again (TW3) in in 2001 (Tanner et al., 2001). Similar to the Greulich-Pyle method (Greulich & Pyle, 1959), the TW3 demands the use of X-ray to allow a trained assessor to match the ossification features of the radius, ulna, short-bones and carpals (see **Figure 4**) to specific written criteria for each stage of the bones development from birth through to complete maturity based on British, Belgian, Italian, Spanish, Argentinean, American and Japanese children (Malina, Bouchard, et al., 2004). The Tanner-Whitehouse method requires each bone to be scored and aggregated to provide a skeletal score ranging from zero (immaturity) to 1,000 (complete maturity). However, poor methodological execution, such as incorrect positioning of the hand when the radiograph is taken (Cox, 1996) have been shown to enhance the variance when determining skeletal age using the Tanner-Whitehouse method. This can lead to an inaccurate appearance of the epiphysis, making X-ray interpretation difficult and inconsistent between observers (Cox, 1996). Therefore, computer-aided estimations of skeletal age are becoming increasingly common for the determination of skeletal age when using either the Tanner-Whitehouse (Tanner et al., 2001) or Greulich-Pyle methods (Greulich & Pyle, 1959).

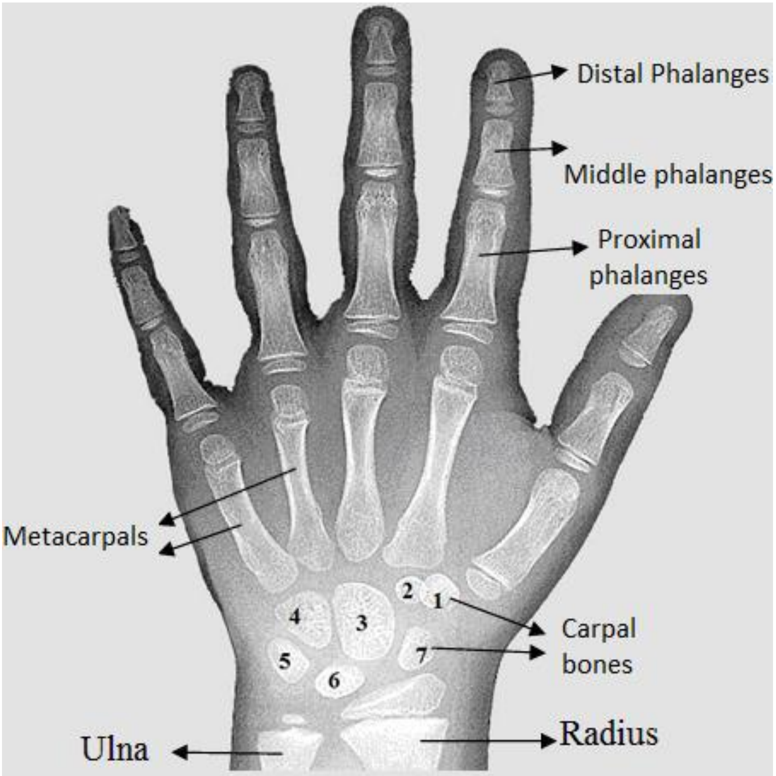


Figure 4. Radiograph of hand and wrist bones (Carpal bones: 1-Trapezium, 2 Trapezoid, 3-Capitate, 4-Hamate, 5-Triquetrum, 6-Lunate, 7-Scaphoid) used for Tanner-Whitehouse (Tanner et al., 2001) sourced from Aydoğdu and Başçiftçi (2014).

2.5.4 Fels Assessment of Skeletal Maturity

Developed using Central American children during the Fels Longitudinal study (Roche et al., 1988), the Fels method uses radiographs of the hand-wrist to assess skeletal maturity.

Skeletal maturity is graded by comparing the size and shape of individual carpals and their epiphyses, in addition to the corresponding diaphyses of the ulna and radius, and the metacarpals and phalanges of the first, third and fifth digits to a described criteria (Malina, Bouchard, et al., 2004; Roche et al., 1988). In addition, the ratio of the width of the epiphysis and metaphysis are calculated, and the grades and ratios are converted in to a measure of skeletal age (Malina, Bouchard, et al., 2004; Roche et al., 1988). Using odds-ratio based statistics, the most appropriate indicator of skeletal age for the child's decimal age is determined and used to calculate the skeletal age and associated standard error of the measure (Malina, Bouchard, et al., 2004; Roche et al., 1988). However, when compared to the TW3 (Tanner et al., 2001), the Fels method determined a group of elite youth soccer players' as having significantly younger skeletal age and their skeletal age was often in advance of their decimal age (Malina, Chamorro, Serratosa, & Morate, 2007). Such findings have implications for the use of establishing skeletal age within international sporting competition where athletes' decimal age may need to be verified before participation according to competition rules.

2.5.5 Application of Skeletal Maturity within Elite Youth Soccer:

Assessment of skeletal maturity is a well-established method of assessing biological maturity amongst pre-pubertal populations (Greulich & Pyle, 1959; Roche et al., 1988; Tanner et al., 2001). Such assessments have been implemented within elite youth soccer to detect the deliberate selection of over age players' to participate in younger age group categories in order to be beneficiaries of unfair physical advantage over their younger counterparts, commonly known as age fraud (Cryer, 2014). To regulate and control age fraud, the world governing body for soccer (The Fédération Internationale de Football Association [FIFA]) introduced magnetic resonance imaging (MRI) during 2009 under U17 soccer World Cup to verify player age. Subsequently, in 2013 the Nigerian U17 national team were discovered to have played a number of over-age players’ after having had mandatory MRI of their wrist plates. Such intervention and legislation are necessary given that the physical advantage associated to older players’ competing against their younger peers (Malina, Eisenmann, et al., 2004). Although some caution is warranted when using skeletal age to verify decimal age, as the Fels (Roche et al., 1988) has been shown to unfairly classify 16% (n = 36) of a U17 cohort as too old to qualify for their decimal age grouping. Consequently providing false evidence that could unfairly disqualify such players’ from competition (Malina, 2011). This is confounded further with the Tanner-Whitehouse (Tanner & Whitehouse, 1962) and Fels (Roche et al., 1988) method reporting different skeletal ages for the same cohort of elite youth soccer players’ with an increased number U15 boys being classified as more skeletally mature with the TW3 method than with the Fels (Malina, Chamorro, et al., 2007). That being said, skeletal maturity has been effectively applied to assess the associated development of anthropometric and physical characteristics of elite youth soccer players’ (Valente dos-Santos, Coelho-e-Silva, et al., 2012; Valente dos-Santos, Coelho Silva, et al., 2012).

Skeletal age assessments of elite youth soccer players’ have established that later skeletally maturing players’ are systematically discriminated against for soccer development programmes in favour of their more mature counterparts (Malina et al., 2000). Such selection bias are likely formed on the basis that these players typically possess inferior maturity related anthropometric and physical fitness characteristics in comparison to their skeletally more mature counterparts (Malina, Eisenmann, et al., 2004). Malina et al. (2000) showed that the relative number of U11 to U13 ‘late’ and ‘early’ skeletally maturing soccer players’ within elite youth soccer development centres to be equal (21%: n = 13). However, as decimal age and specialisation increased, less skeletally mature boys were systematically excluded and represented only 7% (n = 2) and 2% (n = 1) of the U13 to U14, and U15 to U16 cohorts, respectively (Malina, Eisenmann, et al., 2004). Therefore, it might be speculated that that this discrimination was likely due to the early maturing players’ in the sample being characterised as having enhanced stature (U11 to U12: +12 cm; U13 to 14: +13 cm; U15 to U16: +10 cm (Malina et al., 2000)) and thus providing this group of players' with an anthropometrical and aerial) advantage over their less mature counterparts during match-play. However, methods that assess skeletal maturity often require the use of either dual energy X-ray absorptiometry (DEXA) or X-ray/radiograph equipment that possess potential small risks to health given the use of radiation, accompanied by the financial implications and the requirement of a suitably trained members of staff to perform the procedure and interpret the scans. Unfortunately, anecdotal evidence suggests that many soccer development centres cannot provide the financial capital to implement such assessments of skeletal maturity, largely deeming these methods not viable for assessing player maturity within multiple elite youth soccer development centres across the UK.

2.6 Sexual Maturity

Sexual maturity is a different method for assessing soccer player maturity status that can either assess the stage of pubic hair development (stage 1 earliest, stage 5 latest) during clinical examinations (Malina, 2011; Malina, Ribeiro, et al., 2007; Malina, Silva, Figueiredo, Carling, & Beunen, 2012; Roche et al., 1995), or use self-assessment scales of sexual maturity (Leone & Comtois, 2007). In general, physician assessment of sexual maturity have been shown to be reliable (r^2 = 0.86 to 0.97) (Leone & Comtois, 2007). However, evidence exists showing large variability between physicians resulting in boys and girls being rated as being in stage 4 of pubic hair development having achieved 100% of breast (or genital in boys) development (Matsudo & Matsudo, 1994). Such findings might be explained by boys and girl's likely achieving stage 2 of genital and breast development, whilst having only achieved stage 1 of pubic hair development, as the initial enlargement of the testes and breasts are typically the most obvious sign of the onset of puberty (Malina, Bouchard, et al., 2004).

The initiation, tempo and achievement of compete sexual maturity characteristics are difficult to monitor as they development at tempos specific to the individual (Malina, Bouchard, et al., 2004). Therefore, it is common practice for physicians to estimate the mid-point between the previous and current examination of when a stage of puberty has been achieved (Malina, Bouchard, et al., 2004). Consequently, given the requirement of fully-trained clinicians and appropriated permissions being required, it is likely to be considered as unrealistic by soccer practitioners for such assessments to be deployed across multiple soccer development centres to assess sexual maturity status of young elite soccer players'. However, despite the difficulties associated to measuring sexual maturity, it has been used to contextualise smaller samples of elite youth soccer player physical phenotypes and technical development (Malina et al., 2005) within elite youth soccer environments.

2.6.1 Application of Sexual Maturity within Elite Youth Soccer

Despite difficulties to implement, measures of sexual maturity have been applied within individual elite youth soccer environments to assess the anthropometric, physical fitness and skill development of players relative to maturity (Figueiredo, Coelho e Silva, & Malina, 2011; Malina et al., 2005; Malina, Eisenmann, et al., 2004; Malina, Ribeiro, et al., 2007). Malina, Eisenmann, et al. (2004) reported that stage of pubic hair development to be a significant, relative contributor to the explained variance in the development of endurance capacity (Yo-Yo Intermittent Recovery Test (Bangsbo et al., 2008; Krustrup et al., 2003)) among elite youth soccer players'. Showing that U13 to 15 players' who were in stage 5 (advanced) of pubic hair development to possess superior endurance (YYIRT: +1182 m), CMJ (+7 cm) and sprint (-0.6 s) performance capacity versus their team-mates in stage 1 (early) of pubic hair development (Malina, Eisenmann, et al., 2004). However, sexual maturity has displayed little evidence for being a predictor of technical ability in elite youth soccer players circa-adolescence, explaining little variation in dribbling with pass (21%), ball control with head (14%), ball control with body (13%) and shooting accuracy (8%) (Malina et al., 2005). Sexual maturity has also showed little predictive power for forecasting functional capacity when compared to skeletal measures of maturity, which was able to predict CMJ performance (Figueiredo et al., 2011). Given the situational difficulties attached to monitoring sexual maturity, (e.g. appropriately qualified clinician), TD practitioners' are likely to consider alternative, non-invasive methodologies to establish player maturity within a broad population of elite youth soccer players'.

2.7 Somatic Maturity

Longitudinal collection of stature data for a specific individuals during adolescence will reveal the inflection point in which the age at onset of the growth spurt will occur (Malina, Bouchard, et al., 2004). In turn, this can be used to determine the age of the child during the maximum rate of growth during the growth spurt, commonly referred to in the literature as APHV (Mirwald et al., 2002; Sherar et al., 2005). However, this method is limited to 'real-time' measures of players' growth and offers no predictive qualities in order to permit soccer TD practitioners to forecast player anthropometric development. Therefore, non-invasive predictive estimations of player somatic maturity, calculated using anthropometric measures are implemented as a cost effective alternative for estimating player somatic maturity (Deprez, Fransen, et al., 2014; Figueiredo et al., 2011; Mendez-Villanueva et al., 2011). Players' estimated number of years away from achieving PHV (maturity offset [YPHV]) (Mirwald et al., 2002) has been calculated using a cross-validated algorithm (Bailey, 1997; Bailey, McKay, Mirwald, Crocker, & Faulkner, 1999) (**Equation 1**) that uses somatic components (stature, seated height, and leg length) and decimal age, to an accuracy of ± 0.24 years (Mirwald et al., 2002). However, although somatic maturity, skeletal age, stage of pubic hair development, and decimal age are interrelated, cross-sectional analyses of elite youth soccer players' has revealed differences between skeletal age and decimal age versus predicted PHV maturity measures (Malina et al., 2012). Such contrasts are likely to be resultant of anthropometric measurement and method error. However, although skeletal and somatic methods are both measures of maturity, it is important to note that these processes are not necessarily always synchronised (Houston, 1980). For example, for boys aged 13 to 17 years, the radial-ulna bone age is more closely associated (r^2 = 0.65 to 0.75) to APHV than carpal age (r^2 = 0.47 to 0.51) (Houston, 1980). Therefore, although skeletal age and somatic maturity are interlinked (to an extent), it is likely misleading for soccer practitioners to assume that the adolescent growth spurt will be earlier or later to the same degree as bone ossification or age, suggestive that skeletal age and PHV are asynchronous. With this in mind, although cost effective and time efficient, some caution by TD practitioners is warranted when using measures of somatic maturity to identify early, on-time and late developing soccer players'.

Equation 1:

Maturity offset (years) YPHV = -9.236

+ (0.0002708 * (Leg Length * Sitting Height)

+ (- 0.001663 * (Age * Leg Length))

+ (0.007216 * (Weight/Stature * 100))

[R = 0.94, R^2 = 0.89, and s_x = 0.59

2.7.1 Application of Somatic Maturity within Elite Youth Soccer

Estimating the YPHV (Mirwald et al., 2002) (PHV – Decimal age) and predicted adult stature (Sherar et al., 2005) have been frequently implemented by soccer practitioners and researchers to assist the TD processes (Unnithan et al., 2012; Vaeyens et al., 2006), performance analyses (Buchheit et al., 2010a; Mendez-Villanueva et al., 2012), strength (Forbes, Bullers, et al., 2009; Forbes, Sutcliffe, Lovell, McNaughton, & Siegler, 2009; Nedeljkovic, Mirkov, Kukolj, Ugarkovic, & Jaric, 2007; Philippaerts et al., 2006) and aerobic/anaerobic capacity (Buchheit, Mendez-Villanueva, Simpson, & Bourdon, 2010b; Carling et al., 2009; Cunha et al., 2011; Lovell & Parkin, 2012; Valente dos-Santos, Coelho-e-Silva, et al., 2012) development relative to players' somatic maturity and decimal age. The advancement of such approaches has initiated much interest from researchers and practitioners alike, who have examined the importance of age related differences and somatic maturity status of elite youth soccer players' may have on match performance (Buchheit et al., 2010a; Castagna et al., 2010), training capacity (Mendez-Villanueva et al., 2010) injury incidence (Le Gall, Carling, & Reilly, 2007; Malina, 2010) and fitness test performance (Cunha et al., 2011; Mujika, Spencer, Santisteban, Goiriena, & Bishop, 2009). Such is the interest and applied practice of TD practitioners of monitoring somatic maturity, measures of player maturity have been used to discriminate players' for competition tournaments (Doward, 2015) and as an independent variable for assessing player development (EPPP (The English Premier League, 2011)).

Measuring player somatic maturity across the Youth and Professional development phases of the EPPP (The English Premier League, 2011) is necessary given that advanced normative growth (such as stature (Carling et al., 2009; Deprez, Fransen, et al., 2014)) and maturity related advantages (such as superior strength and aerobic capacity) are often considered influential for the early selection (and deselection (Deprez, Fransen, et al., 2015)) of players' for development programs (Lovell et al., 2015). For example, Mendez-Villanueva et al. (2010) showed that the positive effects of decimal age on running speed (maximum aerobic speed, acceleration and sprint speed) development are likely to be maturity related and that superior maturity related anthropometric and physical fitness attributes are likely to characterise specific soccer playing positions (Deprez, Fransen, et al., 2014; Gil et al., 2007) (discussed further in **Chapter 2, Section 2.10**). In addition, Philippaerts et al. (2006) have also shown peak strength, power, speed and endurance development tempos to occur pre, and circa-PHV (13.8 ± 0.8 years) and continue to improve (albeit at a reduced rate) post PHV dependent on individual growth curves and training regime (Philippaerts et al., 2006). Thus, highlighting the pertinence of including a measure of somatic maturity within TD and EPPP (The English Premier League, 2011) criteria and offering some justification for not utilising the Sherar et al. (2005) predictive maturity model, in an effort to reduce the early selection of players for soccer academy programs largely based upon their predicted adult height values in favour of other soccer related player attributes. Such inclusion may reduce the systematic over selection of young players' that exhibit enhanced, transient maturity related, anthropometric and physical fitness characteristics and who are often born in the first quartile of the selection year when categorised chronologically into playing groups (Carling et al., 2009; Deprez et al., 2013; Hirose, 2009).

2.7.2 Limitations of estimations of Somatic Maturity

It is important to note that, although the Mirwald et al. (2002) predictive equation is inexpensive, time efficient and has been validated using annual and semi-annual (10 and 16 and at 18 years), longitudinal anthropometric measures of 7 year old boys (n = 207) and 95 pairs of twin children respectively as part of the Saskatchewan Growth and Development (Mirwald, 1978) and the Leuven Longitudinal Twin Studies (Maes et al., 1993), this thesis recognises that the longitudinal accuracy of the somatic maturity estimation procedure has been questioned (Deprez, Fransen, et al., 2014; Malina & Kozieł, 2014). A validation study (Malina & Kozieł, 2014) of the maturity offset equation (Mirwald et al., 2002) used in a longitudinal sample of Polish boys (n = 193) identified that the predicted APHV was influenced by decimal age and maturity status, showing that the predictive equation to be a valid measure of determining maturity status in boys of 'on-time' maturation trajectory. However, the predictive equation

(Mirwald et al., 2002) purportedly underestimates (-0.32 years) APHV for boys 3 years prior to PHV and overestimates (0.56 years) predicted APHV for boys 3 post PHV (Malina & Kozieł, 2014). Malina and Kozieł (2014) state that mean predicted APHV was the same as the criterion measure (Preece–Baines Model (Preece & Baines, 1978)) of APHV for boys of 12 years and that APHV for boys who are younger or older was either under (for younger) and overestimated (for older) respectively. Therefore, in consideration of these findings, the authors suggest that such discordant is possibly explained by the systematic error (0.59 years) and 95% confidence interval (1.18 years) encompassed within the predicted equation (Malina & Kozieł, 2014) (**See Equation 1**). In addition to this, such variation might also be explained by variance in measurement error, especially for stature (0.29 cm) and estimating leg length from seated height (0.35 cm) (Malina & Kozieł, 2014).

Lastly, the validity of the Mirwald et al. (2002) predictive equation for use within athletic populations has also been questioned (Deprez, Fransen, et al., 2014; Malina & Kozieł, 2014). Given that the estimation of leg length is a key component of the predictive maturity equation (Mirwald et al., 2002), coupled with the overrepresentation of skeletally mature athletes within elite team sports (Malina et al., 2000), the efficacy of the equation is somewhat compromised as growth in leg length is largely complete in early maturing boys, but trunk growth may continue (Malina & Kozieł, 2014). Ultimately, potentially limiting its use within this population. In addition to this, the Mirwald et al. (2002) predictive equation was formed based upon longitudinal growth data of white Canadian children and therefore does not account for variation in maturity status according to ethnicity (Moore et al., 2015). This is of particular importance given the diverse ethnicity of the UK population (Rogers, 2011) and that children of different ethnicities mature at different rates (Malina, Bouchard, et al., 2004). For example, black boys at ages associated to the Foundation phase of the EPPP are likely to have advanced skeletal maturity in comparison to their white peers. However, this trend is typically reversed during ages associated to adolescence (and the Youth phase of the EPPP) whereby white boys will tend to exhibit slightly advanced skeletal maturity (Malina, Bouchard, et al., 2004). Accordingly, the aforementioned limitations of the predictive equation (Mirwald et al., 2002) used within the EPPP test battery (The English Premier League, 2011) should be considered when interpreting benchmark and development data of elite youth soccer players. That being said, given its effectiveness and time efficiency for use within a broad population of elite youth soccer players that reside within the multi-development centre nature of the EPPP, the implementation of such techniques to estimate player maturity are seemingly vindicated on the principle that its limitations are considered during player monitoring and development assessment.

2.9 The Maturation-Selection Hypothesis within Elite Youth Soccer

Superior anthropometrical dimensions (stature and weight) and performance characteristics (power, speed, strength and endurance) often characterise players' selected for elite youth soccer development programs (Carling, Le Gall, & Malina, 2012; Carling et al., 2009; Vaeyens et al., 2006). This selection bias is likely apparent due to TD practitioners' selection of relatively older players', born earlier in the selection year (September to November), who are beneficiaries of experiencing earlier accelerations in stature development across the adolescent growth spurt (Malina, Bouchard, et al., 2004; Malina et al., 2000) and often exhibit advanced anthropometric and physical fitness characteristics (Carling et al., 2009; Hirose, 2009). This selection phenomena often results in the recruitment of players' for TD programmes seemingly based on transient enhancements in physical and anthropometric phenotypes, commonly known referred to as the maturation-selection hypothesis (Cobley et al., 2009; Helsen et al., 2005). It is likely that the maturation-selection hypothesis is a principle contributor to the over-selection of early maturing elite youth soccer players for development programmes, and indeed the systematic discrimination of chronologically categorised players' born in the latter quartiles (Q) (June to August) of the domestic soccer season (1st September - 31st of August) (Carling et al., 2009; Deprez et al., 2013; Hirose, 2009; Lovell et al., 2015), ultimately contributing to the relative age effect (Cobley et al., 2009; Wattie, Cobley, & Baker, 2008). Examination of the relative age effect is of relevance, as this selection phenomena is likely to be a contributing factor of the discrimination of equally talented and relatively younger players from being selected for talent development programs (Helsen, Starkes, & Van Winckel, 1998; Hirose, 2009; Mujika, Vaeyens, et al., 2009), potentially reducing the number of players available for domestic senior and national representation.

2.10 The Relative Age Effect within Elite Youth Soccer

The over-representation of athletes born in the first three months (quartile) in their respective selection years is commonly referred to as the relative age effect (RAE) (Cobley et al., 2009; Wattie et al., 2008). The RAE is prevalent in many elite sports including ice hockey (Wattie, Baker, Cobley, & Montelpare, 2007), rugby league (Till et al., 2014; Till et al., 2010), athletics (Vincent, 1993) and basketball (Delorme & Raspaud, 2009). As with these sports, the RAE in soccer skews the distribution of players' birth dates, favouring a 'leftward' shift towards those players' born in the first quartile of the selection year (September to November in soccer) (Carling et al., 2009; Cobley, Schorer, & Baker, 2008; Helsen et al., 2005; Hirose, 2009; Mujika, Vaeyens, et al., 2009; Romann & Fuchslocher, 2013; Schorer, Cobley, Büsch, Bräutigam, & Baker, 2009; Vaeyens, Philippaerts, & Malina, 2005; Williams, 2010). Using a large sample (n = 2175) of European elite youth (U15 to U18) soccer players', Helsen et al. (2005) showed a clear over-representation of players' born in the first quartile (36% to 50%) of the domestic soccer season in comparison to the last 3 months (3% to 17%).

Further evidence suggests that such between-quartile differences in birth distribution are often more pronounced during pre-adolescence, corresponding with the slowest rate of PHV since birth (Malina, Bouchard, et al., 2004; Tanner et al., 1966). Therefore, when benchmarking player development against national records data (such as the EPPP (The English Premier League, 2011)), there might be justification for TD practitioners to be considerate of players' relative age, given that normative growth curves (Malina, Bouchard, et al., 2004; Malina et al., 2000) of relatively older players', born earlier in the soccer selection year often elicit enhanced maturity and anthropometric characteristics. Although relatively younger players are likely to exhibit inferior maturity related physical phenotypes (Carling et al., 2009), evidence suggests that the minority of relatively younger players' who are recruited for elite development programs are often characterised as having advanced biological maturity and subsequently possessing advanced physical and anthropometric characteristics that enables them to compete with their more mature counterparts on an absolute basis as compensation (Till et al., 2010). In addition to this selection phenomena, birthdate distribution (Romann & Fuchslocher, 2013) coupled with advanced maturity related anthropometric and physical fitness characteristics (Deprez, Fransen, et al., 2014; Gil et al., 2007) have been shown to influence playing position allocation of elite youth soccer players'. However, data on UK based elite youth players' are limited, moreover, there is an absence of research examining the extent of the maturation-selection hypothesis and relative age effect within a broad sample of elite youth soccer players residing in multiple (> 2) development centres.

2.11 Playing Position Characteristics of Elite Youth Soccer Players'

Few studies have examined the role of the maturation-selection hypothesis (Cobley et al., 2009; Helsen et al., 2005) and relative age on the allocation of playing positions with elite youth soccer (Deprez, Fransen, et al., 2014; Romann & Fuchslocher, 2013), with only Romann & Fuchslocher., (2011) specifically investigating the influence of relative age on elite youth (U15 to 21) soccer playing position allocation. Romman & Fuchslocher (2011) showed that within a sample of 630 Swiss elite youth national soccer players', there was a significant ($P \leq 0.05$) over-representation of players' who were born in the first quartile of selection year playing in defensive (79%) playing positions in comparison to strikers (57%), whilst goalkeepers were overrepresented in the second quartile (Romann & Fuchslocher, 2013). Similar trends in playing position allocation relative to birth date distribution have also been identified in Spanish (Del Campo, Vicedo, Villora, & Jordan, 2010) soccer suggesting that such selection bias continues irrespective of national soccer philosophy.

Given the strong relationship between age, maturity and growth (Malina, Bouchard, et al., 2004), it is somewhat unsurprising that elite (Deprez, Fransen, et al., 2014) and sub-elite (Gil et al., 2007) youth soccer defenders and goalkeepers are typically characterised as exhibiting superior stature and body-mass. Likely due to their necessity to physically compete both aerially and on the ground with opposing players'. Romann & Fuchslocher., (2011) findings are somewhat confirmed by a study of 744 elite youth (U8 to U18) Belgian soccer players' (Deprez, Fransen, et al., 2014), that showed goalkeepers and defenders exhibited superior stature (goalkeepers: +0.4 to +3.7 cm; central defenders: +0.5 to +2.8 cm) than their outfield (midfield and attacking) counterparts. However, interestingly there were no significant difference in physical fitness capacity for these players' during the U9 to U15 age groupings (Deprez, Fransen, et al., 2014).

That being said, attacking and midfield players' typically possess superior anaerobic (Buchheit et al., 2010a; Malina, Eisenmann, et al., 2004) and endurance attributes (Malina, Eisenmann, et al., 2004; Stroyer, Hansen, & Klausen, 2004). Buchheit et al. (2010a) established that within a sample (n = 77) of Qatari, elite youth (U13 to 18) soccer players', LM and forwards (FWD) had superior acceleration (-0.01 to -0.04 $m{\cdot}s^{-2}$), peak speed (+0.7 to +2.0 $km.h^{-1}$) and mean repeated sprint time (-0.09 to -1.08) test capacities in addition to exhibiting inferior stature and body-mass in comparison to all other outfield playing positions. Similarly, Malina, Eisenmann, et al. (2004) showed that strikers had the greatest sprint capacity (-0.02 to -0.13 s) and that midfield players' possessed superior surrogate measure of aerobic fitness qualities (+60 m to +241 m). Such anaerobic and aerobic phenotype superiority are likely to be considered by TD as key performance indicators for player selection for midfield and attacking playing positions, given that both youth (Buchheit et al., 2010a) and senior (Di Salvo et al., 2007) elite soccer players' in these positions perform the greatest volume of high speed running and total distances during match-play.

However, the evolution of soccer match-play tactics have impacted the functional demands of lateral players' (Bush, Barnes, Archer, Hogg, & Bradley, 2015). Lateral sided EPL soccer players have increased both the total distance covered at high-intensity (19.8–25.1 km h^{-1}) and sprinting (>25.1 km h^{-1}) during match-play over a 6 year period (2006-07 to 2012-13), likely due to the evolution of match-play tactics and formation employed by managers (Bush et al., 2015). Therefore, given that much of the current playing position literature pertaining to elite youth soccer does not distinguish between central and lateral positions in both defensive and midfield roles (Deprez, Fransen, et al., 2014; Malina, Eisenmann, et al., 2004; Romann & Fuchslocher, 2013), previous findings fail to provide much insight in to the evolution of player physical phenotypes that might be considered essential to succeed in specific playing positions across the EPPP. Therefore, it remains unresolved whether or not the development of position-specific physical attributes simply mirror the match-play requirements of senior elite players or is a product of a selection phenomenon. Further exploration of this is likely to inform current selection criteria and permit soccer TD practitioners to make more informed judgments regarding player current and future athletic and anthropometric development according to playing position, maturity and decimal age.

In addition, although having added to TD literature, drawing broader inferences is somewhat difficult given that many of the previous studies have typically sampled players' from a limited number ($n \leq 2$) of development centres (Buchheit et al., 2010a; Carling et al., 2009; Deprez, Fransen, et al., 2014) and findings likely reflect individual talent development coaching and TD philosophies. Therefore, to enhance TD philosophy and accuracy of national playing position benchmark and development trajectory data in the UK, there is a necessity to systematically quantify and monitor the playing position characterises of a broad sample of UK based elite youth soccer players' relative to their age, birth date distribution and maturity as they navigate the EPPP.

2.12 The Influence of Maturity across the Player Development Pathway

The systematic monitoring of elite youth soccer players' physical phenotypes is of relevance, given that research has identified that players' selected for talent development programs typically have superior physical fitness and performance in comparison to deselected players' (Deprez, Fransen, et al., 2015; Emmonds, Till, Jones, Mellis, & Pears, 2016). Therefore, having established that child growth and physical development is highly individualised and dependent on individual growth curves (Malina, Bouchard, et al., 2004), there is considerable interest from TD practitioners and researchers to apply a holistic approach (Reilly, Williams, et al., 2000; Unnithan et al., 2012; Vaeyens et al., 2006) to TD and early identify desirable physical characteristics of players' suitable for soccer development programs (Deprez, Fransen, et al., 2015). Given that the early selection of players' for the Foundation and Youth development phases of development are often predicted by biases for superior maturity related anthropometric and physical fitness characteristics (Deprez, Fransen, et al., 2015) that remain throughout their development pathway, it is intuitive for the EPPP (The English Premier League, 2011) to mandate the systematic monitoring of anthropometric and physical fitness characteristics of players' relative to their somatic maturity. Such monitoring will better enable TD practitioners to identify and select talented young soccer players' for development programs, and serve as a needs analysis for player physical development that can identify physical fitness deficits to inform future exercise prescription in line with the IOC consensus statement on youth athletic development (Bergeron et al., 2015).

There is a considerable amount of literature that has reported the influence of maturity status on the long-term athletic development (LTAD) of elite youth soccer players' (Balyi & Hamilton, 2004; Deprez, Buchheit, et al., 2015; Deprez, Valente-dos-Santos, et al., 2014; Deprez, Valente-Dos-Santos, Lenoir, Philippaerts, & Vaeyens, 2015; Ford et al., 2011; Lloyd & Oliver, 2012; Valente dos-Santos et al., 2011). The LTAD model proposed Balyi (2004) reports to provide TD practitioners with a strategic framework to child athletic development relative to the onset, tempo and cessation of the child reaching a mature state, according to PHV. Although its efficacy has been questioned (Ford et al., 2011), the LTAD model theorises that athlete maturity may influence the development tempo of physical fitness characteristics, and proposes naturally occurring periods (circa-PHV) of heightened sensitivity to training induced adaptation (Balyi & Hamilton, 2004). These periods are believed to form a critical opportunity for peak strength (12-18 months post PHV), aerobic capacity (0 - 36 months post PHV) and speed (-24 - +24 months PHV) development velocity, commonly known as 'windows of opportunity' (Balyi & Hamilton, 2004). However, a review of the LTAD model (Ford et al., 2011) states little evidence to support such 'windows' and that the development of speed, power, strength and aerobic capacity are largely attributed to a complex interaction of hormonal, muscular, and mechanical factors caused by the onset of puberty (Butterfield, Lehnhard, Lee, & Coladarci, 2004; Rowland, 1985; Viru et al., 1999).

The Youth Physical Development (YPD) model proposed by Ford et al. (2011) strongly suggests the absence of such 'windows of opportunity' and that most components of fitness are trainable throughout the athletes' developmental pathway. Although, the influence of onset, tempo and cessation of somatic maturity and decimal age upon anthropometric and physical performance attributes is unclear, (with the exception of Philippaerts et al. (2006)) there is limited data available that specifically explains the development tempo of elite youth soccer physical phenotypes. Philippaerts et al. (2006) longitudinal study of adolescent (PHV ± 18 months) elite youth soccer players' showed peak strength, power, speed and endurance development tempos to onset at pre- to circa-PHV (13.8 ± 0.8 y) and continue to improve (albeit at a reduced rate) post PHV dependent on individual growth curves and training regime (Philippaerts et al., 2006). Similar findings have also been reported for peak rates of CMJ (Deprez, Valente-Dos-Santos, et al., 2015), running acceleration (Mendez-Villanueva et al., 2011), and speed (Mendez-Villanueva et al., 2010) development circa-PHV. That being said, there is evidence to suggest the existence of a transitional period pre- to circa-PHV of 'markedly' increased maximal sprint speed development (Mendez-Villanueva et al., 2010), which is purported to be more maturity related rather than a consequence of advanced anthropometry (Mendez-Villanueva et al., 2010). Although the literature pertaining to the development tempo of physical phenotypes within elite youth soccer populations is insightful, previous longitudinal analysis (Philippaerts et al., 2006) has been restricted to a 36 month period circa-PHV, therefore the onset and cessation of maturities' influence upon athletic development within soccer TD programmes remains unclear.

The complexities of TD in elite youth soccer might be further confounded, given that the junior (5 to 10 years) population of elite soccer tends to have a greater proportion of relatively older players', who are born earlier in the selection year and typically exhibit enhanced maturity-related anthropometric characteristics (Carling et al., 2009; Helsen et al., 1998). Therefore, physical performance advantages afforded to early-developing players' are often transient, as the onset and tempo of player maturity processes that govern athletic player performance and development are non-uniform (Malina, Bouchard, et al., 2004). This is likely to contribute to the varied spectrum of player physical development that often characterise pre-adolescent, chronologically categorised elite youth soccer teams. Therefore, necessitating the need for TD practitioners to be cognisant of the influence that onset, tempo and cessation of player maturity might have on elite youth soccer player physical phenotype development.

With exception of Philippaerts et al. (2006), inferences pertaining to the onset, tempo and cessation of maturity related athletic development in adolescent soccer players' derived from longitudinal design studies are limited. Therefore, uncertainty remains surrounding the timing and frequency of periods of athletic development in elite youth soccer player's pre-circa PHV, spanning the entire elite youth soccer development pathway. This understanding will provide TD practitioners with appropriate physical phenotype development trajectories for their players' relative to decimal age and somatic maturity, permitting a more considered approach to TD policies and athletic development strategies for elite youth soccer players'.

2.13 Summary and Statement of the Problem

The introduction of the UEFA financial fair play (UEFA, 2012) and EPPP (The English Premier League, 2011) legislations has served as catalysts for professional soccer clubs to further develop talented young players' from within their own development centres in an attempt to restrict expenditure on player imports, operate within their financial means, and produce players' eligible for national representation. Given that the efficacy and sensitivity of measures to assess elite youth soccer players' physical phenotypes are largely dependent on the accuracy and interpretation of the data produced by the battery of standardised field-tests delivered by club practitioners as part of the EPPP (The English Premier League, 2011), it is essential for the chosen battery of field tests to possess high levels of validity and reliability. In isolation, the field-tests implemented by the EPPP (The English Premier League, 2011) to assess aerobic (Krustrup et al., 2003; Leger & Lambert, 1982), lower body power, speed (Lloyd et al., 2009), agility (Pauole et al., 2000) and somatic maturity (Mirwald et al., 2002; Sherar et al., 2005) characteristics have been shown to have adequate reliability. However, with the exception of Deprez, Fransen, et al. (2014), no data is currently available in the literature stating the SWC for such field tests, with no studies having established such parameters of each component of the battery field-tests currently used by multiple UK elite youth soccer development centres. Application of a progressive statistical approach (such as SWC) for analysing player physical phenotype data will permit TD practitioners to evaluate the existence of true changes in player growth, maturity and fitness attributable to athletic intervention or normal population growth curves according to playing age and playing position.

Cross-sectional analysis of elite youth soccer player maturity, relative age and physical phenotypes according to chronological playing age and playing position has identified that there is a large RAE in elite youth soccer (Carling et al., 2009; Cobley et al., 2008; Helsen et al., 2005; Hirose, 2009; Mujika, Vaeyens, et al., 2009; Romann & Fuchslocher, 2013; Schorer et al., 2009; Vaeyens et al., 2005; Williams, 2010), favouring players' born earlier in the domestic soccer season to be selected for talent development programmes and defensive and goalkeeper playing positions (Romann & Fuchslocher, 2013). It is likely that the maturity-selection hypothesis (Cobley et al., 2009; Helsen et al., 2005) is influential during TD practitioner's allocation of players' for positional roles, as defenders are often characterised as being relatively older and exhibiting advanced anthropometric and physical fitness traits in pre-circa adolescent players' (Deprez et al., 2013; Romann & Fuchslocher, 2013). Whilst their midfield and attacking counterparts are often born later in the selection year, possessing superior anaerobic capabilities (Deprez, Fransen, et al., 2014). That being said, making broader inferences using current literature is difficult given that much of the previous research has sampled fewer than two separate development centres and findings are likely to reflect individual TD criteria or overarching governing bodies (Buchheit et al., 2010a; Carling et al., 2009; Deprez, Fransen, et al., 2014). Therefore, cross-sectional analysis of a broad sample of elite youth soccer players' who are participating in the EPPP (The English Premier League, 2011) is necessary in order to quantify the position-specific characteristics of elite-youth soccer players' and further understand the RAE, maturity-selection hypothesis. Future research is also necessary to establish the influence of onset, tempo and cessation of player maturity on the development of elite youth soccer player physical phenotype across the EPPP.

This thesis will adopt a scientific and statistical approach to investigate the influence of the player maturity on elite youth soccer player physical phenotype development. With this in mind, it is anticipated that this thesis will enable TD practitioners to better understand the influence of maturity-selection hypothesis on selection, role allocation and development of elite youth soccer player physical phenotype development. In addition, it is envisaged that the findings from this thesis will further educate TD practitioners about the influence of the maturation-selection hypothesis within elite youth soccer and subsequently contribute to a reduction in the number of erroneous selections (and indeed deselections) of players' for soccer talent programmes based on potentially transient physicality, coupled with unrealistic expectations of rate in physical development. The identification and quantification of such parameters are likely to permit a more considered approach to current TD policies within UK elite youth soccer.

2.14 Aims of the Thesis

The aims of the experimental chapters were:

1. **Chapter 4** will assess the short-term, between and within-practitioner variation of the anthropometric measures used to estimate somatic maturity status of UK elite youth soccer players. Furthermore, this thesis will sought to determine the short-term reliability of a battery of physical fitness field-tests and establish the minimum threshold for SWC for anthropometric, estimated maturity and physical fitness measures in order to accurately monitor player progression throughout the EPPP development pathway. It is hypothesised that the standardised battery of anthropometric and physical fitness

field-tests used within this thesis and delivered by a broad number of elite youth soccer development centres in the UK will have acceptable short-term reliability.

2. **Chapter 5** and **Chapter 6** will examine the extent of the maturity-selection hypothesis on player selection and role allocation by assessing the relationships between anthropometric and physical fitness attributes associated to players' relative age, somatic maturity and decimal age throughout the EPPP 'Youth' and 'Professional' phases of development, examining a broad sample of players' from UK elite youth soccer development centres. It is hypothesised that the selection and role allocation of players' within UK soccer academies will be influenced by transient enhancements in maturity related physical phenotypes associated to players' born earlier in the soccer selection year.

3. **Chapter 7** will investigate the onset, tempo, and cessation of somatic maturity and decimal age upon the development of anthropometric and physical performance attributes in a large cross-sectional sample of UK elite youth soccer players' aged 9-18 years of age residing in multiple soccer development centres. It is hypothesised that the physical development of UK elite youth soccer players across adolescents will largely be linear in nature, with anaerobic phenotypes displaying a heightened rate of yearly development circa-PHV.

Chapter 3. General Methods.

3.1 Introduction to the test battery

To standardise the systematic monitoring of players', the EPPP states that each development centre will be provided with the same test equipment, all tests are conducted on the same playing surface (indoor gym or 3G surface), testing will be conducted during the same time each year (July/December/April), the test battery will not disrupt the coaching programme, and tests to assess players' maximal aerobic and anaerobic power cannot be completed in the same session (The English Premier League, 2011). Across 2011-2015, twenty licenced development centres attached to Football League clubs used a battery of anthropometric (stature, seated height and body-mass) and physical fitness (lower limb power, speed, agility and aerobic endurance) field-tests that monitored the growth and physical development of their players' (The English Premier League, 2011) delivered by staff (including the thesis author for the first 3 years of data collection) employed by Pro-Football Support.

The Pro-Football Support practitioners consisted of full-time (general managers), part-time (post-graduate students [PhD, MRes, MSc] and graduate students) and intern members of staff who were all centrally trained on the delivery of the test battery at the Pro-Football Support headquarters. All part-time and intern members of staff were directly supervised by a Pro-Football Support general manager during each testing session to provide quality control. The progressive undulating sample size (**Chapter 5** [n = 731]; **Chapter 6** [n = 465]; **Chapter 7** [n = 969] within the thesis is reflective of progressive nature of the EPPP testing mandate (from inception [2011] to the end of thesis data collection [2015]) and the exclusion criteria used which was exclusive to each chapter.

All of the physical and anthropometrical measures were collected in combination with player playing position, decimal age and an estimations of player maturity (Mirwald et al., 2002) and are presented in this thesis.

3.2 Definition of Elite Youth Soccer Development Centres'

For the purpose of this thesis, elite youth soccer development centres were defined as TD programmes that were governed by the EPL EPPP (The English Premier League, 2011), located within UK professional soccer clubs competing in the Championship, League 1 and League 2 during the time of data collection.

3.3 Definition of an Elite Youth Soccer Player

For the purpose of this thesis, elite youth soccer players' were defined as young male soccer players' who were participating in talent development programmes regulated by the EPPP (The English Premier League, 2011) during the time of data collection. All of the players' were receiving either 3-5 (Foundation phase, U5 to U11), 6-12 (Youth development, U12-U16) or 16 hours (Professional development, U17-21) of coaching each week at respective centres (The English Premier League, 2011), including potential competitive matches (The English Premier League, 2011). Where required, players' were categorised in to their primary playing position (Goalkeeper [GK], Lateral Defender [LD], Central Defender [CD], Lateral Midfield [LM], Central Midfield [CM] and Forward [FWD]).

3.4 Design and Participants

A summary of the design, inclusion/exclusion criteria, sample size and demographic of the sampled population for each research chapter of this thesis are outlined in **Table 1**, accompanied by general information pertaining to the location of data collection and ethical consent. Players' who were deemed free from injury by a relevant coach within each development centre and were partaking in the EPPP (The English Premier League, 2011) were considered suitable for inclusion for each research chapter of this thesis. During the timing of data collection for the present thesis (2011-2015), the composition of the deployed fitness test battery was deemed suitable by the Football League to fulfil the requirements of the EPPP testing mandate (The English Premier League, 2011). The sequence of tests was selected based on previously outlined recommendations, with players' having anthropometric measures (stature, seated height and body-mass) taken in a rested state, followed by physical movement skill tests (vertical counter movement jump, T-test and linear sprints), and finally the fatigue inducing test (MSFT) (Baechle & Earle, 2008).

Having previously completed the test protocols, all of the sampled players' were familiar with all of the testing procedures prior to their completion and the players refrained from any additional activities or interventions than what they would normally perform during their regular training activity. All activities completed by the players' were preceded by a club led warm-up (unless otherwise specified) and was dictated by their respective development centres in accordance to EPPP legislation (The English Premier League, 2011) and within the pre-existing consent agreements between club and player (guardian) (Macauley & Bartlett, 2000). Given that each player was engaged within both club academy and EPPP systematic and routine physical monitoring, it was considered that the acquisition of formal informed consent was not required for the present thesis as the testing of the sampled players functional and physical capacities were a standard requirement of the development centre they were enrolled (Winter & Maughan, 2009). However, in accordance to the British Olympic Associations position statement on athlete confidentiality (Macauley & Bartlett, 2000), each player was informed that they would be allowed to withdraw their data from the research at any point, without having to give reason. All players' and coaches were informed that their data would be kept confidential between the primary investigators and coaching staff. Ethical approval was granted from the University of Hull ethics committee for each research chapter of this thesis and the primary investigator was Disclosure and Barring Services, checked prior to the commencement of data collection (See **Appendix 1**).

3.5 General Somatic Procedures

3.4.1 Relative Age Distribution Characteristics

Player decimal age was determined from club records and reported as either the day number (RAd) or quartile (Q) (Q1 = 1st September to 30th November; Q2 = 1st December to 28th February; Q3 = 1st March to 31st May; Q4 = 1st June to 31st August) in which they were born relative to the UK domestic soccer selection year (1st September to August 31st) to represent relative age distribution.

3.4.2 Anthropometrics

Following ISAK recommendations (Stewart et al., 2011), a portable stadiometer (seca© 217,Chino, U.S.A) was used to measure player stature. Players' were required to put their shoeless feet together and heels touching the scale, whilst their head was positioned in the Frankfort plane to perform the stretch stature method whereby players were required to take a deep breath in and hold the position of their head whilst duplicate measures of stature were recorded to an accuracy of 0.1 cm (Stewart et al., 2011). Following similar procedures, players' seated height were measured (seca© 217,Chino, U.S.A) whilst they were in a seated position on a standardised plinth with their hands resting on their thighs (Stewart et al., 2011). Similarly to stature, players performed the stretch stature method and their seated height was measured with estimated leg length recorded as stature minus seated height (Malina, Bouchard, et al., 2004). In addition, body-mass (seca© robusta 813, Chino, U.S.A) was recorded whilst players wore their normal training attire with shoeless feet using previously outlined procedures

(Stewart, 2002). If the measurements varied ≥ 0.4 cm or 0.4 kg, a third measure was taken and the median value recorded.

3.4.3 Somatic Maturity Status

Anthropometric measures (stature, seated height, body-mass) and decimal age were used to estimate player somatic maturity. Estimated APHV was calculated using a cross-validated algorithm based on a longitudinal analysis of the interaction between somatic components (stature, seated height, and leg length) and calendar age of 79 Canadian boys aged 8 to 16 years (Mirwald et al., 2002), with an accuracy of 0.24 years (Mirwald et al., 2002). Taking into account the predictive nature of the anthropometric based algorithm used to determine PHV, this thesis will go on to establish the short-term reliability of all anthropometric measures encompassed within this equation (**Equation 1**). Similarly to previous literature (Till & Jones, 2015), for the purpose of this thesis, the term circa (Y)PHV will be used to describe players who are ±0.5 YPHV. Players who are ≤ -0.5 YPHV will be defined as pre (Y)PHV and those who are ≥ 0.5 (Y)PHV will be referred to as post PHV.

3.6 General Physical Fitness Procedures

3.6.1 Vertical Counter Movement Jump

Explosive leg power was assessed using a CMJ on a digital contact mat (SmartJump©, Fusion Sport, Cooper Planes, Australia), whereby players were instructed to maximally jump vertically, having performed a self-selected countermovement that preceded the jump whilst keeping their hands placed on their hips throughout (Stewart, 2002; Winter et al., 2006). Players' performed three CMJ`s interspaced by a 3 min passive recovery which was preceded by players performing a re-warmup consisting of one 50 and 75% of self-perceived maximal CMJ. If the range of the best three jumps varied ≥ 2 cm then the repeated attempts were performed until this criterion was achieved (up to a maximum of 8). The mean of the highest three jumps was used to identify CMJ height.

3.6.2 T-Test

Timed (Brower Timing System, Salt Lake City, Utah, U.S.A) agility performance was established using the T-test (Semenick, 1990). Performance was determined by the time taken for each player to navigate the 'T' shaped course according to the player breaking the infrared beam at the start and finish line that automatically commenced and terminated timing. Players' were instructed to sprint forwards 9.14 m (10 yards), side shuffle left 4.75 m (5 yards) (maintaining a forward facing position), return to the mid-line and repeat for the opposite side of the course before backward running 9.14 m (10 yards) to finish the course. Each player completed two warm-up efforts at 75% of self-perceived maximal effort prior to completing four (2 x left, 2 x right) maximal and timed efforts interspaced by 3 min passive recovery. The average of the fastest times for each direction was used to determine overall agility performance.

3.6.3 Maximal Sprint Speed

Following a standardised re-warm-up that consisted of three 10 and 20 m runs at 50, 75 and 90% of their self-determined maximal sprint, players performed a 20 m maximal sprint test using a previously established method (Stewart, 2002). To best represent each players match play running technique, players were encouraged to adopt a comfortable start position, typically expressed as the body-mass over their dominant front foot, shoulders and hips facing forward and in a slightly crouched position (Stewart, 2002). Players were then instructed to complete three timed (Brower Timing System, Salt Lake City, Utah, U.S.A), maximal 10 and 20 m sprints interceded by 3-min passive recovery. To identify players 10 and 20 m sprint time, infrared, digital timing gates were place at 0, 10 and 20 m in order to ascertain 10 and 20m split time respectively.

3.6.4 Endurance Capacity

The MSFT assessed player endurance capacity, which has been deemed reliable and valid for this purpose (Leger & Lambert, 1982; Ramsbottom, Brewer, & Williams, 1988) and was adapted from a previously outlined method (Stewart, 2002). An experienced test administrator acted as pacer to ensure players' achieved the correct timings during speeds 6-11 $km.h^{-1}$ and the test began thereafter with the speed being increased by 1.0 $km.h^{-1}$ every ~1 min until test cessation. To ensure accuracy in test measurement, there was a 1:3 practitioner to player ratio throughout each test serving as spotters. Failure to complete the 20 m track in the allotted time for the shuttle resulted in a verbal warning from the test administrator(s), with test cessation deemed from a subsequent failure. Total distance covered (m) was used as the outcome measure to assess endurance capacity as maximal aerobic speed is underestimated by ~ 3 $km.h^{-1}$ (Berthoin et al., 1994) using the MSFT due to the multiple accelerations, decelerations and changes of direction required for 20 m shuttle running.

Table 1. Summary table of general information pertaining to the methods of each research chapter of this thesis.

Chapter title	n	Design and aims	Inclusion Criteria	Exclusion Criteria	Demographics	Statistical analysis
Chapter 4 **The Short-Term Reliability and Smallest Worthwhile Changes Associated within an Academy Soccer Field Test Battery**	66	Repeated measures. Assess the test-retest reliability of a standardised battery of anthropometry and physical fitness field-tests in an applied setting. Establish the smallest worthwhile each field test .	Group 1: Young elite, male soccer players' participating in an elite youth soccer TD programme (governed by the EPPP) located within an English lower-league club. Group 2: Senior amateur soccer players Players' were deemed by coaching staff as being free from injury.	Currently suffering from injury. Had participated in vigorous physical activity 24 hours previous to data collection.	Group 1: Football League 2 Players' (n = 45), were divided in to 7 decimal age-groups (under [U] 12: n = 13; U13: n = 9; U14: n = 9; U15: n = 7; U16: n = 7). Group 2: N = 21	95% confidence intervals Percentage coefficients of variation (CV %). Intraclass correlation coefficients (ICC) Mean difference (MD) Typical Error Relative and absolute SWCs required to elicit a probable significant change in physical performance or anthropometrical measure (Kempton, Sirotic, & Coutts, 2013).
Chapter 5 **Physical Phenotypes and Relative Age Effect within Elite-Youth Soccer: Examining the Elite Player Performance Plan**	731	Cross-sectional Descriptive design to examine the application of the maturation-selection hypothesis of TD practitioners by quantifying the relative-age effect and physical phenotypes of a broad sample of elite youth soccer players'.	Young elite, male soccer players', participating in an elite youth soccer TD programme (governed by the EPPP) located within an English lower-league club. Players' were deemed by coaching staff as being free from injury.	Currently suffering from injury. Were ± 4 years APHV	Sampled clubs: Championship (n = 6); League 1 (n = 6); League 2 (n = 5) Players' were divided in to 8 decimal age-groups (U11: n = 85; U12: n = 102; U13: n = 92; U14: n = 105; U15: n = 98; U16: n = 50; U17: n = 116; U18: n = 83).	Linear marginal models and pairwise comparisons assessed between playing position differences ($P \leq 0.05$.) Values reported as the estimated marginal means and associated standard errors, Accompanied by estimates of effect magnitude according (Hopkins, Marshall, Batterham, & Hanin, 2009).

Table 1 (Continued).

Chapter title	n	Design	Inclusion Criteria	Exclusion Criteria	Demographics	Statistical analysis
Chapter 6 **Physical Phenotype, Relative age and Maturity Status Biases on Playing Position According each Development Stage of the Elite Player Performance Plan**	465	Cross-sectional Descriptive design to determine the differences in relative age, anthropometry, maturity, and physical fitness attributes associated with positional role allocation.	Young elite, male soccer players', participating in an elite youth soccer TD programme (governed by the EPPP) located within an English lower-league club. Players' were deemed by coaching staff as being free from injury.	Currently suffering from injury. Were ± 4 years APHV Players' sampled, and who were under 12 years of age were excluded, having been deemed to have insufficient playing experience to establish a regular playing position.	Sampled clubs: Championship (n = 2); League 1 (n = 6); League 2 (n = 8) Players' were divided in to 6 decimal age-groups (U13: n = 96; U14: n = 122; U15: n = 78; U16: n = 31; U17: n = 55; U18: n = 83). Goalkeeper (GK: n = 44); Central defender (CD: n = 79); Lateral defender (LD: n = 81); Central midfield (CM: n = 117); Lateral midfielder (LM: n = 66); Forward (FWD: n = 78).	Chi Squared analysis to assess difference in birth quartile distribution ($P \leq 0.05$.) Linear marginal models and pairwise comparisons assessed between playing position differences ($P \leq 0.05$.) Values reported as the estimated marginal means and associated standard errors. Accompanied by estimates of effect magnitude according (Hopkins et al., 2009).
Chapter 7 **Development Trajectories of Physical Phenotypes for Elite Youth Soccer Players:** **Examining the Elite Player Performance Plan**	969	Cross-sectional Segmented regression analysis.	Young elite, male soccer players', participating in an elite youth soccer TD programme (governed by the EPPP) located within an English lower-league club. Players' were deemed by coaching staff as being free from injury.	Currently suffering from injury. Were ± 4 years APHV.	Sampled clubs: Championship (n = 3); League 1 (n = 10); League 2 (n= 10). Players' were divided in to 10 decimal age-groups (U9: n = 61; U10: n = 112; U11: n = 113; U12: n = 126; U13: n = 106; U14: n = 212; U15: n = 126; U16: n = 26; U17: n = 94; U18: n = 27)	Segmented regression analyses were performed to quantify the location of 'breakpoint(s)' in the response variable (Muggeo, 2003). Precision of break-point estimates was calculated via Wald-based 95% confidence intervals (CI). Slope coefficients and their estimate precision (95% CI's) are reported, and significant slopes were detected using alpha set at $P \leq 0.05$.

Chapter 4. The Short-Term Reliability and Smallest Worthwhile Changes Associated within an Academy Soccer Field Test Battery.

4.1 Introduction

As discussed in in **Chapter 2**, to increase the number of talented 'home-grown'' players' graduating from TD programmes and competing at senior elite level soccer, the EPL introduced the EPPP (The English Premier League, 2011). As part of an holistic approach to TD, the EPPP provides national guidelines for benchmarking athletic development of elite youth soccer players' in the UK (The English Premier League, 2011). The EPPP is a long-term framework that, in part promotes the systematic monitoring of players' anthropometric, maturity and physical fitness characteristics throughout the Youth (U12-U16) and Professional (U17-U21) phases of player development (The English Premier League, 2011). Therefore, EPPP monitoring potentially permits TD practitioners to identify relatively older players', who are likely to exhibit enhanced anthropometric characteristics due to early exposure to normative growth curves (and to a lesser extent superior physical qualities as a result of advance biological maturity) (Carling et al., 2009). These players' are likely to be beneficiaries of possessing greater playing and training experience (Vaeyens et al., 2005), having been early enrolled in to elite development programs. As previously stated in **Chapter 2**, this selection phenomenon is commonly known as the maturation-selection hypothesis (Cobley et al., 2009; Helsen et al., 2005) and is considered a primary contributory factor for the over-selection of early maturing players', and the systematic discrimination of chronologically categorised players' born later in the domestic soccer season (Carling et al., 2009; Deprez et al., 2013; Hirose, 2009; Lovell et al., 2015).

To ensure that equally talented and motivated, less mature players' are not prematurely deselected or unnecessary overlooked for talent development pathways based on transient physical phenotypes, the EPPP mandates the systematic (each trimester) monitoring of players' anthropometric, maturity and physical fitness characteristics across the domestic soccer season (The English Premier League, 2011). This initiative provides TD practitioners with objective, individualised portfolios of player growth, maturity status and physical fitness data (The English Premier League, 2011), permitting the accurate benchmarking of player development against national data records (The English Premier League, 2011). Therefore, necessitating the need for a standardised battery of valid and reliable anthropometric and physical fitness field-tests that can be employed by multiple soccer development centres across the UK.

Criterion, laboratory based assessments such as X-rays to attain skeletal age (Greulich & Pyle, 1959; Tanner et al., 1975) and $\dot{V}O_{2\,max}$ test protocols (Midgley et al., 2007) to establish absolute and relative aerobic capacity require the use of specialised equipment for analysis. However, procedures such as X-ray and $\dot{V}O_{2\,max}$ analysis might be considered inappropriate methods by many TD practitioners given that they are often costly and time inefficient implications of determining both $\dot{V}O_{2\,max}$ and skeletal age within team sport environments. Therefore, given the lack of 'in-season' opportunity to test entire squads within a laboratory environment, their ease of administration and enhanced ecological validity (Hopkins et al., 1999; Svensson & Drust, 2005), field test equivalents of laboratory based testing protocols are seemingly more accepted by TD practitioners and are deployed as part of the EPPP mandate for the collection of player growth, maturity status and physical fitness data (The English Premier League, 2011).

The field test battery implemented by a number of elite youth soccer development centres' to satisfy the EPPP testing mandate in this thesis was comprised of the MSFT (Leger & Lambert, 1982) to exclusively estimate players endurance capacity (Saltin & Astrand, 1967); CMJ height (Buckthorpe, Morris, & Folland, 2012) to establish lower limb power (Street et al., 2001); 10 to 20 m sprint time to estimate sprint speed (Buchheit et al., 2012) and anthropometric measures (stature, body mass) to determine player growth (Stewart et al., 2011). In addition to these tests, a cross-validated (Bailey et al., 1999; Sherar et al., 2005), predictive algorithm (Mirwald et al., 2002) that encompassed the aforementioned anthropometric measures is used to estimate player somatic maturity status (Tanner & Whitehouse, 1962; Tanner et al., 1975). However, although simplistic to administer, anthropometric and physical fitness field-tests should have acceptable short-term reproducibility (Hulse et al., 2012; Leger & Lambert, 1982; Mirwald et al., 2002; Pauole et al., 2000) in order to accurately identify physical prowess and monitor individual player development and growth.

The short-term reliability of field-tests used to monitor anthropometric and physical fitness characteristics of elite youth soccer players' are unlikely to be influenced by age and maturity (Buchheit & Mendez-Villanueva, 2013) and will permit the differentiation between the test 'signal' (true score, minus the error (Baumgartner, 1989)) and 'noise' (true score, including the error (Baumgartner, 1989)). Therefore, permitting TD practitioners to accurately assess the magnitude of player development that is directly related to a training intervention and/or normal growth curves (Malina et al., 2000) and not a product of systematic or random error associated with the test and player variation (Atkinson & Nevill, 1998). However, the long-term reliability of some anthropometric and physical performance field-tests has been questioned (Buchheit & Mendez-Villanueva, 2013), showing elevated levels of within-player variation when monitored longitudinally across adolescence. Therefore, suggesting that some caution might be warranted when interpreting data of this nature.

When assessing athletic development, TD practitioners should be considerate of the within-player variation in elite youth soccer player athletic performance (Hulse et al., 2012). For example, a player's 10 m sprint time may only require a small improvement in performance (e.g. - 0.01 s) to increase that players' ranking within the team. However, the improvement may not be great enough to conclude that a performance improvement has occurred (Hopkins et al., 1999), potentially limiting the test sensitivity for detecting improvements in physical performance for each player in the team (Hopkins et al., 1999).

Therefore, a progressive statistical approach might be applied (Hopkins et al., 2009), that establishes a minimum threshold for SWC. This minimum threshold is calculated by multiplying the between-player variation, standard deviation (SD) for any given measure by Cohen`s *d* effect size of 0.2 (Cohen, 1977). Athletic performance simulations have demonstrated that a SWC as small as 0.2 to 0.4 of an athlete's SD is sufficient to differentiate enhancements in elite athletic performance ('the signal') from within-player variation ('the noise') (Hopkins et al., 1999). Application of a progressive statistical approach of analysing player field test data will provide elite youth soccer TD practitioners with a SWC value to evaluate if a true change in player growth, maturity and fitness has occurred that was attributable to athletic intervention or normal population growth curves. Such application may potentially reduce the number of erroneous selections (and indeed deselections) of elite youth soccer players' for talent programmes based on inflated contributions of field test 'noise'.

In order to accurately investigate the extent of the maturation-selection hypothesis within the EPPP, the primary aim of this chapter was to examine the short-term, between and within-practitioner variation of anthropometrical measures used to estimate growth and maturity status in UK elite youth soccer populations. In addition, the present chapter also sought to assess the short-term reliability of a standardised battery of physical fitness field-tests and to establish the SWC for anthropometric, maturity and physical fitness measures in order to accurately monitor player progression throughout the EPPP. This research is of pertinence to TD practitioners responsible for interpretation and dissemination of the routine monitoring of elite youth soccer player physical phenotypes. It is hypothesised that the standardised battery of anthropometric and physical fitness field-tests delivered by a broad number of elite youth soccer development centres in the UK will have acceptable short-term reliability.

4.2 Procedures

4.2.1 Participants

Having institutional ethical approval and obtained suitable informed consent for participation (see **Chapter 3, Section 3.4**), 45 U12 to U16 elite youth soccer players' (**Table 2**) completed two identical series of anthropometric (stature, seated height and body-mass), estimation of somatic maturity and physical fitness (maximal sprint and aerobic endurance) assessments. All players' were participating in a TD programme (governed by the EPPP) and were sampled from one UK professional (League 2), soccer development centre. Situational restrictions prevented the entire standardised battery of physical fitness tests being completed by the same sample of elite youth soccer players'. Therefore, given that the reliability of test battery was not likely to be influenced by age (U9-18; an immature to mature state) and that the test can likely distinguish between playing standard (Hulse et al., 2012), a second group of senior amateur soccer players' (**Table 2**) completed two separate components (CMJ and T-Test) of the physical fitness field test battery. All measures for the senior amateur soccer players' were taken during the first trimester of the 2015-2016 domestic soccer season. The field test batteries for both the elite youth and amateur senior groups of players' were interspaced by 7-days during the player's normal weekly evening training sessions. All players' performed a standardised warm-up prior to completing all physical fitness tests. Diurnal variation of the field test measures were controlled for by having the players perform the tests at the same time (~7 pm) of day.

The order of field test completion was standardised based on the recommendations of the National Strength and Conditioning Association (Baechle & Earle, 2008) according to the ascending level of exertion required to complete each separate component of the field test battery within a previous testing session. Test feedback to players' was prohibited until both testing sessions were completed. The same experimenters and recording equipment were used for each assessment. The elite youth soccer players' completed fitness assessments on an indoor 3G, rubber crumbed synthetic pitch, whilst the senior amateur players' were tested on a grass surface. All players' wore their usual training attire for both of the testing sessions.

4.2.2 Anthropometric and Somatic Maturity Characteristics

Detail of the anthropometric measures used within the current study are outlined in **Chapter 3**. In summary, anthropometric (stature, body-mass and seated height) measures were recorded using previously outlined methods (Malina, Bouchard, et al., 2004) and were then used in combination with decimal age to estimate player somatic maturity (Mirwald et al., 2002). To establish between-practitioner variability for stature and seated height measures, all players' were measured by the same two practitioners on both testing occasions. Data collected by each practitioner was blinded until after the final data analysis.

Table 2. Summary table of anthropometrical characteristics of the elite youth soccer players' and senior amateur players' taken during week 1 of the test battery.

Chronological playing age	n	Age (years)	Body-mass (kg)	Stature (cm)
Elite youth	45	13.5 ± 1.5	49.2 ± 10.3	160.8 ± 11.1
Senior amateur	21	24 ± 5.3	84.3 ± 7.1	177.7 ± 6.4

4.2.3 Physical Fitness Characteristics

Players' performed CMJ, T-Test, 10 and 20 m timed sprints and the MSFT (Leger & Lambert, 1982; Ramsbottom et al., 1988) on two occasions, separated by 7-days following the detailed procedures outlined in **Chapter 3**.

4.2.4 Statistical Analysis

Using IBM SPSS Statistics 20 (SPSS Inc, Chicago, IL), all data were confirmed as being normally distributed and are presented as the mean ± standard deviation (SD). Inter and intra-tester coefficients of variation (CV) were calculated by dividing the SD of the differences between the physical fitness field test data collected in weeks 1 and week 2 by the square root of two, and then dividing the result by the grand mean of weeks 1 and week 2 and expressed as a percentage CV. The calculations were performed using a customised spreadsheet (Hopkins, 2000) and the results are reported as a percentage mean difference (MD), absolute typical error (TE) and intraclass correlation with appropriate 95% confidence intervals (CI). The subjective thresholds for intraclass correlation coefficients were described as *trivial* ($r^2<0.1$), *small* ($0.1< r^2 < 0.3$), *moderate* ($0.3< r^2< 0.5$), *large* ($0.5< r^2 < 0.7$), *very large* ($0.7< r^2 < 0.9$), *nearly perfect* ($r^2 > 0.9$) and *perfect* ($r^2 = 1$) (Hopkins et al., 2009). The between-player percentage and absolute standard deviations were multiplied by an arbitrary 0.2 to determine both relative and absolute minimum threshold for smallest worthwhile change (SWC, SWC%) (Hopkins et al., 2009; Kempton et al., 2013).

4.3 Results

4.3.1 Anthropometrics and Somatic Maturity Characteristics

The anthropometric assessments of player growth and estimates player maturity were shown to have a good level of within short-term reliability (Practitioner A (**Table 3**), stature: MD [CI] = -0.1% [-0.2 to 0.1%], CV = 0.4% [0.3 to 0.5%]; seated height: MD = 0.1% [-0.4 to 0.4%], CV = 1.1% [0.9 to 1.4%]; body-mass: MD = 0.4 kg [0.1 to 0.7 kg], CV = 0.7% [0.6 to 0.9%]), having a *near perfect*, to *perfect* reproducibility (r = 0.97 to 1.00) for anthropometric and estimated PHV measures, respectively. A similar level of reliability was established for estimated APHV (**Table 3**) (MD = 0.1 % [-0.3 to 0.4%]; CV (0.8% [0.7 to 1.0%]). The full disclosure of within absolute and relative variation and SWC of player stature, seated height, body-mass and estimated APHV as measured by practitioners A and B are displayed in **Tables 3** to **4**. Data pertaining to the between practitioner variation and SWC anthropometric and somatic characteristics of players are displayed in **Table 5**.

4.3.3 Physical Fitness Characteristics

The physical assessments implemented in the present chapter were shown to have high short-term reliability (CMJ: MD = -1.1% [-4.7 to 2.6]; CV = 5.9% [4.6 to 9.0]; agility: MD = 3.0 % [1.9 to 4.1]; CV = 1.7 % [1.3 to 2.4]); 10 m: MD = 2.9 % [1.8 to 4.0], CV = 2.7 % [2.2 to 3.4]; 20 m: MD = -1.1 % [-2.6 to 0.5], CV = 4.9 % [4.1 to 6.4]); MSFT: MD = 0.4% [-2.3 to 3.2%], CV 6.5% [5.5 to 8.7%]). The relative and absolute reliability, accompanied by SWC values of the physical fitness (CMJ, agility, 10, 20 m sprint and MSFT) field tests examined in the present chapter are displayed with in **Table 6**.

Table 3. Summary table of absolute and relative reliability for a standardised battery of anthropometric assessments for elite youth (Under 12 to 16 years) soccer players' collected by practitioner 'A' interspaced by 7-days.

Practitioner A	Stature (cm)	Seated height (cm)	Body-mass (kg)	PHV (Y)
Sample size	*n* = 45	*n*= 45	*n* = 45	*n* = 45
Week 1 (Mean ± SD)	161.3 ± 11.6	78.4 ± 5.6	49.9 ± 11.7	14.6 ± 0.6
Week 2 (Mean ± SD)	161.1 ± 11.2	78.5 ± 4.9	50.2 ± 11.6	14.6 ± 0.6
Week 1 Range	133.1 to 184.3	66.6 to 89.6	29.7 to 82.8	13.3 to 15.7
Week 2 Range	133.2 to 184.1	67.9 to 88.9	30.0 to 83.5	13.4 to 15.7
ICC (CI)	1.00 (1.00 to 1.00)	0.97 (0.95 to 0.98)	1.00 (1.00 to 1.00)	0.96 (0.93 to 0.98)
ICC descriptor	Perfect	Nearly perfect	Perfect	Nearly perfect
MD% (CI%)	-0.1 (-0.2 to 0.1)	0.1 - (-0.4 to 0.4)	0.4 (0.1 to 0.7)	0.1 (-0.3 to 0.4)
Typical error (CI)	0.6 (0.5 to 0.7)	0.9 (0.8 to 1.1)	0.3 (0.3 to 0.4)	0.1 (0.1 to 0.2)
CV% (CI%)	0.4 (0.3 to 0.5)	1.1 (0.9 to 1.4)	0.7 (0.6 to 0.9)	0.8 (0.7 to 1.0)
SWC%	1.5	1.4	5.1	0.8
SWC	2.3	1.1	2.3	0.1

ICC = Intraclass correlation; MD% =Percentage mean difference; CV% = Percentage coefficient of variation; CI = 95% confidence interval; SWC% = Percentage smallest worthwhile change; SWC = Absolute smallest worthwhile change

Table 4. Summary table of absolute and relative reliability for a standardised battery of anthropometric field test measures for elite youth (Under 12 to 16 years) soccer players' collected by practitioner 'B' interspaced by 7-days.

Practitioner B	Stature (cm)	Seated height (cm)	PHV (Y)
Sample size	*n* = 45	*n* = 45	*n* = 45
Week 1 (Mean ± SD)	158.8 ± 1.4	75.3 ± 5.0	15.0 ± 0.7
Week 2 (Mean ± SD)	159.7 ± 12.4	77.5 ± 6.4	14.7 ± 0.6
Week 1 Range	131.3 to 181.3	64.7 to 85.2	13.6 to 16.8
Week 2 Range	131.2 to 184.9	64.8 to 90.9	13.5 to 16.0
ICC (CI)	0.98 (0.96 to 0.99)	0.86 (0.76 to 0.92)	0.76 (0.60 to 0.86)
ICC descriptor	Nearly perfect	Very large	Very large
MD% (CI%)	0.5 (0.0 to 0.1)	2.7 (1.6 to 4.0)	-1.8 (-2.6 to -1.0)
Typical error (CI)	1.9 (1.6 to 2.4)	2.2 (1.8 to 2.8)	0.3 (0.3 to 0.4)
CV% (CI%)	1.2 (0.1 to 1.5)	2.8 (2.4 to 3.6)	2.0 (1.7 to 2.6)
SWC%	1.6	1.5	0.8
SWC	2.5	1.1	0.1

ICC = Intraclass correlation; MD% =Percentage mean difference; CV% = Percentage coefficient of variation; CI = 95% confidence interval expressed in absolute units of measurements; CI% = 95% confidence interval expressed relatively; SWC% = Percentage smallest worthwhile change; SWC = Absolute smallest worthwhile change.

Table 5. Summary table of the inter tester reliability (Practitioner 'A' and Practitioner 'B') data for absolute and relative test measures for a standardised battery of anthropometric field test measures for elite youth (Under 12 to 16 years) soccer players'.

Practitioner A Vs. B	Stature (cm)	Seated height (cm)	PHV (Y)
Sample size	*n* = 45	*n* = 45	*n* = 45
Practitioner A (Mean ± SD)	158.7 ± 36.2	78.1 ± 16.3	14.6 ± 0.6
Practitioner B (Mean ± SD)	156.3 ± 35.3	75.0 ± 14.5	14.9 ± 0.6
Practitioner A range	133.1 to 184.3	66.6 to 89.6	15.7 to 16.8
Practitioner B range	131.3 to 181.3	64.8 to 85.2	13.3 to 13.6
ICC (CI)	1.00 (1.00 to 1.00)	0.93 (0.87 to 0.96)	0.88 (0.80 to 0.93)
ICC descriptor	Perfect	Nearly perfect	Very large
MD% (CI%)	-1.5 (-1.6 to -1.4)	4.0 (-4.6 to -3.1)	2.6 (2.0 to 3.2)
Typical error (CI)	0.4 (0.3 to 0.5)	1.5 (1.2 to 1.9)	0.2 (0.2 to 0.3)
CV% (CI)	0.2 (0.2 to 0.3)	1.9 (1.6 to 2.4)	1.4 (1.2 to 1.8)
SWC%	1.5	1.4	0.8
SWC	2.3	1.1	0.1

ICC = Intraclass correlation; MD% =Percentage mean difference; CV% = Percentage coefficient of variation; CI = 95% confidence interval expressed in absolute units of measurements; CI% = 95% confidence interval expressed relatively; SWC% = Percentage smallest worthwhile change; SWC = Absolute smallest worthwhile change.

Table 6. Summary table of absolute and relative reliability for a standardised battery of physical fitness field test measures for elite youth (Under 12 to 16 years) and senior amateur soccer players' interspaced by 7-days.

	CMJ (cm)	Agility (s)	10 m sprint (s)	20 m sprint (s)	MSFT (m)
Sample size	*n = 21*	*n* = 21	*n* = 44	*n* = 44	*n* = 41
Week 1 (Mean ± SD)	35.1 ± 2.9	10.72 ± 0.41	1.82 ± 0.13	3.25 ± 0.30	1839 ± 370
Week 2 (Mean ± SD)	34.7 ± 2.9	11.04 ± 0.36	1.77 ± 0.11	3.16 ± 0.26	1848 ± 389
Week 1 Range	30.2 to 39.2	10.17 to11.63	1.56 to 2.04	2.28 to 3.56	1120 to 2740
Week 2 Range	28.5 to 39.4	10.49 to 11.90	1.58 to 1.99	2.55 to 3.74	1240 to 2820
ICC (CI)	0.50 (0.14 to 0.79)	0.79 (0.53 to 0.91)	0.85 (0.74 to 0.92)	0.70 (0.51 to 0.82)	0.91 (0.84 to 0.95)
ICC descriptor	Large	Very large	Very large	Very large	Nearly perfect
MD% (CI%)	-1.1 (-4.7 to 2.6)	3.0 (1.9 to 4.1)	2.9 (1.8 to 4.0)	-1.1 (-2.6 to 0.5)	0.4 (-2.3 to 3.2)
Typical error (CI)	2.0 (1.5 to 2.9)	0.17 (0.13 to 0.25)	0.08 (0.06 to 0.10)	0.08 (0.06 to 0.10)	110 (90 to 140)
CV% (CI%)	5.9 (4.6 to 9.0)	1.7 (1.3 to 2.4)	2.7 (2.2 to 3.4)	4.9 (4.1 to 6.4)	6.5 (5.5 to 8.7)
SWC%	1.8	0.7	1.4	1.8	4.7
SWC	0.6	0.08	0.03	0.06	75

ICC = Intraclass correlation; MD% =Percentage mean difference; CV% = Percentage coefficient of variation; CI = 95% confidence interval expressed in absolute units of measurements; CI% = 95% confidence interval expressed relatively; SWC% = Percentage smallest worthwhile change; SWC = Absolute smallest worthwhile change.

4.4 Discussion

The principal aim of this chapter was to examine the between and within-practitioner reliability of anthropometrical field-tests used to measure growth and estimate maturity status of elite youth soccer populations governed by the EPPP (The English Premier League, 2011). This chapter also sought to assess the short-term reliability of a standardised battery of physical fitness field-tests and establish the minimum threshold for SWC for anthropometric, estimated maturity and physical fitness measures in order to help monitor the extent of the maturity-selection hypothesis and player development throughout the EPPP pathway. The main findings were: 1) the anthropometric field-tests used by multiple elite youth soccer development centres to assess player growth and estimate player maturity were shown to have a high level of short-term reliability, having a *near perfect* to *perfect* reproducibility for anthropometric and estimated PHV measures respectively; 2) between-practitioner variability and subsequent short-term reliability for the assessment of player growth and estimated maturity was shown to be high; 3) the physical assessments implemented in the present chapter were shown to have a high level short-term reliability, having *large* to *nearly perfect* between-week correlations.

As the Foundation, Youth and Professional phases of elite youth soccer development are considered specialised areas of the EPPP (The English Premier League, 2011), TD practitioners and coaches are often assigned to work within specific chronological age groups for each of these phases. Therefore, situational factors may lead to players' being subject to inconsistent anthropometric measures caused by between-practitioner variation as players' annually graduate throughout the development pathway. Such variations in practitioner measurement accuracy may result in erroneous baseline measures from which each player is annually evaluated. In the present chapter, anthropometric and estimated somatic maturity data revealed that practitioner s' 'A' and

‘B’ displayed high levels of short-term reliability (**Tables 3 and 4**). However, practitioner ‘A’ demonstrated marginally superior consistency for stature (TE = -1.3 cm, CV = -0.4%), seated height (TE = -1.3 cm, CV = -1.7%) and estimated maturity status (TE = -0.2 years, CV-1.2%). Although the between-practitioner differences were marginal, such variance could exacerbate the measurement error (±0.24 years) encompassed within the predictive equation for player somatic maturity (Mirwald et al., 2002) resulting in ~4 months (~120 days) measurement variation. Such evidence illustrates the potential issues of having multiple TD practitioners responsible for taking anthropometric measures within an applied environment.

Considering that the EPPP mandates the measurement of growth and estimated maturity within its test battery (The English Premier League, 2011), elite youth soccer TD practitioners might be considerate of the influence that between-practitioner variation may have on anthropometric measures of players when benchmarking their growth to club and EPPP records. The minimum threshold for SWC values reported for differences in stature owing to playing position using a sample of Belgian elite youth soccer players’ (U11 to U17) shows a much lower threshold for change (1.1 to 1.8 cm) (Deprez, Fransen, et al., 2014) than reported in the present study (2.3 cm). This is likely due to differences in stadiometer, with Deprez, Fransen, et al. (2014) having used a semi-fixed stadiometer rather than the portable equipment used in the present chapter, which will have likely removed the measurement error embroiled within the estimation of player leg length from stature minus seated height.

Given the individual nature of the adolescent growth curve, it might be considered practical that the deployment of minimum thresholds for SWC should be calculated on an individual level, and that such thresholds should account for multiple practitioner measures (if applicable), permitting each development centres sports-medicine department to evaluate player growth across the EPPP. This rigor will assist TD practitioners to accurately establish true changes in stature, body-mass and PHV when assessing player development trajectories. Regardless, caution is warranted when interpreting changes in maturity status and TD practitioners are urged to be considerate of the absolute error (±0.24 years) associated with the algorithmic equation used to determine players' (male) estimated PHV (Bailey, 1997; Bailey et al., 1999).

The standardised battery of physical fitness field-tests used in the present chapter demonstrated *very large* to *nearly perfect* within-player correlations between repeated week data collection sessions. The CMJ and agility protocols were proven to have adequate short-term measurement reliability (CMJ: CV = 5.9%; agility: CV = 1.7%) that compared to previous literature examining CMJ (Hulse et al. (2012): CV = 4.7 to 5.0%) and agility (Sporis, Jukic, Milanovic, and Vucetic (2010): CV= 3.3%). In accordance to previous reliability studies (Leger & Lambert, 1982; Van Mechelen, Hlobil, & Kemper, 1986), the data presented for the MSFT performance (**Table 6**) in this chapter demonstrated a *nearly perfect* intraclass correlation (r = 0.91) with good short-term reliability (MD = 0.4%, TE = 110 m, CV = 6.5 %) and a SWC of 4.7 % (75 m). Such findings are comparable to that of previously reported data for similar incremental tests (Université de Montreal track test (r = 0.89) (Uger & Boucher, 1980) and the Yo-Yo Intermittent Recovery test (CV = 4.9 %, r = 0.98) (Krustrup et al., 2003) for athletic populations. Short-term reliability data generated in the present chapter supports the notion that the MSFT is a reliable field-test to assess the absolute endurance capacity of multiple players' using the total distance covered during the MSFT.

The endurance capacity is of obvious importance for elite soccer players to train and perform optimally (Reilly, Bangsbo, et al., 2000). However, given that soccer is a multifaceted team sport, that requires players' to perform high intensity intermittent bouts of match activity over the course of a 90 minute soccer match (Buchheit et al., 2010a), the EPPP mandates the monitoring of sprint development within sprint young players'(The English Premier League, 2011). The relative and absolute short-term reliability of the maximal sprint tests (**Table 6**) observed good reliability across 10 and 20 m (10 m:, CV = 2.7%; 20 m: CV = 4.9 %) respectively. Albeit displaying slightly larger CV to previous 10 m (CV = 2.2%) and 20 m (CV = 1.5 to 1.7%) sprint time data reported for other elite youth soccer development centres respectively (Buchheit & Mendez-Villanueva, 2013; Hulse et al., 2012). Although, the sample of elite youth soccer players used in this chapter were representative of those players used in previous research (Buchheit & Mendez-Villanueva, 2013; Hulse et al., 2012), it might be inferred that the slightly enhanced CV for sprint times in this chapter are a result of an inferior sample size and therefore variability in performance is somewhat accentuated. That being said, the SWC established for physical fitness tests in the present chapter (**Table 6**) were comparable to similar tests (CMJ: 0.6 to 0.7 cm; 30 m sprint: 0.01 to 0.05 s; T-Tests: 0.05 to 0.09 s; YYIRT: 40 to 86 m) used for Belgian elite youth (U9 to U17) soccer players' (Deprez, Fransen, et al., 2014) showing consistency across the literature.

The application of the minimum threshold for SWC established in this chapter can retrospectively contextualise previous research studies that have examined the between-birth quartile (Carling et al., 2009), playing position (Deprez et al., 2013; Gil et al., 2007) and selection criteria of elite youth soccer populations. For instance, a study that examined the physical characteristics that influenced the deselection of players' from elite youth soccer development programmes, showed deselected players' to have inferior CMJ (-0.8 to 4.4 cm), 30m sprint (+0.08 to 0.21 s) and aerobic endurance (-113 to 306 m) performances in comparison to their 'selected' counterparts across the entire development pathway (Deprez, Fransen, et al., 2015). Interestingly, many of these differences were not reported as being statistically significant, but exceed the threshold for SWC set for these characteristics in the present chapter. Therefore, TD practitioners should consider the use of implementing a progressive statistical approach to athlete development monitoring and establish the SWC associated to their test battery that will permit them to confidently identify the magnitude of player development attributable to training and normal growth curves.

4.5 Conclusions

In conclusion, the results from the present chapter confirmed that the standardised battery of anthropometric, somatic maturity and physical fitness field-tests implemented in this thesis and by multiple elite youth soccer development centres overall demonstrated a high level of short-term reliability. Subsequently deeming this field test battery as capable of monitoring changes in elite youth soccer player athletic development, growth and maturity in order to further investigate the extent of the maturation-selection hypothesis with the EPPP.

In general, the test battery used in the present thesis (and indeed the EPPP test battery) is simple and easy to administer. However, establishing a rigorous testing protocol for all field-tests, accompanied by between and within-practitioner variation for anthropometric measures should be considered in order to allow TD practitioners to make statistically based assumptions regarding each player's current development status and trajectory. It is acknowledged that the testing battery implemented in the present study was not exhaustive and failed to include field-tests capable of measuring other components of soccer performance such as strength, flexibility, intermittent –endurance capacity, movement-efficiency and technical ability. Future research is required that implements a SWC approach to examine the influence of somatic maturity and chronological playing age across the EPPP on physical phenotype development relative to relative age and playing position of elite youth soccer players'. With this in mind, this thesis will now implement the SWC values established in this chapter to contextualise findings of the following research chapters that will examine the physical phenotypes, maturity status and relative age of elite youth soccer participating within the EPPP.

Chapter 5. Physical Phenotypes and Relative Age Effect within Elite-Youth Soccer: Examining the Elite Player Performance Plan.

5.1 Introduction

Introduced in 2011, the EPPP (The English Premier League, 2011) was established as a longitudinal strategy to provide talented young soccer players' with coaching and support services throughout their soccer development. As discussed in **Chapter 2**, the EPPP mandates the systematic recordings of player somatic maturity status, growth and physical fitness development during the 'Foundation' (U 9 to U11) 'Youth' (U12 to U16) and 'Professional' (U17 to U21) stages of player development, using a standardised battery of physical fitness and anthropometric field-tests (The English Premier League, 2011). Given that the anthropometric and physical fitness field-tests used to assess player growth and physical phenotype development have a high level of short-term reliability (**Chapter 4**), in principle this database permits TD practitioners to quantify the growth and athletic development of players' in relation to their maturity status and benchmark their progress against the EPL national database (The English Premier League, 2011).

TD practitioners ability to accurately benchmark players' development relative to their maturity status and relative age is intuitive given that normative growth curves (Malina, Bouchard, et al., 2004; Malina et al., 2000) of relatively older players', born earlier in the soccer selection year often elicit enhanced anthropometric (stature and body-mass) characteristics. This phenomena often results in the recruitment of players' for talent programmes seemingly based on transient enhancements in physical and anthropometric phenotypes, commonly known as the maturation-selection hypothesis (Cobley et al., 2009; Helsen et al., 2005) (**Chapter 2**). This hypothesis is considered a primary contributory factor for the over-selection of early maturing players', and the systematic discrimination of chronologically categorised players' born later in the domestic soccer season (Carling et al., 2009; Deprez et al., 2013; Hirose, 2009; Lovell et al., 2015). The maturation-selection hypothesis may in part offer explanation for the over-representation of elite youth soccer players' born in the first quartile (Q1) of the selection year in European (Carling et al., 2009; Helsen et al., 2005; Vaeyens et al., 2005) and Asian (Hirose, 2009) soccer leagues, better known as the relative age effect (RAE) (Barnsley, Thompson, & Legault, 1992; Cobley et al., 2008) (**Chapter 2**).

Pertinent research suggests that the physical advantages afforded to relatively older players' may in-fact be tempered by TD practitioners recruitment of players' who enter adolescence earlier (Deprez et al., 2012; Till et al., 2010). This selection phenomena seemingly enables relatively younger players' to physically compete with their relatively older counterparts in absolute terms due to physical advantages owing to their enhanced maturity related anthropometric and physical characteristics. However, consensus suggests that the existence of enhanced anthropometric characteristics for players' born at the beginning of the selection year versus those players' towards the end, subsequently decreases with advancing decimal age (Cobley et al., 2009; Helsen et al., 1999) as players' achieve complete maturity circa to the professional stage (~17 years) of the EPPP pathway (The English Premier League, 2011). Therefore, peak differences in anthropometric characteristics between relatively older versus younger pre-adolescent (U9 to 12) elite youth soccer players' may coincide with the slowest rate of PHV since birth (Tanner et al., 1966). This suggests that the anthropometric advantages afforded to relatively older elite youth soccer players' might be pronounced during the 'Foundation' and 'Youth' development phases of the EPPP, serving as a catalyst for the maturation-selection hypothesis. This is of particular relevance, given that this phase of the EPPP represents the foundation in which the entire development pathway is constructed and therefore, any selection bias here is likely to influence the composition of future age groups as players graduate throughout the development pathway and are exposed to more advanced coaching, competition, and facilities.

A large body of literature is available that has examined the influence of the maturation-selection hypothesis (Cobley et al., 2009; Helsen et al., 2005) and RAE within an elite youth soccer environment (Carling et al., 2009; Cobley et al., 2008; Deprez et al., 2013; Deprez et al., 2012; Helsen et al., 1999; Hirose, 2009). However, fewer studies have specifically investigated if enhancements in maturity related physical phenotypes of relatively older elite youth players' (Carling et al., 2009; Deprez et al., 2012; Malina, Ribeiro, et al., 2007) (particularly during pre-adolescents (Hirose, 2009)) act as discriminatory factors toward the selection (Vandendriessche et al., 2012) and deselection (Helsen et al., 1999) of these players'. With no studies having examined such selection hypotheses using UK elite youth soccer players'. Hence, practical applications drawn from the current literature may be subject to between country differences in player selection bias, which are representative of recruitment policies and local TD philosophies of individual talent development centres having only sampled players' from few (≤ 2) domestic (Deprez et al., 2013; Deprez, Fransen, et al., 2014; Hirose, 2009) and international development centres (Carling et al., 2009). Therefore, the extent of the maturation-selection hypothesis and RAE existence in UK elite youth soccer development centres governed by the EPPP remains unresolved; potentially limiting our understanding of the factors that underpin selection biases and retention policies of UK talent development centres. Therefore, using a standardised battery of reliable field-tests (**Chapter 4**), the aim of the present chapter was to firstly quantify the RAE within a broad sample of elite youth soccer players' and then assess the presence of the maturation-selection hypothesis by quantifying players physical phenotypes according to birth quartile. It is hypothesised that the recruitment of players' for soccer TD programmes within the UK is influenced by transient enhancements in maturity related physical phenotypes associated to players' born earlier in the soccer selection year.

5.2 Procedures

5.2.1 Participants

Having institutional ethical approval, 731 volunteering young elite soccer players' who were partaking within the Pro-Football Support player development program were divided in chronological playing groups (U 11 [n = 85]; U12 [n = 102]; U13 [n = 92] U14 [n = 105]; U15 [n = 98]; U16 [n= 50]; U17 [n = 116]; U18 [n = 83]). Players' were sampled from 17 development centres during an in-season phase (November to May) of the 2011-12, 2012-13, and 2013-14 soccer seasons (1^{st} September to August 31^{st}) (**Chapter 3, Table 1**). All players were participating for, and affiliated to, professional soccer clubs competing in professional competitions in the UK. All players' participated in development programmes governed by the EPL EPPP and dependent on their stage of development, players' received either 6 to 12 (Youth development) and 16 hours (Professional development) of coaching each week (The English Premier League, 2011), competing in at least one competitive soccer match. All of the players' performed a standardised battery of field assessments (**Chapter 3**) to ascertain anthropometric, maturity and physical fitness attributes. All elements of the field test battery were delivered by trained Pro-Football Support members of staff.

The field tests were established as having high short-term reliability (**Chapter 4**). During the tests players' wore their usual training attire and had been habituated with each separate component of the field test battery during routine pre-season testing.

5.2.2 Relative Age Distribution Characteristics

Players' relative age discriminated by birth quartile was established using procedures outlined in **Chapter 3**.

5.2.3 Anthropometric and Somatic Maturity Characteristics

Using the methods outlined in **Chapter 3**, players' stature, seated height and body-mass were recorded. All measures here demonstrated adequate between and within-practitioner short-term reliability (**Chapter 4**). In combination with anthropometric measures, decimal age was used to determine player somatic maturity status using the methods detailed in **Chapter 3**, a method shown to have 'very good' between- and within-practitioner short-term reliability (**Chapter 4**).

5.2.4 Physical Fitness Characteristics

Players' performed a battery of physical fitness tests, consisting of five field-tests implemented to assess individual components (lower-limb power, maximal sprint speed, agility and endurance capacity) of soccer specific fitness according to the methods described in **Chapter 3**. The standardised battery of physical fitness returned 'good' to 'excellent' short-term reliability **(Chapter 4**).

5.2.5 Statistical Analysis

Chi-squared analyses were conducted to investigate differences between birth distribution according to quartiles of the domestic soccer selection season observed for the bi-annual age groupings in the present chapter in comparison to those expected, which were derived from National census data, of UK births between 1996–2004 identified an approximately even birth distribution across quartiles (Q1: 25.6%; Q2: 24.2%; Q3: 24.8%; Q4: 25.4%). A technique for obtaining regression estimates in multilevel modelling known linear marginal models (Heagerty & Zeger, 2000) and pairwise comparisons, with Sidak-adjusted p values, were conducted to determine the difference of anthropometric, maturity status and physical fitness characteristics according to relative age, discriminated by quartile distribution (Q1, Q2, Q3, Q4) across each age group. This thesis also examined if these effects were moderated by the stage of development. Chronological playing age groups were aggregated bi-annually U11 to 12 (n = 187); U13 to 14 (n = 197); U15 to 16 (n = 148); U17 to 18 (n = 199) to facilitate sufficiently powered contrasts as similar to previous studies (Deprez, Fransen, et al., 2014). The minimum thresholds for SWC established in **Chapter 4** of this thesis were applied to contextualise findings and assess if true between quartile differences were apparent. Statistical significance for all null hypothesis tests was set at $P \leq 0.05$. Values are reported as the estimated marginal means and associated standard errors, accompanied by estimates of effect according to the criteria of Hopkins et al. (2009) (<0.2 *trivial*, 0.2-0.6 *small*, 0.6-1.2 *moderate*, 1.2-2.0 *large* and >2.0 *very large*). All statistical assumptions were examined using standard graphical methods (Grafen, 2002) and analyses were completed using IBM SPSS Statistics for windows software (release 22; SPSS Inc., Chicago, IL, USA).

5.3 Results

5.3.1 Relative Age Distribution Characteristics

Between-quartile relative age distributions for each bi-annual age group are shown in **Figure 5**. Pearson Chi-Squared test revealed that the birth distributions observed in the present chapter for each biannual age group significantly differed to those expected for UK births between 1996–2004 (U11 to 12: $P = 0.001$; U13 to 14: $P \leq 0.001$; U15 to 16: $P \leq 0.001$; U17 to 18: $P \leq 0.001$). An un-even distribution was identified for each cohort, showing that 39 to 57% of players’ were born in Q1, and 6 to 14% in Q4. There was a clear over-representation of players’ born in Q1 (39%) of the U11 to 12 cohort, subsequently increasing thereafter in the U11 to 12 (46%) and U15 to 16 (57%) cohorts, before lessening in the U17 to18 (42%) bi-annual age groups.

5.3.2 Anthropometric Characteristics

There were no significant main effects for body-mass and stature between-quartiles (Q1, Q2, Q3, Q4) across the selection year across of all biannual, chronological age groups (body-mass: P = 0.055 to 0.982; stature: P = 0.057 to 0.864) (**Tables 7 to 10**). However, as displayed in **Tables 7 to 9**, players' born in Q1 tended to be *moderately* taller (stature: ES = 0.62 to 1.06) and *small* to *moderately* heavier (body-mass: ES = 0.48 to 0.57) than players' who were born across the rest of the selection year. However such differences did not reach significance (stature: P = 0.115 to 1.000; body-mass: P = 0.090 to 1.000).

5.3.3 Somatic Maturity Characteristics

There was significant main effect for APHV across quartiles for U11 to U12 (P = 0.042) and U17 to U18 (P = 0.001) decimal age categories only (**Table 7 and 10**). The U17 to U18 bi-annual age group demonstrated a statistically significant higher between-quartile difference in maturity for players' born in Q1 versus those born later in the selection year in Q3 (P = 0.015, ES = 0.64) and Q4 (P = 0.010, ES = 0.70) respectively (**Table 10**). However, although a statistically significant main effect was present (P = 0.042) in the U11 to U12 group (**Table 7**), pairwise analysis revealed that no statistically significant between-quartile differences (P = 0.148 to 1.000) were present for maturity.

5.3.4 Physical Fitness Characteristics

There were no significant differences in agility (P = 0.108 to 0.643) performance owing to birth date distribution across all decimal age groups (**Tables 7 to 10**). Similarly, there was no significant main effect for 10 m (P = 0.122 to 0.886) and 20 m (0.090 to 0.911) sprint times respectively (**Tables 7 to 10).** Subsequently demonstrating very little difference in agility (P = 0.810 to 0.972, ES = 0.18 to 0.35) and linear sprint (10 m: P = 0.154 to 1.000, ES: 0.10 to 0.51; 20 m: P = 0.154 to 1.000, ES = 0.07 to 0.54) performance between players' born in Q1 versus Q4 across all age groups (**Tables 7 to 10**).

Moderate between-quartile differences were identified for CMJ in the U17 to U18 cohort (**Table 11**), whereby players' born in Q1 displayed greater CMJ capacity than their Q3 counterparts (P = 0.004, ES = 0.73). Pairwise analyses identified a statistically significant main effect owing to birth date distribution for MSFT performance (P = 0.031) in the U15 to U16 cohort (**Table 9**), showing that players born in Q1 have a *small, moderate* enhancement in MSFT performance (ES = 0.34 to 0.91) performance that was significant for Q2 versus Q4 (P = 0.041, ES = 0.91).

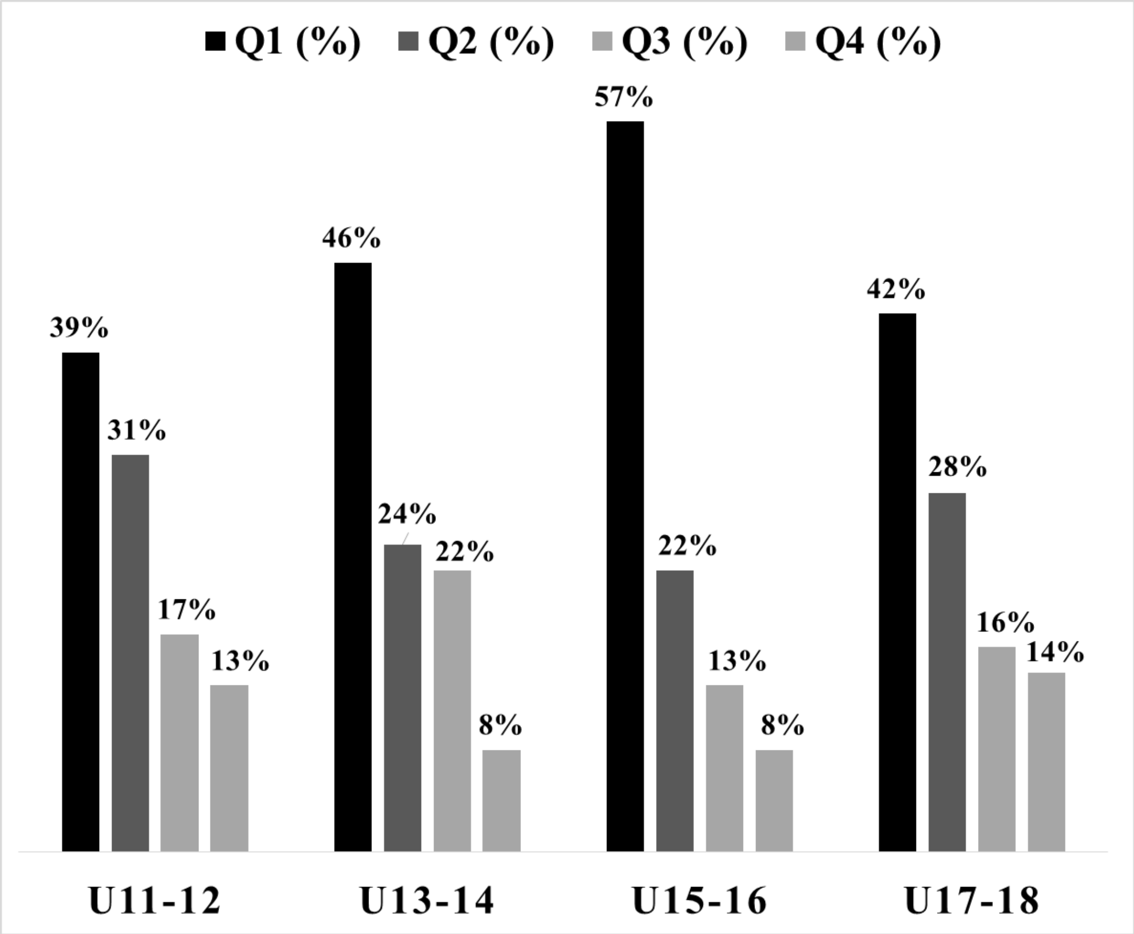


Figure 5. Quartile (Q1 = 1st September to 30th November; Q2 = 1st December to 28th February; Q3 = 1st March to 31st May; Q4 = 1st June to 31st August) birth date distribution of 731 English elite youth soccer players according to bi-annual age groups.

Table 7. Estimated marginal means (SE) of anthropometrical and physical fitness characteristics for elite youth (U11 to 12) soccer players' according to their relative age from 15 different elite soccer development centres in England.

U11-12

Variable	**Cohort**	**Q1**	**Q2**	**Q3**	**Q4**	***P***	**Q Differences**
n (%)	187 (100)	71 (39)	58 (31)	33 (17)	25 (13)		
Age (y)	11.7 (0.4)	11.9 (0.1)	11.7 (0.1)	11.5 (0.1)	11.2 (0.1)	***P* ≤ 0.001**	Q1 > ***Q2**, *<u>**Q3**</u>, *<u>**Q4**</u>
Stature (cm)	148.8 (0.6)	149.2 (0.8)	149.0 (0.9)	147.6 (1.2)	145.4 (1.4)	*P* = 0.096	Q1 > *Q2*, <u>Q3</u>, **Q4**
Body-mass (kg)	39.6 (0.5)	40.3 (0.7)	39.8 (0.8)	38.0 (1.0)	36.9 (1.2)	*P* = 0.055	Q1 > *Q2*, <u>Q3</u>, <u>Q4</u>
APHV	13.9 (0.1)	14.0 (0.1)	13.8 (0.1)	13.8 (0.1)	13.8 (0.1)	***P* = 0.042**	Q1 > <u>Q2</u>, <u>Q3</u>, <u>Q4</u>
CMJ (cm)	23.3 (0.5)	23.4 (0.7)	24.0 (0.8)	21.6 (1.1)	22.4 (1.2)	*P* = 0.306	Q2 > Q1, Q3, Q4
T-Test (s)	11.09 (0.04)	11.00 (0.06)	11.07 (0.07)	11.28 (0.09)	11.13 (0.10)	*P* = 0.108	Q1 < *Q2*, <u>Q3</u>, <u>Q4</u>
10 m sprint (s)	1.86 (0.01)	1.84 (0.01)	1.85 (0.01)	1.87 (0.02)	1.89 (0.02)	*P* = 0.122	Q1 < *Q2*, <u>Q3</u>, <u>Q4</u>
20 m sprint (s)	3.41 (0.01)	3.40 (0.02)	3.39 (0.02)	3.43 (0.03)	3.48 (0.03)	*P* = 0.090	Q2 < *Q1*, <u>Q3</u>, <u>Q4</u>
MSFT (m)	1447.6 (20.9)	1460.8 (33.2)	1469.9 (39.1)	1372.4 (48.9)	1445.3 (56.0)	*P* = 0.420	Q2 < *Q1*, <u>Q3</u>, *Q4*

* Denotes threshold for significance set at P ≤ 0.05 for subscripted variables; Q = Quartile of the selection year (September 1st to August 31st), APHV = estimated age at peak height velocity, MSFT = Distance achieved during the Multi-Stage Fitness Test, CMJ = Vertical counter movement jump. *Italic*, <u>underlined</u>, **emboldened** denote trivial, small and moderate magnitudes of effect observed. With <u>***large***</u> and <u>**very large**</u> effects signified using a combination of the previously aforementioned annotations.

Table 8. Estimated marginal means (SE) of anthropometrical and physical fitness characteristics for elite youth (U13 to 14) soccer players' according to their relative age from 15 different elite soccer development centres in England.

U13-14

Variable	**Cohort**	**Q1**	**Q2**	**Q3**	**Q4**	***P***	**Q Differences**
n (%)	197 (100)	90 (46)	48 (24)	43 (22)	16 (8)		
Age (y)	13.7 (0.1)	13.9 (0.1)	13.7 (0.1)	13.5 (0.1)	13.2 (0.1)	***P* ≤ 0.001**	Q1 > ***Q2**, ****Q3*****,** ***Q4**
Stature (cm)	162.9 (0.7)	164.0 (0.9)	162.5 (1.3)	160.9 (1.3)	158.8 (2.0)	*P* = 0.057	Q1 > *Q2*, Q3, **Q4**
Body-mass (kg)	51.5 (0.6)	52.1 (0.8)	51.2 (1.2)	50.0 (1.2)	48.1 (2.0)	*P* = 0.253	Q1 > *Q2*, Q3, Q4
APHV	14.2 (0.1)	14.1 (0.1)	14.1 (0.1)	14.2 (0.1)	14.1 (0.1)	*P* = 0.721	Q3 < *Q1*, *Q2*, *Q4*
CMJ (cm)	27.6 (0.4)	27.7 (0.6)	28.3 (0.9)	27.0 (0.9)	25.9 (1.5)	*P* = 0.493	Q4 < Q1, Q2, *Q3*
T-Test (s)	10.2 (0.04)	10.28 (0.05)	10.18 (0.08)	10.32 (0.08)	10.17 (0.13)	*P* = 0.563	Q4 < Q1, *Q2*, Q3
10 m sprint (s)	1.72 (0.01)	1.71 (0.01)	1.76 (0.01)	1.73 (0.01)	1.72 (0.01)	*P* = 0.472	Q1 < *Q2*, Q3, *Q4*
20 m sprint (s)	3.13 (0.01)	3.12 (0.02)	3.13 (0.02)	3.16 (0.03)	3.16 (0.04)	*P* = 0.582	Q1 < *Q2*, Q3, *Q4*
MSFT (m)	1803.9 (21.5)	1804.2 (30.8)	1777.5 (44.1)	1801.2 (44.9)	1900.0 (73.2)	*P* = 0.558	Q4 < Q1, Q2, Q3

* Denotes threshold for significance set at P ≤ 0.05 for subscripted variables; Q = Quartile of the selection year (September 1st to August 31st), APHV = estimated age at peak height velocity, MSFT = Distance achieved during the Multi-Stage Fitness Test, CMJ = Vertical counter movement jump. *Italic*, underlined, **emboldened** denote trivial, small and moderate magnitudes of effect observed. With ***large*** and **very large** effects signified using a combination of the previously aforementioned annotations.

Table 9. Estimated marginal means (SE) of anthropometrical and physical fitness characteristics for elite youth (U15 to 16) soccer players' according to their relative age from 15 different elite soccer development centres in England.

U15-16

Variable	**Cohort**	**Q1**	**Q2**	**Q3**	**Q4**	***P***	**Q Differences**
n (%)	148 (100)	84 (57)	32 (22)	19 (13)	13 (8)		
Age (y)	15.5 (0.1)	15.7 (0.1)	15.5 (0.1)	15.4 (0.1)	15.0 (0.1)	***P* ≤ 0.001**	Q1 > ***Q2**, ****<u>Q3</u>***, ***<u>Q4</u>**
Stature (cm)	174.9 (0.5)	175.8 (0.7)	174.6 (1.2)	175.5 (1.6)	174.9 (1.9)	*P* = 0.842	Q1 > *Q2*, *Q3*, *Q4*
Body-mass (kg)	64.4 (0.6)	65.4 (0.8)	63.1 (1.3)	65.0 (1.7)	65.4 (2.1)	*P* = 0.531	Q1 < <u>Q2</u>, <u>Q3</u>, <u>Q4</u>
APHV	14.1 (0.1)	14.1 (0.1)	14.1 (0.1)	14.1 (0.1)	13.9 (0.1)	*P* = 0.574	Q4 < <u>Q1</u>, <u>Q2</u>, <u>Q3</u>
CMJ (cm)	28.7 (0.6)	28.6 (0.1)	27.6 (1.4)	31.7 (01.8)	28.3 (2.3)	*P* = 0.368	Q3 > <u>Q1</u>, <u>Q2</u>, <u>Q4</u>
T-Test (s)	9.61 (0.04)	9.55 (0.05)	9.52 (0.09)	9.57 (0.11)	9.74 (0.14)	*P* = 0.643	Q4 > <u>Q1</u>, <u>Q2</u>, <u>Q3</u>
10 m sprint (s)	1.61 (0.01)	1.61 (0.01)	1.61 (0.01)	1.62 (0.02)	1.63 (0.02)	*P* = 0.886	Q4 > *Q1*, <u>Q2</u>, *Q3*
20 m sprint (s)	2.92 (0.01	2.92 (0.02)	2.90 (0.02)	2.93 (0.03)	2.93 (0.04)	*P* = 0.911	Q2 < *Q1*, *Q3*, *Q4*
MSFT (m)	2087.0 (22.3)	2107.8 (29.1)	2219.3 (46.8)	2065.5 (59.8)	1975.5 (75.6)	***P = 0.031***	Q4 < <u>Q1</u>, **Q2**, <u>Q3</u>

* Denotes threshold for significance set at P ≤ 0.05 for subscripted variables; Q = Quartile of the selection year (September 1st to August 31st), APHV = estimated age at peak height velocity, MSFT = Distance achieved during the Multi-Stage Fitness Test, CMJ = Vertical counter movement jump. *Italic*, <u>underlined</u>, **emboldened** denote trivial, small and moderate magnitudes of effect observed. With ***<u>large</u>*** and **<u>very large</u>** effects signified using a combination of the previously aforementioned annotations.

Table 10. Estimated marginal means (SE) of anthropometrical and physical fitness characteristics for elite youth (U17 to 18) soccer players' according to their relative age from 15 different elite soccer development centres in England.

U17-18

Variable	Cohort	Q1	Q2	Q3	Q4	*P*	Q Differences
n (%)	199 (100)	84 (42)	56 (28)	31 (16)	28 (14)		
Age (y)	17.4 (0.1)	17.8 (0.1)	17.5 (0.1)	17.1 (0.1)	17.0 (0.1)	***P* ≤ 0.001**	Q1 < ***Q2**, *<u>***Q3***</u>, *<u>***Q4***</u>
Stature (cm)	179.0 (0.4)	178.7 (0.6)	178.8 (0.8)	179.7 (1.0)	178.8 (1.1)	*P* = 0.864	Q3 < *Q1*, *Q2*, *Q4*
Body-mass (kg)	73.2 (0.5)	73.3 (0.7)	73.1 (0.9)	72.9 (1.1)	72.8 (1.2)	*P* = 0.982	Q1 < *Q2*, *Q3*, *Q4*
PHV	14.6 (0.1)	14.7 (0.1)	14.7 (0.1)	14.4 (0.1)	14.4 (0.1)	***P = 0.001***	Q1 > ***Q3**, ***Q4**; <u>Q2</u> > Q3, Q4
CMJ (cm)	35.7 (0.4)	36.8 (0.6)	35.0 (0.8)	31.7 (1.0)	36.5 (1.0)	***P = 0.005***	Q1 > <u>Q2</u>, ***Q3,** <u>Q4</u>
T-Test (s)	9.3 (0.1)	9.22 (0.04)	9.34 (0.06)	9.31 (0.07)	9.29 (0.08)	*P* = 0.395	Q1 > <u>Q2</u>, <u>Q3</u>, *Q4*
10 m sprint (s)	1.59 (0.01)	1.59 (0.01)	1.59 (0.01)	1.60 (0.01)	1.57 (0.01)	*P* = 0.250	Q4 < <u>Q1</u>, <u>Q2</u>, <u>Q3</u>
20 m sprint (s)	2.87 (0.01)	2.86 (0.01)	2.87 (0.01)	2.89 (0.02)	2.85 (0.02)	*P* = 0.322	Q4 < *Q1*, *Q2*, *Q3*
MSFT (m)	2299.9 (19.3)	2302.7 (29.1)	2284.4 (38.6)	2309.8 (47.8)	2347.0 (50.7)	*P* = 0.805	Q4 > *Q1*, <u>Q2</u>, *Q3*

* Denotes threshold for significance set at P ≤ 0.05 for subscripted variables; Q = Quartile of the selection year (September 1st to August 31st), PHV = estimated age at peak height velocity, MSFT = Distance achieved during the Multi-Stage Fitness Test, CMJ = Vertical counter movement jump. *Italic*, <u>underlined</u>, **emboldened** denote trivial, small and moderate magnitudes of effect observed. With <u>***large***</u> and <u>**very large**</u> effects signified using a combination of the previously aforementioned annotations.

Table 11. Summary table of between-quartile differences (Q1 – Q4) in anthropometric & fitness capacities between relatively older (Q1) and younger (Q4) soccer players' according to bi-annual age-groups.

Age group	Variable	Q1	Q4	Q1 - Q4 (± 95% CI)	ES	Qualitative	*P*
U11 to 12	n (%)	71 (39)	25 (13)	-	-	-	-
	Stature (cm)	149.2 (0.8)	145.4 (1.4)	3.8 (-0.5 to 8.2)	1.06	Moderate	*P* = 0.115
	Body-mass (kg)	40.3 (0.7)	36.9 (1.2)	3.4 (-0.3 to 7.1)	0.57	Moderate	*P* = 0.090
	APHV	14.0 (0.1)	13.8 (0.1)	0.2 (-0.1 to 0.5)	0.52	Moderate	*P* = 0.148
	CMJ (cm)	23.4 (0.7)	22.4 (1.2)	1.0 (-2.7 to 4.8)	0.17	Trivial	*P* = 0.979
	T-Test (s)	11.00 (0.06)	11.13 (0.10)	-0.12 (-0.46 to 0.20)	0.24	Small	*P* = 0.886
	10 m sprint (s)	1.84 (0.01)	1.89 (0.02)	-0.04 (-0.09 to 0.01)	0.51	Small	*P* = 0.154
	20 m sprint (s)	3.40 (0.02)	3.48 (0.03)	0.08 (-0.18 to 0.02)	0.54	Small	*P* = 0.154
	MSFT (m)	1460.8 (33.2)	1445.3 (56.0)	15.5 (-157.7 to 188.8)	0.02	Trivial	*P* = 0.791
U13 to 14	n (%)	90 (46)	16 (8)	-	-	-	-
	Stature (cm)	164.0 (0.9)	158.8 (2.0)	0.8 (-4.8 to 6.4)	0.62	Moderate	*P* = 0.128
	Body-mass (kg)	52.1 (0.8)	48.1 (2.0)	3.9 (-2.0 to 10.0)	0.48	Small	*P* = 0.400
	APHV	14.1 (0.1)	14.1 (0.1)	0.1 (0.4 to 0.5)	0.14	Trivial	*P* = 0.997
	CMJ (cm)	27.7 (0.6)	25.9 (1.5)	1.9 (-2.4 to 6.1)	0.31	Small	*P* = 0.826
	T-Test (s)	10.28 (0.05)	10.17 (0.13)	0.11 (-0.27 to 0.50)	0.21	Small	*P* = 0.972
	10 m sprint (s)	1.71 (0.01)	1.72 (0.01)	-0.01 (-0.07 to 0.05)	0.10	Trivial	*P* = 0.1000
	20 m sprint (s)	3.12 (0.02)	3.16 (0.04)	-0.03 (-0.14 to 0.08)	0.17	Trivial	*P* = 0.1000
	MSFT (m)	1804.2 (30.8)	1900.0 (73.2)	-95.7 (-307.1 to 115.5)	0.33	Small	*P* = 0.791

* Denotes threshold for significance set at P ≤ 0.05 for subscripted variables; Q = Quartile of the selection year (September 1st to August 31st), APHV = estimated age at peak height velocity, MSFT = Distance achieved during the Multi-Stage Fitness Test, CMJ = Vertical counter movement jump.

Table 11. (*Continued*)

Age group	Variable	Q1	Q4	Q1 - Q4 (± 95% CI)	ES	Qualitative	*P*
U15 to 16	n (%)	84 (57)	13 (8)	-	-	-	-
	Stature (cm)	175.8 (0.7)	174.9 (1.9)	0.8 (-4.7 to 6.4)	0.12	Trivial	*P* = 0.999
	Body-mass (kg)	65.4 (0.8)	65.4 (2.1)	0.1 (-6.0 to 6.2)	0.30	Small	*P* = 1.000
	APHV	14.1 (0.1)	13.9 (0.1)	0.2 (-0.2 to 0.7)	0.40	Small	*P* = 0.709
	CMJ (cm)	28.6 (0.1)	28.3 (2.3)	0.3 (-6.4 to 7.1)	0.04	Trivial	*P* = 0.1000
	T-Test (s)	9.55 (0.05)	9.74 (0.14)	-0.18 - (-0.61 to 0.24)	0.35	Small	*P* = 0.810
	10 m sprint (s)	1.61 (0.01)	1.63 (0.02)	-0.02 (-0.09 to 0.05)	0.19	Trivial	*P* = 0.991
	20 m sprint (s)	2.92 (0.02)	2.93 (0.04)	-0.01 (-0.13 to 0.11)	0.07	Trivial	*P* = 0.991
	MSFT (m)	2107.8 (29.1)	1975.5 (75.6)	132.3 (-80.9 to 348.5)	0.49	Small	*P* = 0.485
U17 to 18	n (%)	84 (42)	28 (14)	-	-	-	-
	Stature (cm)	178.7 (0.6)	178.8 (1.1)	0.1 (-3.5 to 3.4)	0.01	Trivial	*P* = 1.000
	Body-mass (kg)	73.3 (0.7)	72.8 (1.2)	0.5 (-3.3 to 4.2)	0.07	Trivial	*P* = 1.000
	APHV	14.7 (0.1)	14.4 (0.1)	0.4 (0.1 to 0.6)	0.70	Moderate	***P* = 0.010**
	CMJ (cm)	36.8 (0.6)	36.5 (1.0)	0.4 (-2.9 to 3.6)	0.07	Trivial	*P* = 1.000
	T-Test (s)	9.22 (0.04)	9.29 (0.08)	-0.07 (0.31 to 0.16)	0.18	Trivial	*P* = 0.963
	10 m sprint (s)	1.59 (0.01)	1.57 (0.01)	0.02 (-0.02 to 0.05)	0.27	Small	*P* = 0.796
	20 m sprint (s)	2.86 (0.01)	2.85 (0.02)	0.02 (-0.04 to 0.07)	0.15	Trivial	*P* = 0.796
	MSFT (m)	2302.7 (29.1)	2347.0 (50.7)	-44.3 (-199.9 to 111.3)	0.17	Trivial	*P* = 0.972

* Denotes threshold for significance set at P ≤ 0.05 for subscripted variables; Q = Quartile of the selection year (September 1st to August 31st), APHV = estimated age at peak height velocity, MSFT = Distance achieved during the Multi-Stage Fitness Test, CMJ = Vertical counter movement jump.

5.4 Discussion

The primary aim of this chapter was to assess the influence of the maturation-selection hypothesis within player recruitment by quantifying the RAE and physical phenotypes of a broad sample of elite youth soccer players' enrolled in multiple elite youth soccer development centres in the UK, spanning U11 to U18 years of age. The main findings identified in this chapter were: 1) a clear un-even birth distribution was observed for each bi-annual age group, demonstrating an over-representation of players' born in Q1 of the selection year in each cohort which was significantly different to corresponding UK birth distribution records; 2) between-quartile differences were identified for measures of stature and body-mass in the cohorts typically associated to pre-circa PHV (U11 to U12 and U13 to U14), where relatively older players' (Q1) tended to be taller and heavier than players' born later in the selection year (Q4); 3) older players' competing in the 'Professional' (U17 to 18) phase of the EPPP were advanced maturers in comparison to players' born later in the selection year; 4) however, no such enhancements in maturity status were attributed to players' in the 'Youth' (U11 to U16) development phases of the EPPP; 5) relatively older players' demonstrated little physical advantage over their relatively younger counterparts across the entire (U11 to 18) EPPP development pathway.

In accordance to previous team-sport literature (Schorer et al., 2009; Sherar et al., 2007; Till et al., 2010) and indeed soccer (Carling et al., 2009; Cobley et al., 2008; Deprez et al., 2012; Helsen et al., 1999; Helsen et al., 2005; Mujika, Vaeyens, et al., 2009), there was a pronounced over-representation of players' born in first quartile of the selection year across the EPPP (**Figure 5**). This trend is in stark contrast to that of UK birth data, recorded over a ten year period (1993-2003) that showed an almost even across-quartile birth distribution (Q1: 25%; Q2: 24.2%; Q3: 25.1%; Q4: 25.7%) (Royal College of Paediatrics and Child Health., 2013). Additionally, these differences would continue if the birth distribution of the general population were separated according to decimal age-groupings (i.e. U11, U12, 13 etc.) often applied in sporting scenarios to categorise players' (Till et al., 2010). Given that the relationship of relative age, APHV and player physical phenotypes varied with advancing decimal age, the results of this chapter will now be discussed according to chronological, biannual age categories.

Under 11 to 12

The RAE achieved its lowest magnitude in the U11 to U12 (Q1 = 39%) bi-annual cohort, demonstrating that relatively older players' (Q1) were moderately (P = 0.148, ES = 2.01) advanced in terms of APHV in comparison to players' born later in the selection year (Q4), whilst expressing a *moderate* effect magnitude for enhanced stature (+ 3.8 cm). Given the decline in normative growth rate achieves its lowest since birth at approximately 11 years of age (Tanner et al., 1966), followed by a fast acceleration in growth nearing PHV pre-circa adolescents (approx. 12 years.) (Tanner et al., 1966), it can be assumed that that relatively younger U11 to U12 players' (and to lesser extent U13 to U14) are at risk of being disadvantaged in terms of stature due to the *moderate* (ES = 0.52) effect magnitude for enhanced estimated APHV between players' born in Q1 and Q4 (P = 0.148, ES = 0.52). This suggests that anthropometric differences observed in the Youth development phase of the EPPP (particularly the U11 to U12 cohort) likely reflect the relatively older player's earlier onset of the adolescent growth spurt. Therefore, suggestive of TD practitioner's preference for maturity related anthropometric characteristics and providing some evidence to affirm the presence of maturation-selection hypothesis within UK elite youth soccer development centres.

In addition, U11 to 12 players who were born in Q1 one of the selection year demonstrated *small* (10m: ES = 0.51; 20m: ES = 0.54) advantages in anaerobic qualities, having faster 10 (-0.04 s) and 20 m (-0.08 s) sprint times than their counterparts born in

Q4 (**Table 11**) which were marginally greater than the SWC established for 10 (0.03 s) and 20 m (0.06 s) in **Chapter 4** of this thesis. However, such *small* differences were transient, becoming *trivial* in the U13 to U14 (ES = 0.10 to 0.17), U15 to 16 (ES = 0.19 to 0.07) and U17 to 18 (ES = 0.15 to 0.17) cohorts. The physiological mechanisms that underpin these small improvements at U11-12 remains largely unresolved. However, given that the advanced maturity status and stature of these players, it is plausible to suggest that advanced APHV may offer explanation for advantages in anaerobic qualities of relatively older U11 to U12 players as these players are likely to be recipients of earlier performance related advantages (i.e. rate of speed development) associated to increased neural function developed circa-PHV (Mendez-Villanueva et al., 2010) (**Figure 1**.). Such mechanisms might act as a causal factor of the strong RAE within the EPPP, as anaerobic attributes (such as sprint speed) have been demonstrated to be desirable characteristics for TD selectors (Deprez, Fransen, et al., 2015).

Under 13 to 14

There was a statistically significant main effect for stature ($P \leq 0.001$) present within the U13 to U14 cohort, with relatively older (Q1) players being identified as *moderately* (ES = 0.62) taller (+ 5.2 cm) when compared to their relatively younger (Q4) counterparts, although not statistically significant (P = 0.128). Findings here, revealed that both U11 to U12 and U13 to U14 biannual age groups surpassed the group based threshold set for SWC in stature (1.1 cm) established in **Chapter 4** of this thesis, signifying a practical difference was present for Q1 versus Q4 of the selection year. Such between quartile (Q1 *vs*. Q4) differences in stature here are consistent to those for Japanese (Hirose, 2009) and French (Carling et al., 2009) elite youth soccer players across the youth phase of their development. However, similar to previous research (Carling et al., 2009), findings here show that relatively older (Q1) U13 to U14 players' demonstrated only *small* advantages in MSFT (ES = 0.33), CMJ (ES = 0.31) and agility (ES = 0.21) performance. Although such physical advantages afforded to relatively older players may contribute to the RAE bias during age categories associated to circa-PHV, the precise reasons for these physical advantages are not within the scope of this research chapter and therefore remains somewhat unresolved. However, it would be appealing to speculate that the mechanisms responsible for these *small* physical advantages afforded to relatively older U13 to 14 players are related to the earlier onset of rapid growth in the muscle-mass, respiratory and pulmonary systems experienced by these players across adolescence (**Figure 1**) (Malina, Bouchard, et al., 2004). However, the U13 to 14 players' born in Q1 versus Q4 (**Table 11**) of the selection year demonstrated no statistical difference in APHV (P = 0.997, ES = 0.14), suggesting that a maturity related mechanism was unlikely and that selection might have been a product of TD philosophy or the aforementioned limitations of using the Mirwald et al. (2002) maturity predictive equation (see **Chapter 2, Section 7.2**).

Under 15 to 16

The RAE peaked within the U15 to 16 cohort, demonstrating that 57% of players were born in Q1 versus only 8% in Q4. That being said, there were no statistical, between Q1 and Q4 differences in APHV (P = 0.709, ES = 0.40), anthropometric (P = 0.999 to 1.000, ES = 0.12 to 0.30) and physical fitness (P = 0.450 to 1.000, ES = 0.07 to 0.49) characteristics. This trend is likely indicative of the relatively younger (Q4), and *moderately* (ES = 0.52) less mature players identified in the U13 to14 age category having caught up with their relatively older (Q1) counterparts in terms of physical and anthropometric development.

Under 17 to 18

As with the U15 to U16 cohort, there were no statistical difference (P = 1.000), between Q1 and Q4 for anthropometric and physical fitness (P = 0.0796 to 1.000) characteristics, showing that any differences were *trivial* to *small* (ES = <0.1 to 0.3). However, a *moderate* (ES = 0.70) difference, that was also statistically different (P = 0.010), was present for APHV between Q1 and Q4. The underlying reason for this difference is unknown, however, it might be speculated that such difference is a result of the predictive equation (Mirwald et al., 2002) used within this chapter likely overestimated the APHV for players over the age of 16 (see **Chapter 8, Section 8.2**).

In Summary, the findings of this chapter have identified an obvious relative age bias across the EPPP that favours players born in the first quarter of the domestic soccer selection year. The RAE was most prominent in age groups circa to post PHV (U13 to U14 and U15 to U16) but achieving its lowest prevalence in the U11 to U12 bi-annual cohort. Relatively older players within age groupings circa to PHV (U11-12) were moderately taller and demonstrated *small* advantages for MSFT, CMJ, and agility. Although such physical advantages were transient and disappeared with advancing chronological age. These findings may be indicative of TD practitioner's preference for advanced maturity related anthropometric characteristics (such as stature) during TD. However, inferences here are somewhat difficult to make given the prominent underrepresentation of players born in the last quarter of the selection year within the EPPP.

5.5. Conclusion

In conclusion, our findings here affirm the research hypothesis and are in agreement with previous literature (Cobley et al., 2008; Helsen et al., 1999; Mujika, Vaeyens, et al., 2009; Romann & Fuchslocher, 2013) that confirms the obvious birth distribution bias that favours the selection of players' who are born earlier in the soccer selection year, who possess enhanced maturity related anthropometric characteristics. Interestingly, these players' possessed little/transient physical advantage over players' born later in the selection year (Carling et al., 2009; Deprez et al., 2012). Therefore, given the accelerated normative growth rate of players' in the Youth development phase due to the onset of puberty, it is recommend that talent selectors and club practitioners should increase the frequency of player growth, performance and maturity monitoring during this phase of the EPPP. This will ensure the accurate assessment of player development informing future TD and retention policies in which players' are benchmarked. This is likely to reduce the premature deselection of players' based on transient, maturity related characteristics and strengthening the pool of young players' available senior club and national selections. Having established a strong RAE and maturation-section within UK elite youth soccer academies, this thesis will now examine how the maturation-selection hypothesis and physical phenotype development of players' influences playing position allocation.

Chapter 6. Physical Phenotype, Relative Age and Maturity Status Biases on Playing Position According to Each Development Stage of the Elite Player Performance Plan.

6.1 Introduction

As concluded in **Chapter 5**, advanced normative growth and maturity related advantages are considered a significant factor - and problem - in the systematic discrimination against players' born in the latter months of the selection year, when categorised chronologically into playing groups (Carling et al., 2009; Deprez et al., 2013; Hirose, 2009). Results in **Chapter 5** also showed that in UK soccer, relatively older players' (i.e. born in the first quartile of the selection year) are more likely to be selected into TD programmes across the entire EPPP (U11 to U12: Q1 = 39%; U13 to U14: Q1 = 46%; U15 to U16: Q1 = 57%; U17 to U18: Q1 = 42%). These players are likely to be exposed to more advanced coaching expertise, and exposed to more match-play time (Vaeyens et al., 2005) as a consequence of having enhanced physical and anthropometrical characteristics; this is also known as the maturation-selection hypothesis (Cobley et al., 2009; Helsen et al., 2005). This hypothesis may also account for players' early positional role assignment within TD programmes, particularly when competition and performance is integral (Hirose, 2009). Such biases might threaten the efficacy of the TD and selection processes of the EPPP, yet to our knowledge the role of relative age and maturity on positional role allocation have not been explored in UK elite youth soccer.

Previous research has identified that playing positions are often characterised by specific anthropometric and physical fitness traits in pre and circa-adolescent players' (Deprez, Fransen, et al., 2014). For example, players' who exhibit superior anthropometric characteristics such as stature (and to a lesser extent body-mass) are more likely to be selected for defensive roles (e.g., goalkeeper & central defence) that involve frequent physical duels and aerial contests in both elite (Buchheit et al., 2010a; Deprez, Fransen, et al., 2014; Malina et al., 2000) and recreational (Gil et al., 2007) youth soccer.

Attacking and midfield players' are often characterized by their superior anaerobic (Buchheit et al., 2010a; Malina, Eisenmann, et al., 2004) and endurance (Malina, Eisenmann, et al., 2004) attributes, respectively. Whilst goalkeepers demonstrate a distinct fitness profile that manifests as early as the Foundation phase (U5-U11), displaying inferior aerobic, sprint and agility capacities versus other outfield positions (Deprez, Fransen, et al., 2014; Gil et al., 2007). Though previous studies have identified these biases and may have informed TD processes, drawing broader and accurate inferences is challenging as sampled populations have typically represented fewer than two soccer development centres (Buchheit et al., 2010a; Carling et al., 2009; Deprez, Fransen, et al., 2014), and findings could equally reflect localised playing and developmental philosophies. Moreover, previous research has not distinguished between central and lateral positions in defensive and midfield roles (Deprez, Fransen, et al., 2014; Malina, Eisenmann, et al., 2004; Romann & Fuchslocher, 2013) which may mask relevant position-specific differences in player characteristics, and this seems necessary given their distinct activity profiles during matches (Dellal et al., 2011; Dellal, Wong, Moalla, & Chamari, 2010). Thus, research on a broader scale is warranted to determine the position-specific characteristics of elite-youth soccer players', and to determine whether a transient nature of these influences exists across the stages of the player development pathway.

The aim of this chapter was to determine the extent of the maturity-selection hypothesis within UK, elite youth soccer development centres by examining the differences in relative age, anthropometry, somatic maturity status, and physical fitness attributes associated with positional role allocation throughout the EPPP 'Youth' and 'Professional' phases of development, examining a broad sample of players' from multiple UK soccer TD centres. Research of this nature is useful to national policy-makers as well as TD practitioners, including professional club TD managers, coaches, selectors, and sport science support staff involved in holistic and long-term development of players. It is hypothesised that goalkeepers and central defenders will be taller and heavier, particularly in the early stages of the development pathway, and that these advantages might be afforded by a combination of advanced somatic maturity status and an earlier birth date within their selection year. It is also theorised that position-specific physical attributes would become apparent in the latter stages of talent development due the increased contribution of playing position specific training and conditioning.

6.2 Procedures

6.2.1 Participants

With institutional ethical approval, data on 465 young elite soccer players' partaking within the Pro-Football Support player development program participated in the study. To reduce the impact of individual club playing philosophy, all of the players were selected from 16 elite youth soccer TD programmes (governed by the EPPP) located within UK professional soccer leagues (Championship [n = 2]; League 1 [n = 6]; League 2 [n = 8]) clubs were obtained between February 2013 - April 2014. Players' were categorised in to 7 decimal age-groups (U13 [n = 96]; U14 [n = 122]; U15 [n = 78]; U16 [n= 31]; U17 [n = 55]; U18 [n = 83]). A reduced sample of U16 players' was expected given that development centres typically de-select players' from progressing to the professional stage of development during the latter months of the domestic soccer season. Players' under 12 years of age were excluded from the study, having been deemed to have insufficient playing experience to establish a regular playing position in the normative game format (i.e., 11 vs. 11). In accordance with previous research (Deprez, Fransen, et al., 2014), players' were categorised in to the following positional roles: goalkeeper (GK, n = 44), central defender (CD, n = 79), lateral defender (LD, n = 81), central midfield

(CM, n = 117), lateral midfielder (LM, n = 66), and forward (FWD, n = 78). Following procedures outlined in **Chapter 3,** each player had been previously been habituated with each component of the field test battery and players' performed a standardised battery of three anthropometric and five physical fitness assessments that replaced their regular training during that day. All elements of the field test battery were delivered by trained Pro-Football Support members of staff.

6.2.2 Relative Age Distribution Characteristics

To allow for a more sensitive and unique unit of measure, the relative age distribution of each player discriminated by days born in the selection year (RAd) was established using the method outlined in **Chapter 3**.

6.2.3 Anthropometrics and Maturity Characteristics

Having established high between and within-practitioner short-term reliability **Chapter 4**, players' stature, seated height, body-mass and maturity status were recorded following the methods detailed in **Chapter 3**.

6.2.4 Physical Fitness Characteristics

Using the physical fitness test battery described in **Chapter 3**, players' were required to perform lower-limb power, sprint speed, agility and endurance capacity field-tests. All physical fitness field-tests were reported as having high short-term reliability (**Chapter 4**).

6.2.5 Statistical Analysis

Similarly to **Chapter 4**, linear marginal models and pairwise comparisons, with Sidak-adjusted *P* values, were conducted to determine differences in relative age distribution, anthropometric, somatic maturity status and physical fitness characteristics according to positional role allocation (GK, CD, LD, CM, LM, FWD). This chapter examined if these effects were moderated by the stage of development according to chronological playing age groups which were aggregated bi-annually (U13 to U14 [n = 218]; U15 to U16 [n = 109]; U17 to U18 [n = 138] to facilitate sufficiently powered contrasts between playing positions, in accordance with previous research (Deprez, Fransen, et al., 2014). Statistical significance for all null hypothesis tests was set at $P \leq 0.05$. Values are reported as the estimated marginal means and associated 95% confidence intervals, accompanied by relevant effect sizes (<0.2 *trivial*, 0.2-0.6 *small*, 0.6-1.2 *moderate*, 1.2-2.0 *large* and >2.0 *very large*) (Hopkins et al., 2009). All statistical assumptions were examined using standard graphical methods (Grafen, 2002) and analyses were completed using IBM SPSS Statistics for windows (release 22; SPSS Inc., Chicago, IL, USA).

6.3 Results

6.3.1 Relative Age Distribution Characteristics

There was no significant main effect for RAd according to playing position across all decimal age-groups (P = 0.053 to 0.632) (**Tables 12 to 14**). Although, LD were born later in the selection year than their CD counterparts in the U13 to U14 age group (P = 0.041, ES = 0.72) (**Table 12**).

6.3.2 Anthropometric Characteristics

There were significant between playing positions differences in body-mass and stature across all decimal age groups (body-mass: $P \leq 0.001$ - 0.002; stature: $P \leq 0.001$). As displayed in **Tables 12 to 14**, LD, CM and LM players' displayed moderate to large effects for inferior stature versus GK (stature: $P \leq 0.001$ to 0.024, ES = 0.66 to 1.58) and CD (stature: $P \leq 0.001$ to 0.04, ES = 0.68 to 1.56). LD and LM were leaner than GK ($P \leq 0.001$, ES = 0.73 to 1.01) and CD ($P \leq 0.001$, ES = 0.70 to 1.27) in the U13 to U14 and U15 to 16 decimal age groups. LM remained leaner than both GK (ES = 1.31) and CD (ES =1.32) in U17 to U18, with LD displaying a similar trend versus both GK (ES = 0.88) and CD (ES - 0.91), but did not reach statistical significance. CM were also *moderately* leaner than GK and CD at U13 to U14 (ES = 1.01, ES = 1.24) and U17 to U18 (ES = 0.92; ES = 1.32), but not at U15 to U16.

6.3.3 Somatic Maturity Characteristics

Estimated APHV differed significantly across playing positions for U13 to U14 ($P \leq 0.001$) and U15 to U16 ($P \leq 0.015$). However, significant playing position differences were only present in the U13 to14 decimal age-group, in which GK ($P \leq 0.001$ to 0.021, ES = 0.79 to 1.05) and CD ($P \leq 0.001$ - 0.029, ES = 0.96 to 1.22) players' were advanced maturers versus LD, CM, LM (moderate effect sizes; see **Table 12**). Whilst there were no statistically significant positional role differences for the U15 to 16 and U17 to U18 groups, *moderate* standardised effects were observed indicating advanced somatic maturity status in GK and CD versus CM and LD (**Tables 12** and **13**, respectively).

6.3.4 Physical Fitness Characteristics

There were no significant differences in CMJ performance owing to playing position across all decimal age groups ($P = 0.052$ to 0.626).

GK had inferior agility performance versus CD, LD, CM, LM and FWD positions ($P \leq 0.001$ to 0.017, ES = 0.58 to 0.74), having slower sprint times than CD, CM and FWD over 10 m ($P = 0.019$ to 0.022, ES = 0.35 to 0.57), and slower versus CD, LM and

FWD over 20 m distances (P = 0.040 to 0.043, ES = 0.78 to 0.92) in the U13 to U14 decimal age group; but these differences were not statistically significant in the U15 to U16 and U17 to U18 cohorts. CM demonstrated a tendency of slower 10 and 20 m sprint times versus LM at U15 to U16 (10 m ES = 0.61; 20 m ES = 1.00), which became a statistically significant difference in U17 to U18 (10 m ES = 0.94; 20 m ES = 1.07). LD also tended to be faster than their CD counterparts at U17 to U18 (10 m: ES = 0.72; 20 m ES = 0.83).

Playing position differences were identified for total distance covered during the MSFT in the U13 to U14 cohort (**Table 12**), where GK exhibited a *moderate* effect magnitude for inferior aerobic capacity when compared to LD (P = 0.036, ES = 0.80), CM (P = 0.015, ES = 0.81) and LM (P = 0.009, ES = 0.95). The magnitude of these effects continued through U15 to U16 and U17 to U18 age-groups, but was not statistically significant. CM (ES = 0.64) and LM (ES = 0.69) also tended (non-significant) to have an increased MSFT performance versus FWD in U17 to U18.

Table 12. Estimated marginal means (95% confidence intervals) of relative age, maturation, anthropometric, and physical fitness characteristics for elite youth (Under 13-14) soccer players according to cohort and playing position in English elite soccer development centres.

Variable	*n*	Cohort	*n*	GK	*n*	CD	*n*	LD	*n*	CM	*n*	LM	*n*	FWD	*p*	ES positional difference
Age (yrs.)	*218*	13.8 (13.6-13.9)	*24*	13. 7 (13.5 - 13.8)	*33*	13.8 (13.7 - 13.9)	*38*	13.6 (13.5 - 13.7)	*57*	13.7 (13.6 - 13.8)	*30*	13.8 (13.7 - 13.9)	*36*	13.8 (13.7 - 13.9)	*P* = 0.072	
RAd (days)	*218*	139 (126-152)	*24*	138 (100-176)	*33*	98 (62 -132)	*38*	169 (138-199)	*57*	152 (127-177)	*30*	129 (94-162)	*36*	127 (96-158)	*P* = 0.053	CD < GK, *LD, CM, LM, FWD
Stature (cm)	*191*	164.6 (163.4-165.8)	*20*	168.5 (164.9-172.1)	*29*	171.1 (167.7-174.4)	*33*	159.9 (157.1-162.8)	*52*	162.8 (160.5-165.0)	*26*	160.7 (157.5-163.8)	*31*	164.3 (161.4-167.2)	***P* ≤ 0.001**	GK > LD, *LM, CM, FWD CD > *LD, *CM, *LM, *FWD
Body-mass (kg)	*190*	52.3 (50.7-53.8)	*20*	58.3 (55.2-61.7)	*29*	57.1 (54.1-60.1)	*33*	47.3 (44.7-49.8)	*52*	51.1 (49.0-53.1)	*25*	48.6 (45.6-51.5)	*31*	51.7 (49.1-54.3)	***P* ≤ 0.001**	GK > *LD, *CM, *LM, *FWD CD > *LD, *CM, *LM, FWD
APHV (yrs.)	*189*	14.1 (14.0-14.3)	*20*	13.8 (13.6-14.0)	*29*	13.7 (14.5-13.9)	*33*	14.4 (14.2-14.6)	*51*	14.3 (14.1-14.4)	*25*	14.4 (14.2-14.6)	*31*	14.2 (13.9-14.4)	***P* ≤ 0.001**	GK < *LD, *CM, *LM, FWD CD < *LD, *CM, *LM, *FWD
CMJ (cm)	*189*	21.5 (17.5-25.2)	*20*	21.6 (17.3-25.9)	*29*	23.7 (19.4-27.9)	*38*	21.5 (17.3-25.7)	*57*	22.2 (18.1-26.3)	*30*	23.8 (19.5-28.0)	*36*	23.8 (19.5-28.0)	*P* = 0.052	LD < GK, CD, CM, LM, FWD
T-Test (s)	*218*	10.40 (10.22-10.53)	*24*	10.84 (10.58-11.11)	*33*	10.36 (10.10-10.61)	*32*	10.45 (10.20-10.69)	*52*	10.30 (10.07-10.53)	*26*	10.37 (10.12-10.63)	*30*	10.43 (10.18-10.67)	***P* ≤ 0.001**	GK > *CD, *LD, *CM, *LM, *FWD
10m sprint (s)	*216*	1.77 (1.73-1.80)	*24*	1.83 (1.78-1.89)	*33*	1.75 (1.69-1.80)	*37*	1.79 (1.74-1.85)	*57*	1.78 (1.72-1.83)	*30*	1.78 (1.72-1.83)	*35*	1.76 (1.70-1.81)	***P* ≤ 0.001**	GK > *CD, LD, *CM, LM *FWD
20m sprint (s)	*213*	3.21 (3.17-3.23)	*24*	3.34 (3.26-3.41)	*32*	3.15 3.07-3.22)	*37*	3.26 (3.19-3.33)	*57*	3.22 (3.16-3.29)	*29*	3.19 (3.11-3.26)	*34*	3.17 (3.10-3.25)	***P* ≤ 0.001**	GK > *CD, LD, CM, *LM, *FWD
MSFT (m)	*215*	1910 (1872-1947)	*24*	1712 (1600-1824)	*33*	1931 (1827-2035)	*38*	1936 (1846-2026)	*57*	1938 (1865-2012)	*28*	1982 (1878-2085)	*35*	1841 (1600-1824)	*P* = 0.060	GK < CD, *LD, *CM, *LM, FWD

* Denotes statistically significant difference for subscripted variables (P ≤ 0.05); GK = goalkeeper, CD = central defence, LD = lateral defence, CM = central midfield, lateral midfield, FWD = forward, RAd = number of days born in the selection year (September 1st to August 31st), APHV = estimated age at peak height velocity, MSFT = distance achieved during the Multi-Stage Fitness Test, CMJ = vertical counter movement jump. Italic, underlined, emboldened denote trivial, small and moderate magnitudes of effect observed, with large effects signified using *a* combination of the three previously aforementioned annotations.

Table 13. Estimated marginal means (95% confidence intervals) of relative age, maturation, anthropometric, and physical fitness characteristics for elite youth (Under 15-16) soccer players according to cohort and playing position in 16 English elite soccer development centres.

Variable	*n*	Cohort	*n*	GK	*n*	CD	*n*	LD	*n*	CM	*n*	LM	*n*	FWD	*p*	ES positional difference
Age (yrs.)	*109*	15.6 (15.4-15.7)	*10*	15.8 (15.5-15.9)	*25*	15.9 (15.7-16.0)	*19*	15.7 (15.5-15.9)	*27*	15.8 (15.6-15.9)	*13*	15.7 (15.5-15.9)	*15*	15.8 (15.6-15.9)	*P* = 0.765	
RAd (days)	*109*	108 (90-126)	*10*	129 (63-194)	*25*	95 (54-136)	*19*	133 (79-186)	*27*	91 (50-131)	*13*	145 (71-218)	*15*	100 (49-149)	*P* = 0.632	CM < GK, <u>*CD*</u>, <u>LD</u>, <u>LM</u>, *FWD*
Stature (cm)	*97*	174.8 (173.1-176.4)	*8*	182.1 (177.8-186.4)	*21*	180.9 (178.1-183.5)	*17*	171.2 (167.3-174.9)	*27*	172.3 (170.0-175.0)	*11*	172.3 (168.7-175.8)	*13*	176.0 (172.6-179.4)	***P* ≤ 0.001**	GK > ***<u>*LD*</u>**, ***<u>*CM*</u>**, ***<u>*LM*</u>**, **FWD** CD > ***<u>*LD*</u>**, ***<u>*CM*</u>**, ***<u>*LM*</u>**, **FWD**
Body-mass (kg)	*97*	64.5 (62.5-66.3)	*8*	72.5 (66.9-78.1)	*21*	70.0 (66.4-73.5)	*17*	60.4 (55.5-65.3)	*27*	64.5 (61.3-67.8)	*11*	59.0 (54.4-63.6)	*13*	67.8 (63.5-72.2)	***P* = 0.002**	GK > ***<u>*LD*</u>**, **CM**, ***<u>*LM*</u>**, <u>FWD</u> CD > ***LD**, **CM**, ***<u>*LM*</u>**, <u>FWD</u>
APHV (yrs.)	*97*	14.2 (14.1-14.4)	*8*	13.9 (13.5-14.2)	*21*	14.0 (13.8-14.2)	*17*	14.5 (14.1-14.7)	*27*	14.4 (14.2-14.6)	*11*	14.4 (14.1-14.7)	*13*	14.2 (13.9-14.5)	***P* = 0.015**	GK < ***LD***, ***CM***, ***LM***, ***FWD*** CD < ***LD***, ***CM***, ***LM***, <u>FWD</u>
CMJ (cm)	*107*	25.8 (21.8-29.8)	*10*	24.5 (19.1-29.9)	*25*	25.8 (20.8-30.8)	*19*	28.5 (23.2-33.7)	*26*	27.8 (22.8-32.7)	*12*	28.3 (23.1-33.6)	*15*	28.9 (23.7-34.1)	*P* = 0.105	GK < *CD*, <u>LD</u>, <u>CM</u>, <u>LM</u>, <u>FWD</u>
T-Test (s)	*95*	9.71 (9.54-9.87)	*8*	9.80 (9.50-10.11)	*20*	9.61 (9.38-9.83)	*17*	9.71 (9.45-9.97)	*27*	9.67 (9.44-9.89)	*10*	9.57 (9.24-9.91)	*13*	9.60 (9.34-9.85)	*P* = 0.747	GK > *CD*, <u>LD</u>, <u>CM</u>, <u>LM</u>, <u>FWD</u>
10m sprint (s)	*105*	1.64 (1.61-1.68)	*10*	1.68 (1.62-1.73)	*24*	1.65 (1.60-1.68)	*19*	1.62 (1.57-1.66)	*26*	1.66 (1.61 - 1.70)	*12*	1.59 (1.53-1.65)	*14*	1.62 (1.57-1.67)	***P* = 0.047**	GK > <u>CD</u>, <u>LD</u>, *CM*, **LM**, **FWD** CD > **LD**; CM > **LM**
20m sprint (s)	*105*	2.96 (2.92-2.99)	*10*	3.01 (2.93-3.01)	*24*	2.94 (2.88-2.98)	*19*	2.91 (2.84-2.97)	*26*	2.99 (2.93-3.03)	*12*	2.85 (2.74-2.93)	*14*	2.91 (2.84-2.96)	***P* = 0.022**	GK > <u>CD</u>, **LD**, *CM*, **LM**, **FWD** CD > <u>LD</u>; CM > **LM**
MSFT (m)	*107*	2181 (2127-2234)	*10*	1944 (1766-2121)	*25*	2235 (2125-2345)	*18*	2303 (2140-2465)	*26*	2184 (2074-2292)	*13*	2283 (2085-2480)	*15*	2283 (2148-2419)	***P* = 0.038**	GK < **CD, LD, CM, LM, *FWD** CD < <u>LD</u>; CM < LM

* Denotes statistically significant difference for subscripted variables ($P \leq 0.05$); GK = goalkeeper, CD = central defence, LD = lateral defence, CM = central midfield, lateral midfield, FWD = forward, RAd = number of days born in the selection year (September 1st to August 31st), APHV = estimated age at peak height velocity, MSFT = distance achieved during the Multi-Stage Fitness Test, CMJ = vertical counter movement jump. Italic, <u>underlined</u>, emboldened denote trivial**,** small and moderate magnitudes of effect observed, with large effects signified using ***<u>a</u>*** combination of the three previously aforementioned annotations.

Table 14. Estimated marginal means (95% confidence intervals) of relative age, maturation, anthropometric, and physical fitness characteristics for elite youth (Under 17-18) soccer players according to cohort and playing position in 16 English elite soccer development centres.

Variable	*n*	Cohort	*n*	GK	*n*	CD	*n*	LD	*n*	CM	*n*	LM	*n*	FWD	*p*	ES positional difference
Age (yrs.)	*138*	17.8 (17.6-17.9)	*10*	17.8 (17.4-17.9)	*21*	17.7 (17.5-17.8)	*24*	17.7 (17.5-17.9)	*33*	17.8 (17.7-17.9)	*23*	17.6 (17.4-17.8)	*27*	17.6 (17.4-17.8)	*P* = 0.406	
RAd (days)	*138*	133 (117-149)	*10*	122 (57-187)	*21*	122 (76-158)	*24*	142 (101-183)	*33*	116 (82-149)	*23*	161 (121-200)	*27*	125 (80-163)	*P* = 0.573	GK < *LD*, *CM*, LM, *FWD* CD < LD, *CM*, LM, FWD
Stature (cm)	*133*	178.7 (177.2-180.1)	*10*	184.7 (181.0-188.4)	*20*	184.3 (181.9-186.7)	*23*	176.6 (174.178.9)	*31*	176.8 (174.8-178.7)	*22*	175.6 (173.2-177.9)	*27*	178.9 (176.6-181.1)	***P* ≤ 0.001**	GK > ***LD***, ***CM***, ***LM***, **FWD** CD > ***LD***, ***CM***, ***LM***,***FWD**
Body-mass (kg)	*133*	72.3 (70.6-74.0)	*10*	76.8 (72.6-81.0)	*20*	76.6 (73.9-79.3)	*23*	71.0 (68.2-73.6)	*31*	70.1 (67.9-72.3)	*22*	68.3 (65.6-70.8)	*27*	73.4 (70.8-75.8)	***P* ≤ 0.001**	GK > **LD**, **CM** ***LM***, FWD CD > **LD**, ***CM**,***LM***, FWD
APHV (yrs.)	*134*	14.9 (14.8-15.0)	*10*	14.6 (14.1-14.9)	*21*	14.7 (14.5-14.9)	*23*	15.0 (14.7-15.1)	*31*	15.0 (14.8-15.2)	*22*	14.9 (14.7-15.1)	*27*	14.8 (14.6-15.1)	*P* = 0.320	GK < **LD**, **CM, LM,** FWD CD < LD, CM, LM, *FWD*
CMJ (cm)	*123*	32.5 (28.5-36.4)	*9*	30.8 (25.6-35.9)	*20*	30.4 (25.4-35.2)	*20*	31.6 (26.7-36.5)	*30*	30.5 (25.2-34.8)	*19*	31.1 (26.2-35.9)	*25*	31.6 (26.7-36.4)	*P* = 0.626	GK < *CD, LD, CM, LM, FWD*
T-Test (s)	*117*	9.22 (9.10-9.40)	*8*	9.33 (9.08-9.57)	*17*	9.33 (9.12-9.48)	*19*	9.10 (8.94-9.30)	*30*	9.25 (9.09-9.42)	*19*	9.16 (8.98-9.34)	*24*	9.13 (8.95-9.30)	*P* = 0.219	GK > *CD*, LD, *CM*, LD, FWD
10m sprint (s)	*123*	1.62 (1.58-1.66)	*9*	1.65 (0.10 - 0.22)	*20*	1.65 (0.10 - 0.22)	*20*	1.61 (0.10 - 0.22)	*30*	1.66 (0.10 - 0.22)	*19*	1.60 (0.10 - 0.22)	*25*	1.63 (0.10 - 0.22)	***P* = 0.003**	GK > *CD*, **LD**, *CM*, **LM**, FWD CD > **LD**; CM > **LM**
20m sprint (s)	*123*	2.89 (2.85-2.92)	*9*	2.94 (2.88-2.99)	*20*	2.92 (2.88-2.95)	*20*	2.86 (2.82-2.89)	*30*	2.93 (2.90-2.96)	*19*	2.84 (2.80-2.87)	*25*	2.87 (2.84-2.90)	***P* = 0.000**	GK > *CD*, **LD**, *CM*, **LM**, **FWD** CD > **LD**; CM > **LM**
MSFT (m)	*123*	2383 (2333-2433)	*9*	2223 (2060-2386)	*20*	2348 (2245-2450)	*20*	2370 (2264-2474)	*30*	2456 (2370-2542)	*19*	2472 (2365-2579)	*25*	2293 (2194-2392)	***P* = 0.028**	GK > **CD**, **LD**, **CM**, LM, FWD CD > *LD*; CM > *LM* FWD < **CM, LM**

* Denotes threshold for significance set at P ≤ 0.05 for subscripted variables; GK = Goalkeeper, CD = Central defence, LD = Lateral defence, CM = Central midfield, Lateral midfield, FWD = Forward, RAd = Number of days born in the selection year (September 1st to August 31st), APHV = estimated age at peak height velocity, MSFT = Distance achieved during the Multi-Stage Fitness Test, CMJ = Vertical counter movement jump. Italic, underlined, emboldened denote trivial**,** small and moderate magnitudes of effect observed. With large effects signified using ***a*** combination of the three previously aforementioned annotations.

6.4 Discussion

The main aim of this chapter was to assess the influence of the maturity-selection hypothesis and physical phenotype development of players on role allocation within multiple EPPP governed development centres in the UK, spanning U13 to 18 years of age. This was achieved by quantifying the differences in relative age distribution, anthropometry, somatic maturity status and physical fitness characteristics on positional role allocation. A secondary aim was to assess whether these differences were transient across the age-groups of player development. The main findings identified were: 1) At U13 to U14's, LD were born later in the selection year than CD; 2) At U13 to U14, GK and CD were advanced maturers versus other outfield players'; 3) Irrespective of decimal age, GK and CD were *moderately* taller and heavier than LD, CM and LM; 4) GK had inferior endurance and sprint capacities versus their outfield team-mates at U13 to U14, but anaerobic phenotypes did not differ to outfield players' at U15 to 16 and U17 to U18; and, 5) At U17 to U18's, lateral defensive and midfield players' were *moderately* faster sprinters than their centrally positioned counter-parts.

Findings here confirm previous research (Deprez, Fransen, et al., 2014; Romann & Fuchslocher, 2013), supporting the general hypothesis that playing positions of elite youth soccer players' can be discriminated by anthropometric attributes. GK and CD were the tallest and heaviest players', adhering to prior studies (Buchheit et al., 2010a; Deprez, Fransen, et al., 2014; Malina et al., 2000), and was a trend identified across the age-groups (**Tables 12** to **14**). However, the magnitude of the standardised effect (*moderate*) for between-position differences was typically greater than that reported in Belgian and Qatari elite youth soccer players' (*small*; (Buchheit et al., 2010a; Deprez, Fransen, et al., 2014)). It is unclear whether the greater magnitude of anthropometric differences in the current study is due to between country differences in talent selection and position allocation policy, or because this chapter uniquely distinguished between lateral and central defenders. Nonetheless, anthropometrical advantages are largely explained by maturity status (Deprez et al., 2013; Lovell et al., 2015), and in the U13 to U14 stage the taller and heavier GK and CD were earlier maturers. This suggests that positional allocation by TD practitioners in soccer centres is clearly being influenced by immediate anthropometrical factors from an early development stage.

The anthropometric advantages afforded to CD positions in this chapter may also be influenced by their relative age. U13 to U14 CD were born earlier in their selection year versus their LD peers (**Table 12**). As established in **Chapter 5**, at this developmental stage in the UK youth system, the RAE on selection is particularly strong (**Tables 7 to 9**) which likely reflects the onset of accelerated growth during puberty in combination with advanced normative growth of the relatively older players' (Cobley et al., 2009). The findings in this chapter suggest that those fewer relatively younger players' selected for representative level squads, tend not to be allocated to CD positions. Whilst Romann and Fuchslocher (2003) found that defenders were born earlier in their selection year versus other field positions, in this study no other between-position differences in relative age were observed, and the current chapter is the first to distinguish the positional role characteristics of lateral versus central developmental soccer players'. The observation that CD are relatively older, taller, heavier, and advanced in terms of somatic maturity status when compared to LD is unsurprising , given their tactical and physical differences during match-play (Bloomfield et al., 2007; Di Salvo et al., 2007). This also reinforces the influence of anthropometric characteristics in talent selection and role allocation, and suggests that future research should distinguish between these defensive roles, particularly when development systems adopt an 11 vs. 11 match-play format. Further longitudinal research is necessary to determine whether positional role allocation varies according to the within-squad rank of players' body size, which likely varies throughout development stages owing to the variability of biological maturation processes.

In this study GK displayed inferior physical performance attributes in relation to most outfield positions. GK endurance performance in particular was lower (*moderate-large* effects) than most outfield positions at U13 to U14, with the difference being greater than the minimum threshold for SWC (75 m) in MSFT performance established in **Chapter 4**. A lower endurance capacity reflects the typical activity profile of GK in both matches and training (Deprez, Fransen, et al., 2014), and is therefore likely to be considered a redundant physical attribute to perform this role at the representative level. An interesting observation was that U13 and U14 GK's were slower sprinters and less agile than players' in all other positions (with the exception of LD), surpassing the minimum thresholds for SWC (10 m: 0.03 s; 20 m: 0.06 s; T-Test: 0.08 s) established in **Chapter 4**. Yet, older GK's from the U15 to U16 and U17 to U18 cohorts were inferior only to LM in terms of sprint performance. U13 to U14 GK were more advanced maturers, which is typically associated with enhanced sprint running performance in youth soccer players' (Mendez-Villanueva et al., 2011), perhaps mediated by neuromuscular function and/or endocrine effects on muscle power during puberty (Malina, Eisenmann, et al., 2004). Despite these maturity-related advantages, GK's were slower at U13 to U14, which suggests that anthropometric characteristics are stronger determinants of their role allocation, perhaps enabling them to dominate aerial duels and reduce the shot-target available to opposition players' due to their enhanced stature (and arm span (Moghadam, Azarbayjani, & Sadeghi, 2012)). As the inferior sprint performance of GK's was somewhat transient, it is appealing to suggest that GK coaches place greater emphasis on sprinting performance at later stages of the development process, perhaps enabling them to quickly close down the space available to goal-bound attackers. However, the cross-sectional nature of this chapter renders this as speculation, and further longitudinal research is warranted on GK to identify role allocation bias and athletic development priorities.

To our knowledge, this is the first study to demonstrate the physical fitness characteristics of elite youth players' in central versus lateral roles. Whilst no differences were observed between these roles in U13 to U14, LM tended to be faster sprinters versus CM at U15 to U16, an effect magnitude which exceeded the earlier established minimum threshold for the SWC (10m: 0.03 s; 20m: 0.06 s) in **Chapter 4**, with the difference becoming statistically significant at U17 to U18. Similarly, a greater sprint capacity in LD compared to CD was observed in the U17 to U18 squads. As this variation was not observed before APHV, it may reflect the development of position-specific physical attributes mirroring the professional match requirements of lateral players' (Di Salvo et al., 2007), as opposed to a selection phenomenon, but further work is warranted to confirm this hypothesis. The magnitude of sprint capacity differences between laterally- and centrally-orientated roles was greater than that reported in previous research for other outfield positional contrasts (Di Salvo et al., 2007), further emphasising the requirement to distinguish between these field positions in future research and national benchmarking schemes. However, consideration of the tactical formations administered by coaches and/or TD systems are warranted (e.g. 4-4-2 vs. 4-3-3), given it is likely to influence positional role allocation.

The cross-sectional research design of this chapter limits the generalisability of conclusions drawn. That said, it is accepted this limitation is considerate of the broad representative sample of elite youth soccer players, which we could draw from in the study. While the analysis of the present chapter was confined to examining positioning allocation in relation to somatic and physical fitness characteristics, it is probable that other factors contribute, and may also be more or less important at different development stages. Technical and perceptual-cognitive attributes also likely contribute to positional allocation by TD coaches/selectors (Deprez, Fransen, et al., 2015). Lastly, as previously discussed in **Chapter 2**, it is recognised that the longitudinal accuracy of the maturity estimation procedure adopted in our study has been questioned (Deprez, Fransen, et al., 2014; Malina & Kozieł, 2014). However, the purpose of this chapter was to examine positional role differences in somatic maturity within development stages, which somewhat attenuates the confounding influence of decimal age on the APHV prediction. Nonetheless, practitioners should be cognisant of the limitations that confound the accurate estimation of APHV when administering talent development and selection processes.

This chapters findings suggest that anthropometric characteristics influence the positional role allocation at the 'Youth' development stage of the EPPP, where GK and CD demonstrated body size advantages afforded by advanced maturity and decimal age. Whilst these advantages might be realized in competitive match-play scenarios involving frequent physical contests and aerial duels, they were not manifest in the physical fitness tests administered in the study. Body size advantages in these key defensive roles transcended the developmental stages surveyed, whereas the inferior physical performance capacities of GK (agility, sprinting, and endurance) were transient, and specific performance phenotypes in lateral outfield players' emerged in the latter stages of the development process. Whether these trends are borne from position-specific conditioning or selection criteria is a matter for further study, nonetheless, they demonstrate the transitory nature of physical characteristics influenced by the individuals' rate and stage of biological maturity. Hence, TD practitioners should be cautious in positional role allocating due to transient physical characteristics (**Chapter 5**), and instead perhaps prioritizing tactical and technical development. The distinct physical attributes of players' selected into CD and GK roles from an early stage, might reflect the competitive nature that exists between development centers in the match-play program, and may actually become a barrier to long-term holistic player development. With development centers operating within the EPPP obligated to monitor growth and maturity trajectories, findings from this study suggest that centres can reduce the impact of this factor on positional role allocation. To add and support, awareness and education regarding biological development bias maybe warranted for TD practitioners.

6.5 Conclusion

Findings in this chapter confirmed the research hypothesis identifying that irrespective of chronological age group, specific anthropometrical attributes characterised playing positions in UK elite youth soccer development programmes, with relatively older, maturer, taller, heavier, players being predominantly selected for GK and CD roles. Distinguishing characteristics of defensive and midfield players allocated to either central or lateral positions, also revealed position-specific differences in physical fitness attributes in the latter stages of development programmes. Trends suggested that transient body size advantages conferred by relative age and maturity status may influence positional role allocation in existing youth soccer programmes. Since physical development trajectories are individual-specific and moderated by biological maturity, the EPPP mandate to audit them may assist coaches and selectors in adopting a ‘plastic’ approach to positional role assignment until complete maturity is achieved. Given that **Chapters 5** and **6** of this thesis have established that player maturity status heavily influences the selection of players for talent development programs and role allocation within the team, **Chapter 7** will now explore the influence of the onset, tempo and cessation of the adolescent growth spurt (PHV) and chronological age upon physical phenotype development of elite youth soccer players’ in the UK.

Chapter 7. Development Trajectories of Physical Phenotypes for Elite Youth Soccer Players': Examining the Elite Player Performance Plan.

7.1 Introduction

Selecting and preparing talented young athletes for elite adult competition is a challenging task (Barreiros, Côté, & Fonseca, 2014; Güllich & Emrich, 2014) and is often unsuccessful, with less than 1% of boys recruited to TD centres' in UK youth soccer go on to forge a professional career (Green, 2009). This could be reflective of that the selection and success of LTAD of talented young soccer players being complex and often confounded by the highly individualised timing and tempo of adolescent maturity (Malina, Bouchard, et al., 2004). These factors can influence the development of specific physical phenotypes, as identified in the literature (Carling et al., 2012; Lovell et al., 2015; Malina, Eisenmann, et al., 2004; Malina et al., 2000; Mendez-Villanueva et al., 2010; Philippaerts et al., 2006) and **Chapters 5** and **6** of this thesis. Such phenotypes are considered to contribute to the selection (Deprez, Fransen, et al., 2015; Lovell et al., 2015), deselection, (Deprez, Fransen, et al., 2015; Figueiredo, Gonçalves, Coelho e Silva, & Malina, 2009) and allocation of players' for specific tactical roles (Deprez, Fransen, et al., 2014) as confirmed in **Chapter 6**. Therefore, it is necessary for development centres to systematically monitor player anthropometric and physical fitness characteristics relative to decimal age and somatic maturity status throughout their development (The English Premier League, 2011).

Given that poor performance for some physical fitness characteristics might only be partially caught up upon achieving complete maturity (Deprez, Buchheit, et al., 2015), the International Olympic Committee consensus statement on youth athletic development encourages the early identification of fitness deficits (so that they can be remedied), and advocates physical assessments that are specific to the athletic demands of the sport (Bergeron et al., 2015). Therefore, given that soccer match-play activity is highly playing-position specific (Di Salvo et al., 2007; Mendez-Villanueva et al., 2012), and is primarily characterised of high intensity, intermittent match activity, interspersed by periods of low intensity exertion lasting 90-minutes that taxes both the aerobic and anaerobic energy systems (Di Salvo et al., 2007; Mohr et al., 2003), it can be assumed that explosive attributes such as speed and lower-limb power are necessary for soccer players' to compete in physical duels with opponents. These physical requirements are coupled with players having a well-developed aerobic capacity so that they can repeat these explosive actions at regular intervals throughout the match duration. Such is the relative importance of player maturity on the development of these attributes, some LTAD models purport to provide coaches with a strategic framework for child athletic development, centred around naturally occurring periods circa-PHV of heightened sensitivity to training induced adaptation, commonly referred to 'windows of opportunity' (Balyi & Hamilton, 2004).

The Ford et al. (2011) review of the LTAD model states an absence of such 'windows of opportunity'. They suggest that most components of fitness such as speed, power, strength and aerobic capacity are largely attributed to a complex interaction of hormonal, muscular, and mechanical factors caused by the onset of puberty (Butterfield et al., 2004; Rowland, 1985; Viru et al., 1999) that are trainable throughout an athletes' development pathway. Although pertinent, such LTAD research (Balyi & Hamilton, 2004; Ford et al., 2011; Lloyd & Oliver, 2012) provides little evidence to assist TD practitioners understanding of the influence that the onset, tempo and cessation of somatic maturity may have upon physical phenotype development of elite youth soccer players'. However, Philippaerts et al. (2006) longitudinal study on adolescent (PHV ± 18 months) elite youth soccer players', demonstrated that peak strength, power, speed and endurance development tempos onset pre, and circa-PHV (13.8 ± 0.8 years) and continue to improve (albeit at a reduced rate) post-PHV dependent on individual growth curves and training regime (Philippaerts et al., 2006). Similar findings were also reported for peak rates of CMJ (Deprez, Valente-Dos-Santos, et al., 2015), acceleration (Mendez-Villanueva et al., 2011), and speed (Mendez-Villanueva et al., 2010) development circa-PHV. That said, there is evidence to suggest the existence of a transitional period pre- to circa-PHV of ‘markedly’ increased maximal sprint speed development (Mendez-Villanueva et al., 2010). However, inferences made by such studies are difficult, given that their limited sample size and conclusions are likely to reflect local training prescription and talent identification philosophy having used players from one development centre.

Many longitudinal elite youth soccer player development studies have used intra-class correlations (Philippaerts et al., 2006), multivariate (Deprez, Buchheit, et al., 2015; Deprez, Fransen, et al., 2015; Vaeyens et al., 2006) and covariate (Deprez, Valente-dos-Santos, et al., 2014; Deprez, Valente-Dos-Santos, et al., 2015) analyses to explain the development velocities of anthropometric and physical fitness characteristics according to age and maturity. However, many previous studies have sampled players from few (≤ 2) different elite youth soccer development centres (Deprez, Buchheit, et al., 2015; Deprez, Fransen, et al., 2015; Deprez, Valente-dos-Santos, et al., 2014; Deprez, Valente-Dos-Santos, et al., 2015) (as previously discussed in **Chapter 2**), with many studies having also used relatively narrow sample sizes (n = < 50) (Deprez, Buchheit, et al., 2015; Philippaerts et al., 2006; Wrigley, Drust, Stratton, Atkinson, & Gregson, 2014). Consequently, it might be speculated that some longitudinal studies did not possess the statistical power to accurately detect any transitions (Muggeo, 2003; Stasinopoulos & Rigby, 1992) in which the relationship between player development and decimal age/biological maturity is no longer linear, eliciting an abrupt response within the outcome variable (i.e. non constant regression parameters).

Given such limitations, it might be assumed that assertions from previous studies are representative of both individual talent selection philosophies of soccer player athletic development in general rather than exclusively examining the development of elite adolescent players. Consequently, raising justification for an advanced statistical approach that is capable of estimating the 'breakpoints' and yearly rate of anthropometric and physical fitness development relative to decimal age and somatic maturity status within a broad cross-section of elite you soccer players. Therefore, using an analytical approach, this chapter aims to estimate the development tempo of anthropometric and physical fitness characteristics in a broad cross-sectional sample of UK elite youth soccer players' relative to their chronological and biological ages. It is hypothesised that the estimated physical development of UK elite youth soccer players across adolescence will largely be linear in nature, with anaerobic phenotypes displaying a heightened rate of yearly development circa-PHV. Given that **Chapters 5** and **Chapter 6** have confirmed the presence of the maturity-selection hypothesis (Cobley et al., 2009; Helsen et al., 2005), it is hypothesised that the estimated PHV of the sample will onset earlier than reported within the general population.

7.2 Procedures

7.2.1 Participants

Using a standardised battery of reliable field-tests (**Chapter 4**) administered by Pro-Football Support practitioners, assessments of anthropometric and physical fitness attributes were performed by 969 young elite soccer players', participating in 1 of 23 elite youth soccer TD programmes (governed by the Elite Player Performance Plan (The English Premier League, 2011)) located within UK, professional (Championship, League 1, and League 2) soccer clubs. All assessments had institutional ethical approval and data was obtained between January and July of the 2011/12, 2012/13, 2013/14 and 2014/15 domestic soccer seasons. Players' were divided in to 10 decimal age groups (U9`s [n = 61]; U10`s [n = 112]; U11`s [n = 113]; U12`s [n = 126]; U13`s [n = 106]; U14`s [n = 212]; U15`s [n = 126]; U16`s [n = 26]; U17`s [n = 94]; U18`s [n = 27]) and dependent on their age and stage of development, players' typically received either 3-5 (U5 to U11), 6-12 (U12 to 16) or 16 hours (U17 to U21) of coaching each week at respective centres (The English Premier League, 2011), including potential competitive matches. As per procedures outlined in **Chapter 3**, each player was previously habituated with each component of the field test battery and players' performed a standardised battery of three anthropometric and four physical fitness assessments that replaced their regular training during that day.

7.2.2 Anthropometrics

The methods for anthropometric (stature, body-mass and seated height) measures that were then used in combination with decimal age to estimate player somatic maturity (Mirwald et al., 2002) are outlined in **Chapter 3**. Taking into account the predictive nature of the anthropometric based Mirwald et al. (2002) algorithm used to determine PHV, and the between-practitioner variation associated to using multiple development centre cohorts, this thesis established the test-retest reliability of all anthropometric measures encompassed within the equation (**Chapter 4**).

7.2.3 Physical Fitness

Physical fitness characteristics of players' were assessed using a standardised battery of five physical fitness tests (CMJ, 10, 20 m sprints, T-Test, MSFT) to determine players' lower-limb power, maximal sprint speed, agility and endurance capacities using the procedures described in **Chapter 3**. All physical fitness field-tests were reported as having high short-term reliability (**Chapter 4**).

7.2.4 Statistical analysis

Statistical analysis was conducted using R (v 3.0.2). *A priori*, data from participants whose YPHV exceeded the tolerance limits of the somatic maturity prediction equation (± 4 years; Mirwald et al. (2002)) were discarded (n = 2). Next, simple linear regressions of the response (anthropometric/ performance data) versus explanatory (decimal age, YPHV) variables were visually inspected, and examined empirically (Davies test) to test for abrupt response variable changes. For each individual regression analysis, Davies tests identified non-constant regression parameters ($P < 0.05$), with the exception of CMJ-Decimal age ($P = 0.295$), however this thesis elected to proceed with further analysis of this model to enable comparisons to CMJ-YHPV. Using the 'Segmented' package (v 0.3-0.0) in R, segmented regression analyses were performed to quantify the location of 'breakpoint(s)' in the response variable (Muggeo, 2003). Precision of break-point estimates was calculated via Wald-based 95% confidence intervals (CI). Slope coefficients and their estimate precision (95% CI's) are reported, and significant slopes were detected using alpha set at 0.05. The variance explained by each of the segmented regression models was quantified using r^2.

7.3 Results

Breakpoint(s) and annual rate of anthropometric and physical fitness characteristic development according to player decimal age are presented in **Table 15**, whereas data according to somatic maturity are displayed in **Table 16**. Graphical representations (estimated breakpoints [95% CI]) of anthropometric (stature and body-mass) development data according to decimal age and somatic maturity are depicted in **Figures 6** and **7,** whilst physical fitness (CMJ, agility, 10, 20m sprint, MSFT) development data are shown in **Figures 8 to 12**.

7.3.1 Athropometric Characteristics

Estimated stature increases were highest between 10.7 to 15.2 years, and between -3.2 to 0.8 YPHV, with annual growth rates of 7.5 and 8.6 cm·year^{-1} identified for decimal age and YPHV respectively. Estimated body-mass gains were also increased (7.1 kg·year^{-1}) between 11.9 to 16.1 years of age, whereas when modelled against somatic maturity, estimated body-mass increases continued at 7.5 kg·year^{-1} from -1.6 to 4.0 YPHV, without plataeu. Model strength and coefficient estimate precision (95% CI width) were slightly higher in YPHV (r^2 = 0.89) versus decimal age (r^2 = 0.81) for both stature and body-mass.

7.3.2 Physical Fitness Characteristics

Estimated CMJ development tempo decreased from 2.5 to 1.3 cm·year^{-1} circa-PHV (0.6 years; 95% CI's: -0.4 to 1.6 YPHV). However modelling of CMJ trajectories was not strong for either exploratory variables (r^2 = 0.52 to 0.53), and whilst an estimated breakpoint was identified in the CMJ-decimal age model, the 95% CI of the two adjacent slopes overlapped. Estimated agility performance gains ceased from 15.8 years of age onwards, but when modelled against somatic maturity status, estimated improvements slowed by ~43% at 0.4 YPHV. Players' estimated endurance capacity increased by 169 and 185 m·year^{-1}, until 16.4 years and 2.1 years post PHV, repectively, therafter MSFT performance changes were not significant (P = 0.164 to 0.252).

Segmented regression modelling of 10 and 20m sprint performance, derived consistent trends using both explanatory viariables (r^2 = 0.71 to 0.76). Estimated sprint speed development increased until 11.8 years of age, or -1.8 YPHV, before development tempo increased (31 to 43%) until 15.8 years, or 1.2 to 1.3 YPHV. Thereafter estimated sprint speed development was not further improved (P = 0.186 to 0.964), with the exception of 20m sprint vs. YPHV, where subtle declines in sprint time continued (-0.02; 95% CI's: -0.05 to 0.01 s/YPHV).

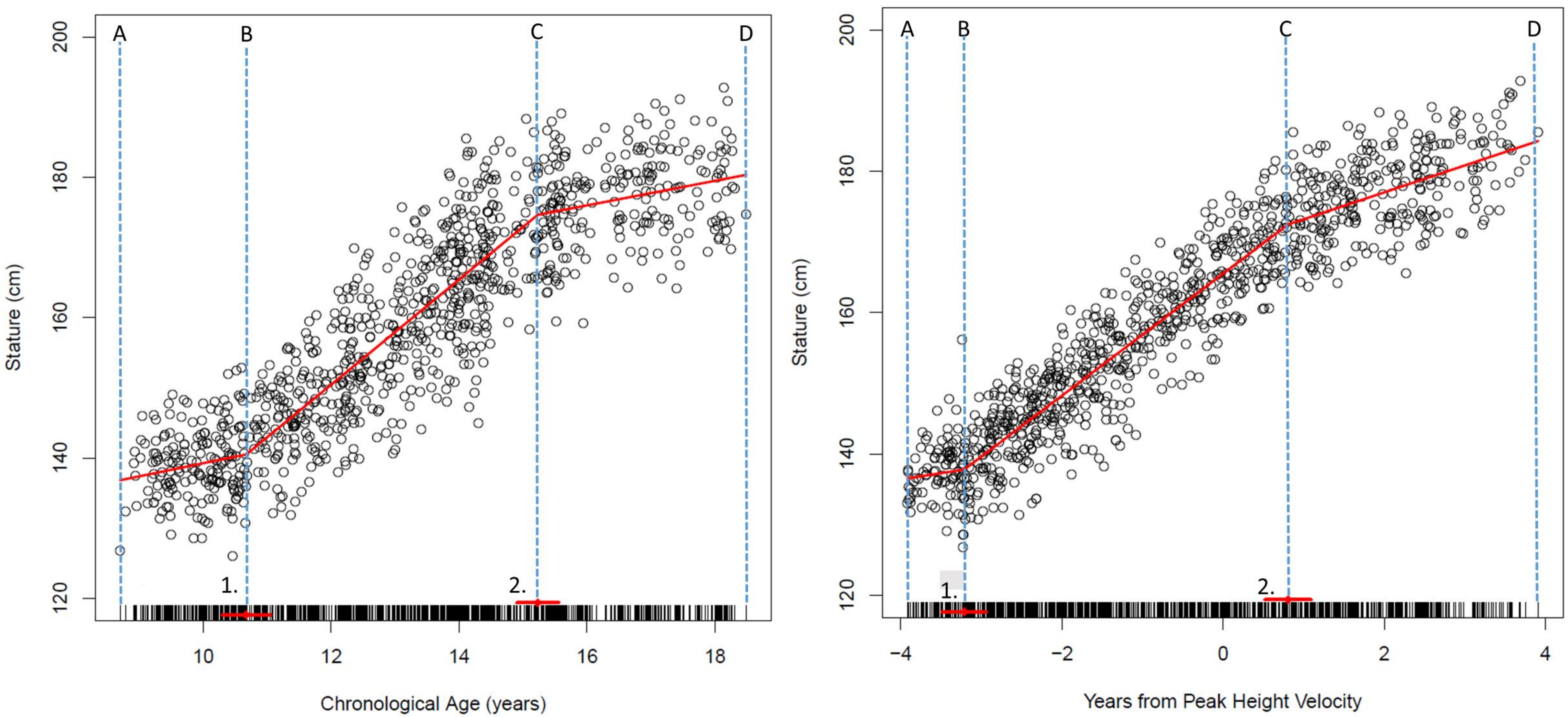
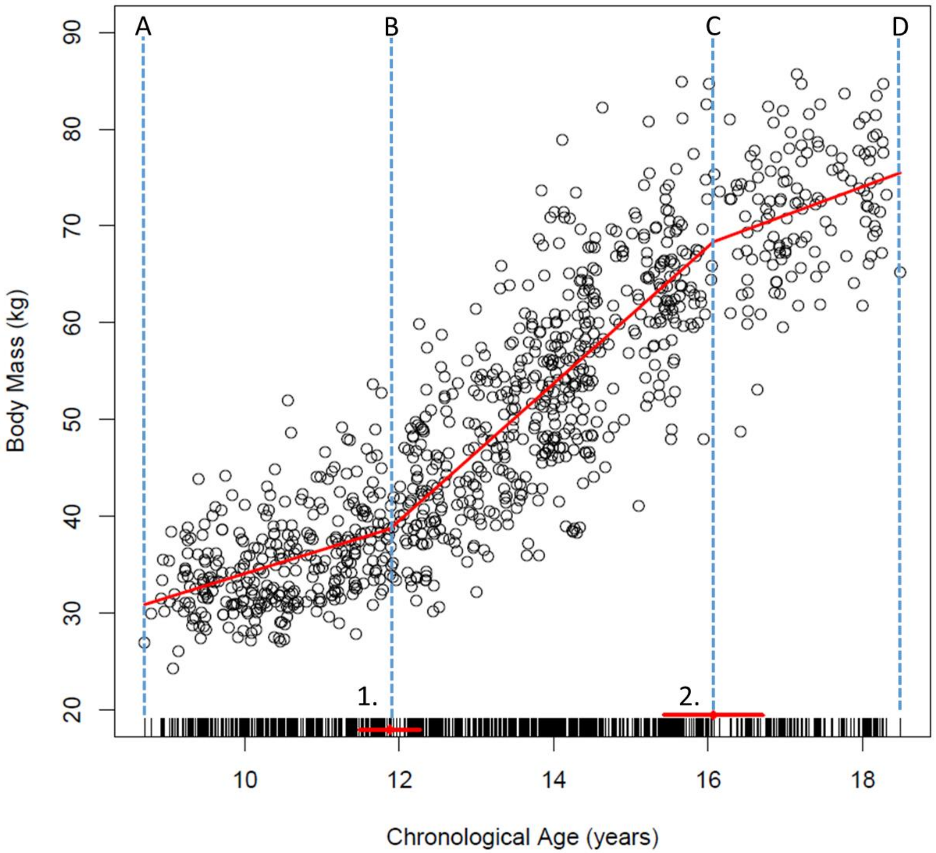


Figure 6. Cross-sectional analysis of UK elite youth soccer player stature development according to age and years to peak height velocity (YPHV), accompanied by a frequency distribution tally depicted along the 'X' axis. See Tables 16 and 17 for data corresponding to breakpoints A, B, C, & D.



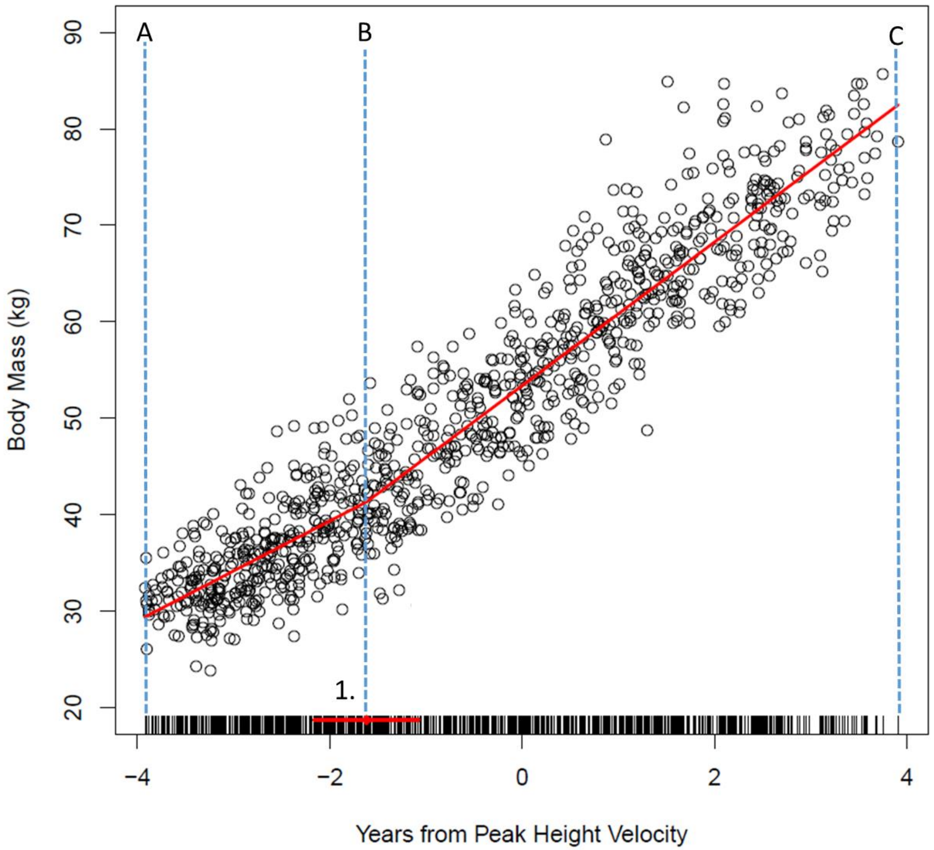


Figure 7. Cross-sectional analysis of UK elite youth soccer player body-mass development according to age and years to peak height velocity (YPHV), accompanied by a frequency distribution tally depicted along the 'X' axis. See Tables 16 and 17 for data corresponding to breakpoints A, B, C, (& D).

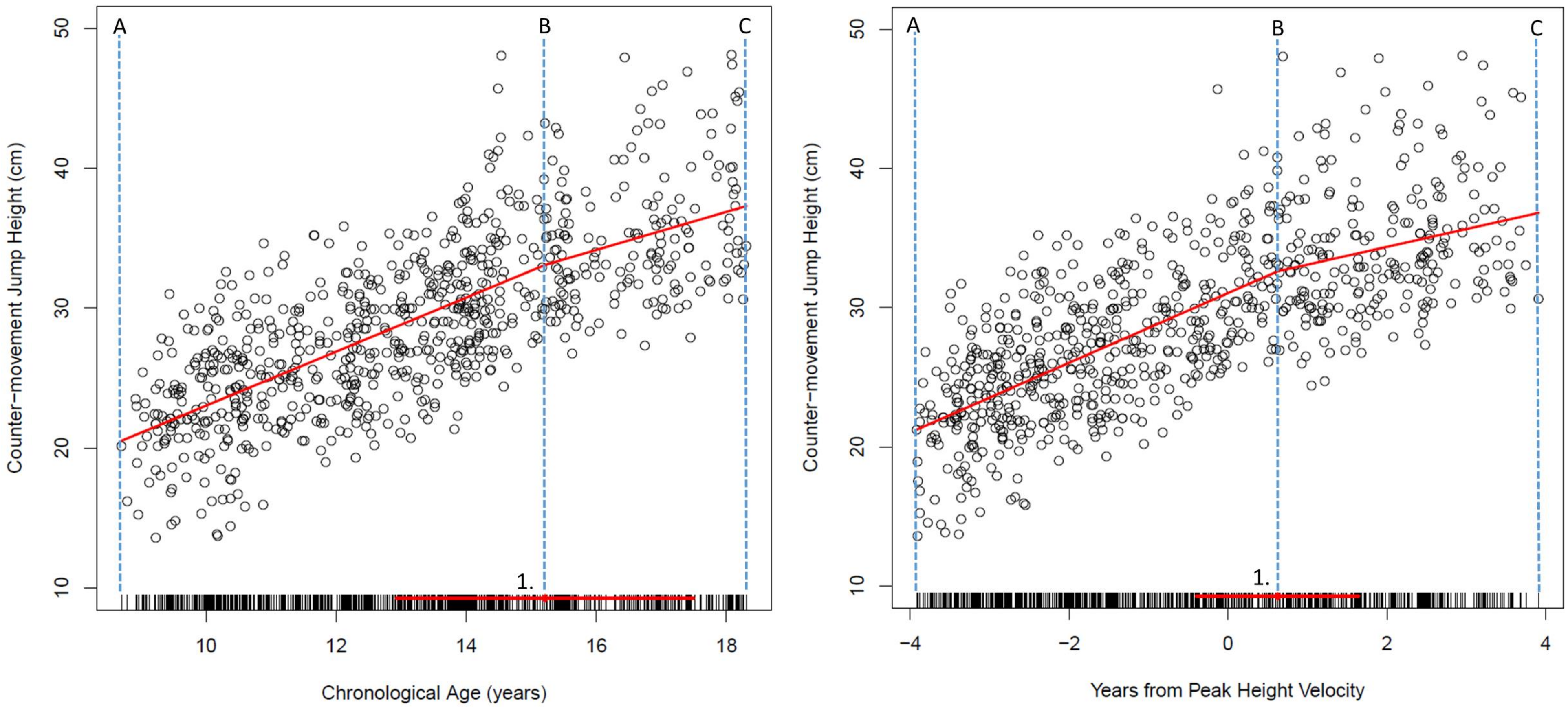


Figure 8. Cross-sectional analysis of UK elite youth soccer player counter-movement jump development according to age and years to peak height velocity (YPHV), accompanied by a frequency distribution tally depicted along the 'X' axis. See Tables 16 and 17 for data corresponding to breakpoints A, B, & C.

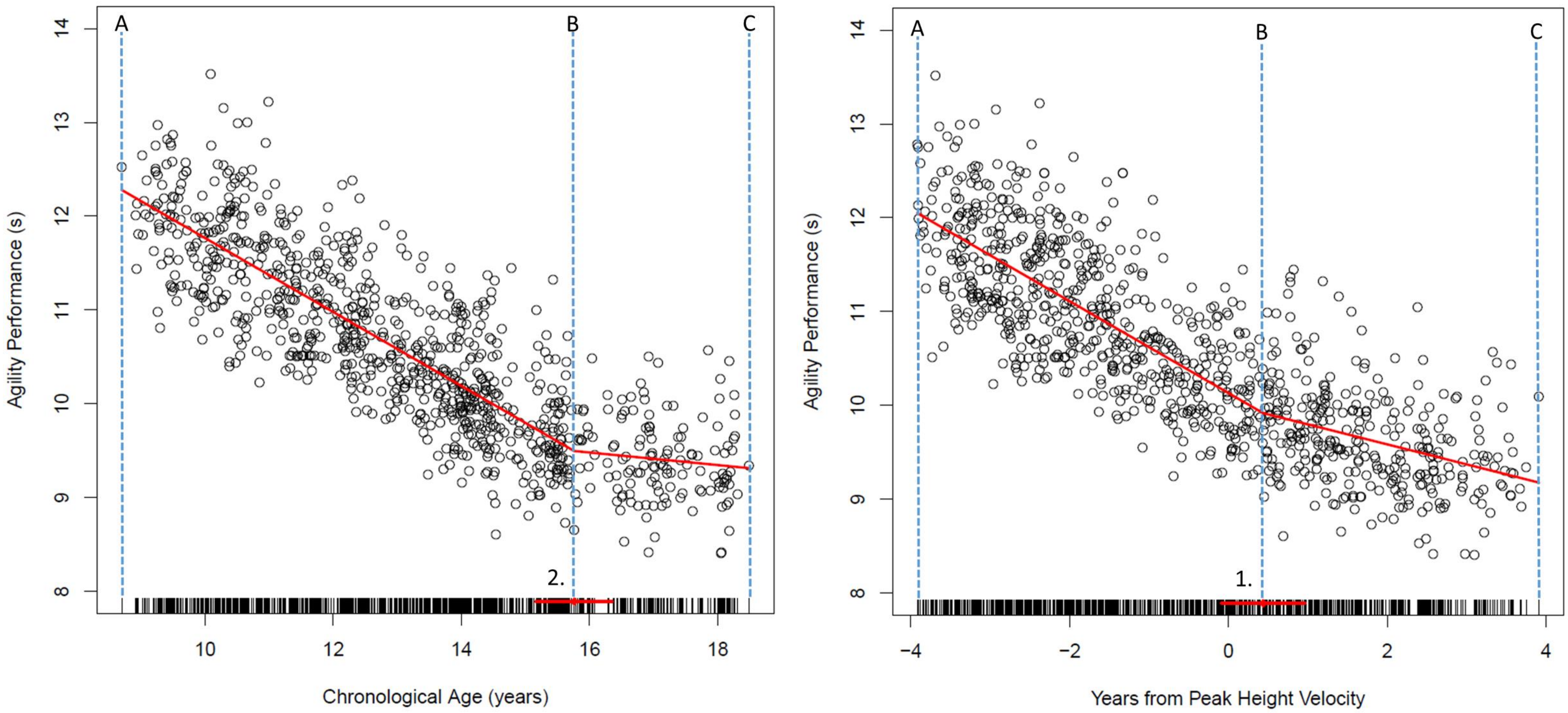


Figure 9. Cross-sectional analysis of UK elite youth player soccer agility development according to age and years to peak height velocity (YPHV), accompanied by a frequency distribution tally depicted along the 'X' axis. See Tables 16 and 17 for data corresponding to breakpoints A, B, & C.

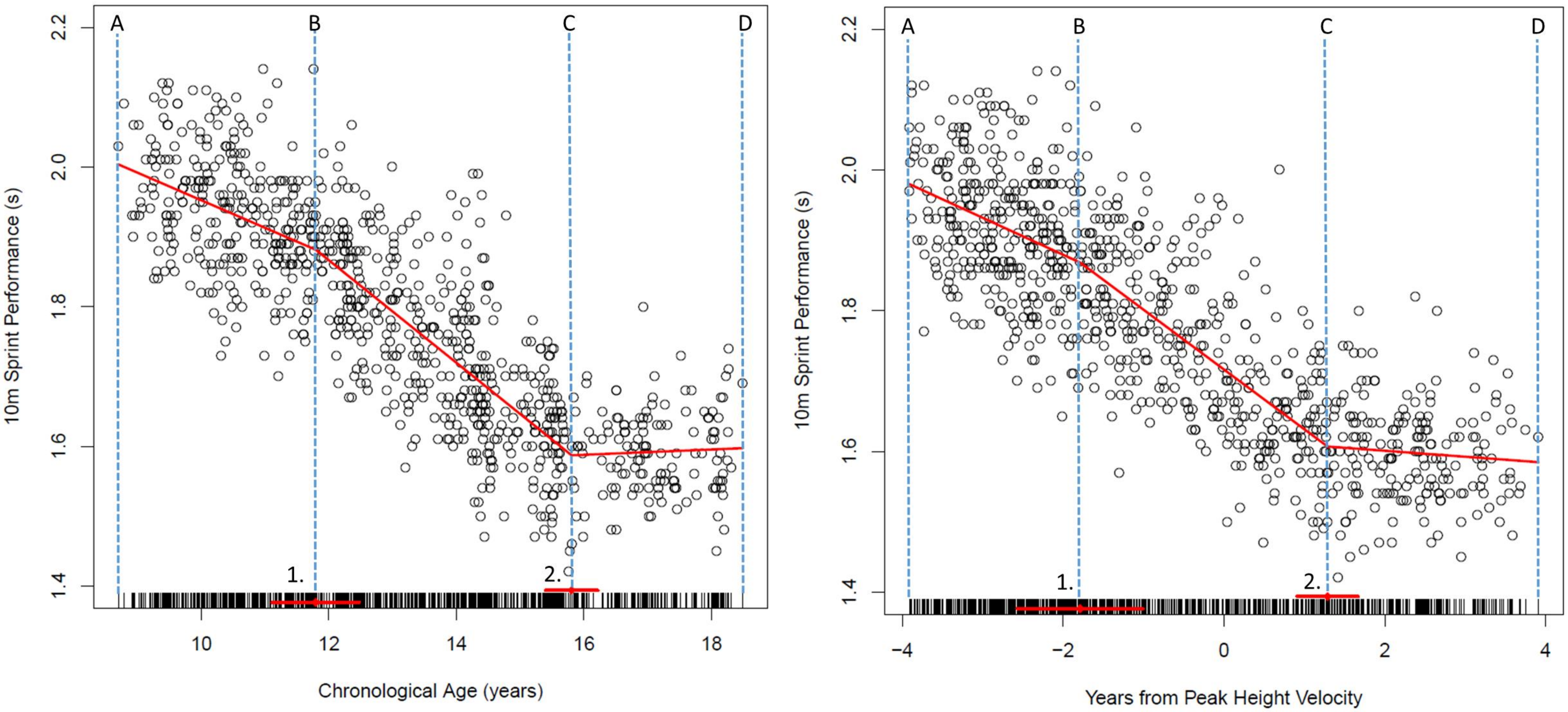


Figure 10. Cross-sectional analysis of UK elite youth soccer player 10m sprint development according to age and years to peak height velocity (YPHV), accompanied by a frequency distribution tally depicted along the 'X' axis. See Tables 16 and 17 for data corresponding to breakpoints A, B, C & D.

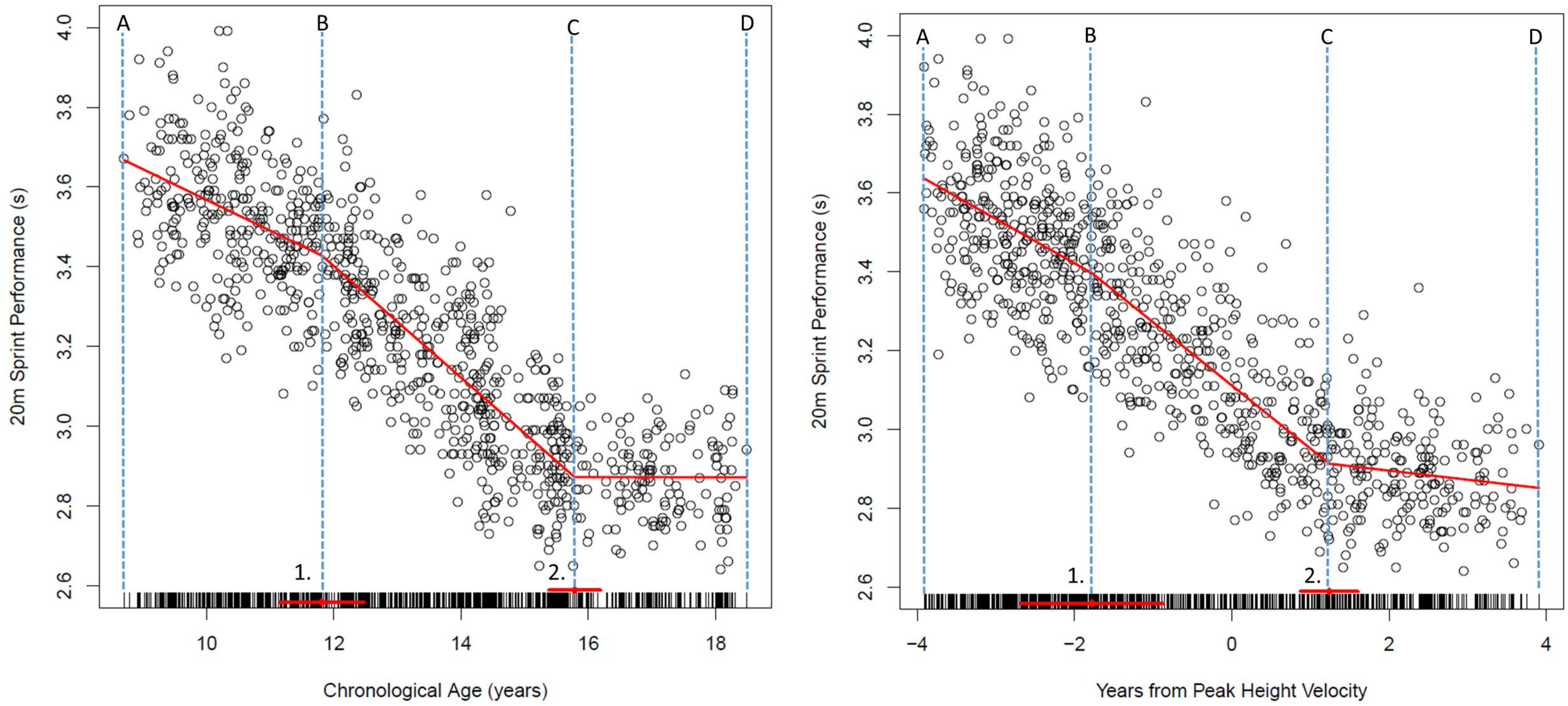


Figure 11. Cross-sectional analysis of UK elite youth soccer player 20m sprint development according to age and years to peak height velocity (YPHV), accompanied by a frequency distribution tally depicted along the 'X' axis. See Tables 16 and 17 for data corresponding to breakpoints A, B, C & D.

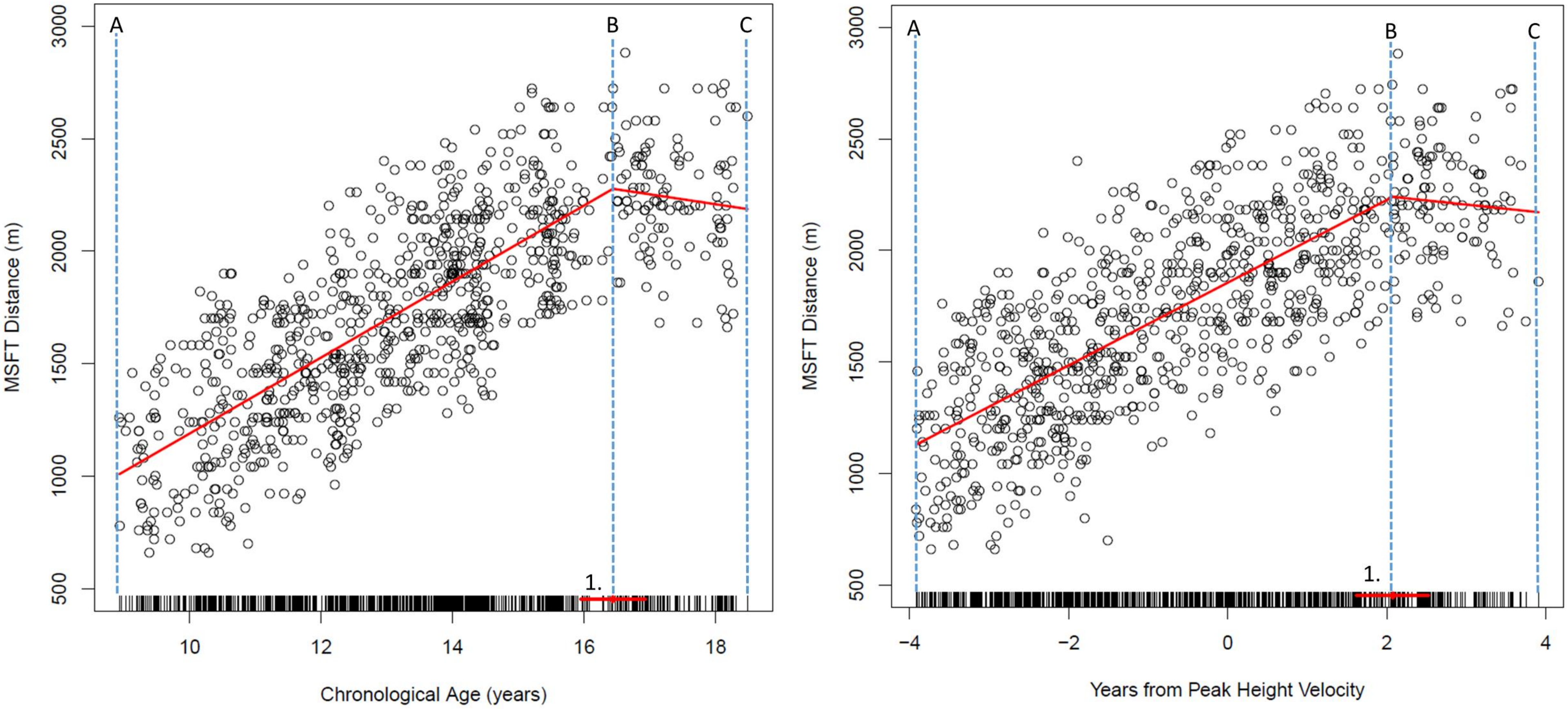


Figure 12. Cross-sectional analysis of UK elite youth soccer player Multi-Stage Fitness Test (MSFT) development according to age and years to peak height velocity (YPHV), accompanied by a frequency distribution tally depicted along the 'X' axis. See Tables 16 and 17 for data corresponding to breakpoints A, B, & C.

Table 15. Anthropometric and physical fitness development trajectories of English elite youth soccer players' according to decimal age in years.

		Breakpoints in development (years)		Rate of player development						
Variable	**n**	**Breakpoint #1 (95% CI)**	**Breakpoint #2 (95% CI)**	**Slope A-B (95% CI)**	***P***	**Slope B-C (95% CI)**	***P***	**Slope C-D (95% CI)**	***P***	**r^2**
Stature (cm)	*969*	10.7 (10.2 to 11.2)	15.2 (14.8 to 15.7)	1.8 (-0.1 to 3.8)	***P = 0.031***	7.5 (7.0 to 7.9)	***P ≤ 0.001***	1.8 (0.9 to 2.7)	***P ≤ 0.001***	0.81
Body-mass (kg)	*969*	11.9 (11.5 to 12.3)	16.1 (15.5 to 16.7)	2.5 (1.6 to 3.3)	***P ≤ 0.001***	7.1 (6.6 to 7.6)	***P ≤ 0.001***	2.9 (1.2 to 4.7)	***P = 0.001***	0.81
CMJ (cm)	*774*	15.2 (12.9 to 17.4)	---	1.9 (1.7 to 2.1)	*P* = 0.252	1.4 (0.7 to 2.0)	***P ≤ 0.001***	---	---	0.53
T-Test (s)	*926*	15.8 (15.2 to 16.4)	---	-0.39 (-0.41 to -0.37)	***P ≤ 0.001***	-0.07 (-0.18 to 0.05)	*P* = 0.132	---	---	0.72
10m sprint (s)	*875*	11.8 (11.2 to 12.5)	15.8 (15.3 to 16.3)	-0.04 (-0.05 to -0.02)	***P ≤ 0.001***	-0.07 (-0.08 to -0.07)	***P ≤ 0.001***	0.01 (0.01 to 0.02)	0.34518	0.73
20m sprint (s)	*875*	11.8 (11.2 to 12.4)	15.8 (15.3 to 16.3)	-0.08 (-0.09 to -0.06)	***P ≤ 0.001***	-0.14 (-0.15 to -0.13)	***P ≤ 0.001***	-0.01 (-0.03 to 0.03)	0.96411	0.76
MSFT (m)	*876*	16.4 (15.9 to 17.0)	---	169 (158 to 179)	***P ≤ 0.001***	-44 (-132 to 44)	*P* = 0.1642	---	---	0.61

Table 16. Anthropometric and physical fitness development trajectories of English elite youth soccer players' according to estimated number of years to/from PHV.

		Breakpoints in development (years)		Rate of player development						
Variable	**n**	**Breakpoint #1 (95% CI)**	**Breakpoint #2 (95% CI)**	**Slope A-B (95% CI)**	***P***	**Slope B-C (95% CI)**	***P***	**Slope C-D (95% CI)**	***P***	**r^2**
Stature (cm)	*969*	-3.2 (-3.5 to -2.9)	0.8 (0.5 to 1.1)	1.8 (-3.1 to 6.6)	*P* = 0.240	8.6 (8.3 to 9.0)	***P ≤ 0.001***	3.8 (3.0 to 4.5)	***P ≤ 0.001***	0.89
Body-mass (kg)	*969*	-1.6 (-2.1 to -1.1)	---	5.2 (4.4 to 6.0)	***P ≤ 0.001***	7.5 (7.2 to 7.7)	***P ≤ 0.001***	---	---	0.89
CMJ (cm)	*774*	0.6 (-0.4 to 1.6)	---	2.5 (2.2 to 2.8)	***P ≤ 0.001***	1.3 (0.7 to 1.9)	***P ≤ 0.001***	---	---	0.52
T-Test (s)	*926*	0.4 (-0.1 to 0.9)	---	-0.49 (-0.53 to -0.45)	***P ≤ 0.001***	-0.21 (-0.28 to -0.15)	***P ≤ 0.001***	---	---	0.68
10m sprint (s)	*875*	-1.8 (-2.5 to -1.0)	1.3 (0.8 to 1.8)	-0.05 (-0.07 to -0.04)	***P ≤ 0.001***	-0.08 (-0.09 to -0.08)	***P ≤ 0.001***	-0.01(-0.03 to 0.01)	*P* = 0.186	0.71
20m sprint (s)	*875*	-1.8 (-2.5 to -1.0)	1.2 (0.1 to 2.3)	-0.11 (-0.14 to -0.08)	***P ≤ 0.001***	-0.16 (-0.12 to -0.14)	***P ≤ 0.001***	-0.02 (-0.05 to 0.01)	***P ≤ 0.001***	0.74
MSFT (m)	*876*	2.1 (1.6 to 2.5)	---	185 (173 to 198)	***P ≤ 0.001***	-38 (-148 to 73)	*P* = 0.252	---	---	0.58

95% CI (95% confidence interval); MSFT = distance achieved during the Multi-Stage Fitness Test, CMJ = vertical counter movement jump.

7.4 Discussion

The primary aim of this chapter was to establish the estimated development tempo of anthropometric and physical fitness characteristics within a broad cross-sectional sample of elite youth soccer players' relative to their decimal age and somatic maturity. The main findings identified were: 1) Somatic maturity was able to explain more of the variance for measures of stature and body-mass than decimal age; 2) CMJ, agility and MSFT estimated rate of development improved linearly from ~ 9 years before reducing in tempo at ages circa-post PHV; 3) Estimated 10 and 20m sprint performance development demonstrated the potential for a distinct phase for increased rate of development during the ages circa-PHV.

Findings here revealed that the estimated onset of increased rate in stature development (10.7 to 15.2 years) (**Table 15**, **Figure 6**) for UK elite youth soccer players' may be earlier and subsequently prolonged than previously reported in child development literature (11.8 to 13.8 years (Malina, Bouchard, et al., 2004)). The precise underpinning reason for this is unclear. However, as discussed in **Chapter 2** (see **Chapter 2, Section 7.2**), the predictive equation (**Equation 1**) (Mirwald et al., 2002) used for the estimation of player somatic maturity in this thesis (and the EPPP) is acknowledged as a study limitation, given that it underestimates APHV for boys 3 years (-0.32 years) prior to PHV and overestimates predicted APHV (0.56 years) for boys 3 years post PHV (Malina & Kozieł, 2014). Therefore, such limitations likely explain the identified broad span of growth according to YPHV. In addition to this, **Chapter 5** of this thesis also showed that U13 to U16 players' (Youth development phase of the EPPP (The English Premier League, 2011)) who were born later in the selection year, typically possessed advanced maturity and anthropometric characteristics for their decimal age which in turn may have also contributed to the elongated period of player growth.

Although having an extremely powerful sample size (likely unachievable during longitudinal designs), the cross-sectional nature of the present study might be considered a limitation as development rates, time of onset and cessation of maturity related phenotypes are approximates. Such limitations within the design are identifiable within the growth data, as it is plausible to suggest that the advanced maturity related characteristics of players' recruited later in the development pathway may also be in part be responsible for the earlier estimated onset (-1.1 years), elongation of players' PHV established in the present chapter.

In addition to this, the present chapter also showed an enhanced estimated rate of anthropometric development peaking between 10.7 to 15.2 years, and between -3.2 to 0.8 YPHV, whereby estimated annual growth rates in stature and body-mass were 7.5 to 8.6 $cm \cdot year^{-1}$ and 7.1 to 7.5 $kg \cdot year^{-1}$ respectively. Such annual growth rates far exceed that of English birth charts (Royal College of Paediatrics and Child Health., 2013), showing that boys on the 50^{th} percentile according to decimal age (10.7 to 15.2 years) grow at an annual rate of ~6.4 $cm \cdot year^{-1}$ and 4.5 $kg \cdot year^{-1}$ for stature and body-mass respectively. This disparity might be a consequence of the previously discussed limitations (**Chapter 2**, (Section 7.2) of using the Mirwald et al. (2002) predictive equation within a diverse sample of children, given that the predictive algorithm is based upon longitudinal growth data of white Canadian children. Therefore, findings within this chapter do not account for the variations in maturity status according to players' ethnicity. That said, the cross-sectional nature of this study may also evidence that taller players are simply retained or selected into the system throughout the EPPP.

Enhanced model strength and coefficient estimate precision (confidence interval width) was apparent when the anthropometric data was expressed according YPHV (r^2 = 0.89) versus decimal age (r^2 = 0.81) for both stature and body-mass (**Table 16**). These findings can be considered as intuitive given the well documented relationship between child growth and biological maturity (Malina, Bouchard, et al., 2004; Mirwald et al., 2002; Sherar et al., 2005). The present chapter also revealed that estimated player stature was on average 141 cm at the onset (10.7 years) (**Table 15**) of players' growth spurt, corresponding to the 50th centile according to decimal age when compared to English birth charts (Royal College of Paediatrics and Child Health., 2013). However, estimated player stature at the end (15.2 years) of PHV (175 cm) (**Table 15**) resided around the 75th centile. Therefore, it might be speculated that the proposed reduced rate of peak annual growth and enhanced stature at the end of PHV is possibly a result of UK soccer development centres systematic exclusion of players' who are typically relatively younger and possess inferior maturity-related anthropometric characteristics, similar to that established in Belgian (Deprez, Fransen, et al., 2015) and Portuguese (Figueiredo et al., 2009) youth soccer development centres. Such speculation is justified, given that findings in **Chapter 5** showed a clear underrepresentation of players who wore born in the last 3 months (Q4) of the selection year, who possessed inferior maturity related anthropometric characteristics and affirming the presence of the maturation-selection hypothesis (Cobley et al., 2009; Helsen et al., 2005). These findings are of particular relevance to TD practitioners as data here provides a guide, of the estimated rates of anthropometric development of UK elite youth soccer players'.

The current chapter also revealed that estimated CMJ, agility and MSFT performance developed linearly from ~9 years (**Table 15**), before establishing approximate breakpoints in annual rate of development at 15 to 16 years of age (CMJ: 15.2 years; Agility 15.8 years; MSFT; 16.4 years) associated to circa to PHV (CMJ: 0.6 years; agility 0.1 years; MSFT; 1.6 years) (**Figure 8, 9 and 12**). Similarly to Philippaerts et al. (2006), findings according to YPHV (**Table 16**) in the present study suggests that estimated peak developmental velocities for agility (-0.49 s·year^{-1}), CMJ (2.5 cm·year^{-1}) and aerobic capacity (185 m·year^{-1}) development occur circa-PHV which are greater than the SWC for each of these attributes (agility: 0.08 s; CMJ: 0.6 cm; MSFT: 75 m) as established in **Chapter 4**. However, these fitness attributes continue to develop at a slower estimated rate (agility: -0.21 s·year^{-1}; CMJ: 1.3 cm·year^{-1}), if not decline (MSFT -38 m·year^{-1}) after PHV (**Table 16**). Although the primary aim of this study wasn't to investigate the existence of specified training 'windows of opportunity' *per se*, these data incidentally suggest an absence of such discrete 'windows' for these components of fitness. Suggesting that most components of fitness might be trainable throughout childhood as outlined in the YPD model (Ford et al., 2011; Lloyd & Oliver, 2012).

Given that high-intensity running qualities have been shown to discriminate between players who are selected and deselected for Belgian soccer development programs (Deprez, Fransen, et al., 2015), it can be argued that an understanding of how these attributes develop across the EPPP is of relevance for TD practitioners. The present chapter showed that estimated sprint performance development increased for 10 (-0.07 s·year^{-1}) and 20m (-0.14 s·year^{-1}) distances at decimal ages (11.8 to 15.8 years) (**Table 15**) spanning PHV (-1.8 to 1.3 YPHV) (**Table 16**). Therefore, it might be speculated that this change in development tempo is onset by the enhancements in neural-function and increases in circulating testosterone, altering muscle architecture circa-PHV (Mendez-Villanueva et al., 2010). Such findings are similar to a longitudinal (7 years) study of 267 Dutch elite youth soccer players who demonstrated rapid improvements in sprint speed across ages (12 to 14 years) typically associated to circa-PHV (Huijgen, Elferink-Gemser, Post, & Visscher, 2010).

The increased rate of sprint speed development confirms findings by Buchheit et al. (2010b) who suggest that the transition from pre-PHV to circa-PHV represents a period of notable increase in maximal sprint performance in comparison to a reduced development tempo circa- to post-PHV. Although such findings are seemingly in contrast to the consensus that most components of fitness are trainable throughout childhood

(Ford et al., 2011; Lloyd & Oliver, 2012; Philippaerts et al., 2006; Rumpf, Cronin, Oliver, & Hughes, 2012; Wrigley et al., 2014) and that training adaptation across adolescence is dependent on individualised periodisation for different components of fitness (Rumpf et al., 2012). Previous literature suggests that the rate of speed development in adolescent players' to be influenced by training modalities that specifically target neural activation in pre-adolescents and structural development in adolescent athletes (Mendez-Villanueva et al., 2010; Rumpf et al., 2012; Wrigley et al., 2014). Mendez-Villanueva et al. (2010) also acknowledge that improvements in neural-function are more likely responsible for an increased rate in sprint speed development circa-PHV rather than anthropometric advantages. However, they do not exclude the possibility of multi-joint coordination, elevated levels of circulating testosterone and growth hormone accompanied by adaptations to oxidative and non-oxidative metabolism having an enhancing effect of sprint speed development during these periods.

That said, Wrigley et al. (2014) have also shown that when matched to non-academy soccer players and accounting for differences in in baseline measures and maturation status, the magnitude in soccer specific physical characteristic development spanning adolescents was superior for elite youth soccer players versus their non-elite counterparts. Suggestive that, systematic, high intensity training modalities are likely responsible for continual and accelerated rates of player physical development independent of maturity status *per se*. Therefore, although the data presented in this chapter does suggest the presence of a transitional period in sprint speed development (Mendez-Villanueva et al., 2010), it remains unclear whether if such notable improvements in sprint performance shown here are a result of an increased sensitivity to specific training prescription circa-PHV (Balyi & Hamilton, 2004) or are simply a product of high intensity training (associated to elite youth soccer development centres) volumes, independent of maturation (Wrigley et al., 2014) trainable throughout adolescence (Ford et al., 2011; Philippaerts et al., 2006). Findings here represent justification to further investigate if these findings represent a plausible ‘window of opportunity’ or if this development rate is a relic of systematic training regime.

In summary, it is acknowledged that the cross-sectional nature of the experimental design in this chapter limits the generalisability of conclusions drawn. However, this limitation is accepted considerate of the broad representative sample of elite youth soccer players’, utilised in the present chapter. It is understood that the development of fitness attributes measured in the present chapter may have been influenced by individual development centre programmes. Therefore, it is acknowledged that the absence of empirical training data is a limitation of this thesis research chapter, given that between academy centre training prescription is likely to be heterogeneous and that academy soccer training prescription has been shown to influence the magnitude of long-term physical development of elite youth soccer players independent of maturation status (Wrigley et al., 2014). Similarly to previously published literature (Vaeyens et al., 2006), the U16 cohort was somewhat reduced in comparison to the other decimal age groups likely onset with the timing of data collection coinciding with UK development centres annual de-selection of players’ progressing from the Youth (U16) to the Professional (U17 to 18) development phase of the EPPP (The English Premier League, 2011). However, although lower, it was considered that the number of U16 players’ sampled in the present study presented enough statistical power to not effect trends presented in this chapter.

7.5 Conclusion

This chapter identified that model strength and coefficient estimate precision were slightly higher in YPHV versus decimal age for both stature and body-mass. However these trends were not apparent for estimated development of CMJ, agility and MSFT physical fitness attributes. Suggesting that TD practitioners might consider using somatic maturity as the independent variable when assessing the development of anthropometric characteristics *per se*. Evidence here also suggests the potential existence of a phase of increased sprint speed development established in ages typically associated with the onset of PHV. Such phases might be of particular relevance to TD practitioners given that player enhanced sprint capacity has been shown to discriminate between those players who are selected versus those deselected from soccer development programs (Deprez, Fransen, et al., 2015). Therefore, TD practitioners might opt to abstain from using measures of sprint speed as an exclusive (de)selection criteria until complete maturity has been achieved. Such an approach to player selection might help reduce the deselection of equally talented but slower players who may reach the same sprint capacity in adulthood, but are slightly later maturers versus there team-mates.

Although the ideology of a 'window of opportunity' for speed development may be appealing, given the cross-sectional nature of this study and the absence of a controlled group of matched (age, maturity and training prescription) elite youth soccer players, fitness practitioners should be cautious when considering the implementation of such anaerobic training periodisation concepts. It remains unclear if the increased rate of sprint development shown in the present chapter was a result of increased sensitivity to specific training prescription circa-PHV, a result of normative improvements owing to normal growth and maturity or simply a product of elite youth soccer academy training prescription that is independent of maturity status.

As well as estimating the onset and cessation of PHV, results from this chapter have also produced a guide of estimated annual development tempos for anthropometric and physical fitness characteristics relative to chronological and somatic maturity in a broad sample of elite youth soccer players. Ultimately, findings in this chapter provide further insight for elite youth soccer TD practitioners regarding the future physical and anthropometric development trajectories of their players'. Permitting soccer practitioners to better forecast players' rate of anthropometric and physical fitness characteristics development at an early stage of their development and facilitate the effective management of development centre resources when considering player potential.

Chapter 8. General Discussion, Limitations, Future Research Recommendations, Conclusions and Practical Recommendations

8.1 General Discussion

The first aim of this thesis was to examine the short-term, between and within-practitioner variation of the anthropometric measures used to estimate somatic maturity status of UK elite youth soccer populations. In addition, this thesis also sought to assess the reliability of a standardised battery of field-tests and to establish the minimum threshold for SWC for anthropometric, estimated maturity and physical fitness measures in order to accurately monitor player progression throughout the EPPP development pathway. On achieving this, it was then the aim of this thesis to apply the minimum threshold for SWC calculated for each component of the test battery used in this thesis and examine the extent of the maturity-selection hypothesis on player selection, the maturity related physical phenotypes that bias role allocation and explore how these interact during player development.

The EPPP (The English Premier League, 2011) was introduced by the EPL in 2011 with the general aims of reducing financial expenditure on player imports at the domestic level, and to expand the pool of talented players' for international representation by means of improving development centre player support infrastructure. Pertinent to this thesis, the EPPP mandates that each UK elite youth soccer talent development centre systematically monitors player athletic development relative to players' estimated somatic maturity via the use of a standardised battery of anthropometric, maturity and physical fitness field-tests. Although there is much literature assessing the reliability of such physical fitness field-test used within soccer (Buchheit & Mendez-Villanueva, 2013; Deprez, Buchheit, et al., 2015; Hulse et al., 2012), little-to-no data exists that has evaluated the short-term, between and within-practitioner variation of the anthropometric measures used to estimate player maturity within a soccer environment, with few research studies having established the SWC to determine ‘true-change’ in athletic development and growth (Deprez, Fransen, et al., 2014; Kempton et al., 2013). **Chapter 4** sought to further assess these qualities by having soccer players’ complete a standardised battery of three anthropometric (stature, seated height and body-mass) and five physical fitness (CMJ, 10 and 20m sprints, T-Test and MSFT) (**Chapter 3**) field tests on two test occasions, interspaced by 7-days.

Considering the multi-development centre dynamic of the EPPP, a key finding of this thesis was that the between-practitioner (practitioner A *versus* practitioner B), short-term reliability of the tested anthropometric field-tests were shown to have a high level of short-term reliability (stature: MD = -1.5%, TE = 0.4 cm, CV = 0.2 %; seated height: MD = 4.0 cm, TE = 1.5 cm, CV = 1.9 %; YPHV: MD = 2.6%, TE = 0.2, CV = 1.4 %) for anthropometric and estimated APHV measures. Although, having been determined as possessing a good level of between-practitioner, short-term reliability within this thesis, TD practitioners should be cognisant of the situational factors that might enhance measurement error within applied environments. For example, TD practitioners and coaches’ responsible for anthropometric measures of players’ can often be assigned to work within specific decimal age groups for each phase (Foundation, Youth and Professional) of the EPPP. Consequently, players’ are likely to be subject to between-practitioner variation in anthropometric measurement accuracy as they annually graduate throughout the EPPP development pathway. This in turn is likely to lead to inaccurate baseline measures from which each players’ development is annually evaluated. Therefore, it is recommended that the same, suitably trained individual remains responsible for the anthropometric data collection of players throughout their progression of the EPPP (as is common policy for many EPPP development centres). However, it is acknowledged that situational factors (staff turn-over, equipment availability etc.) are likely to restrict this recommendation and it is therefore advised that the between practitioner variation in anthropometrical measures are accounted for when evaluating player growth data derived from multiple practitioners.

Replicated in **Chapter 4**, Kempton, Sirotic and Coutts (2013) were amongst the first research studies to apply a minimum threshold for SWC approach to assess differences within an applied sporting environment. With only Deprez, Fransen, et al. (2014) having used the approach to assess the differences in player physical phenotypes according to playing position, it is to the authors best knowledge that the study presented in **Chapter 4**, is the first to have presented minimum thresholds for SWC for a standardised battery of anthropometric, somatic maturity and physical fitness tests used extensively within a broad sample of UK elite youth soccer development centres'.

The minimum thresholds for SWC presented in **Chapter 4** were very similar to thresholds established by Deprez, Fransen, et al. (2014), for a comparable cohort of elite youth (U9 to U17), Belgian soccer players' (stature: 1.1 to 1.8 cm; body-mass: 0.9 to 1.8 kg; CMJ: 0.6 to 0.7 cm; 30 m sprint: 0.01 to 0.05 s; T-Tests: 0.05 to 0.09 s; YYIRT: 40 to 86 m), demonstrating consistency in reported data across the literature. The short-term-reliability of anthropometric and physical fitness field-tests presented in **Chapter 4** were also comparable to previously reported data for other soccer test batteries (Hulse et al., 2012).

The EPPPs' mandate for TD practitioners to systematically monitor player anthropometric, somatic maturity and physical fitness development during the Foundation (U 9 to U11), Youth (U12 to U16) and Professional (U17 to U21) phases of development enables selectors to quantify the growth and athletic development of players' in relation to their maturity status. Subsequently, permitting medical staff to benchmark player development against the EPL national database (The English Premier League, 2011). Given that normative growth curves (Malina, Bouchard, et al., 2004; Malina et al., 2000) of relatively older players', born earlier in the soccer selection year often elicit enhanced maturity and anthropometric attributes, it might be considered important for TD practitioners to be cognisant of benchmarking players' according their relative age and maturity status. Such consideration is likely to limit the over-selection of relatively older players' recruited for development programs (the RAE), seemingly based on transient enhancements in physical and anthropometric phenotypes, commonly referred to as the maturation-selection hypothesis (Cobley et al., 2009; Helsen et al., 2005). However, there is consensus that few differences in physical performance characteristics exist between players' born in the first (Q1) and last (Q4) quartiles of the domestic soccer selection year (Deprez et al., 2013; Deprez et al., 2012). Additionally, there is also evidence to suggest that relatively younger players' who are selected for talent development programmes typically exhibit advanced maturity-related characteristics that enable them to compete on absolute terms with their relatively older counterparts (Deprez et al., 2013; Deprez et al., 2012). This is of particular importance, as such selection philosophy may prevent equally talented but relatively younger and less mature soccer players being recipients of expert coaching and facilities having been systematically discriminated against due to their inferior physical phenotype which are likely to be transient.

Using a standardised battery of field-tests (**Chapter 3**) deemed as having high short-term reliability in **Chapter 4**, **Chapter 5** of this thesis sought to further investigate the extent of the maturation-selection hypothesis within UK elite youth soccer development centres. This was achievable by quantifying the RAE and physical phenotypes of a broad sample of elite youth soccer players' enrolled in multiple UK development centres, spanning U11 to U18 years of age categorised in to bi-annual age groups. The main findings in **Chapter 5** identified, a clear un-even birth distribution of players' born in Q1 of each bi-annual age group, that differed significantly to UK birth distributions, retrieved for UK birth records between 1996–2004 (U11 to 12: P = 0.001;

U13 to 14: $P \leq 0.000$; U15 to 16: $P \leq 0.000$; U17 to 18: $P \leq 0.000$). Subsequently demonstrating that the RAE was prevalent at the entry-point to UK soccer developmental programmes and players' circa-PHV (U11 to U12: Q1 = 39%, Q2 = 13%; U13 to U14: Q1 = 46%, Q4 = 8%; U15 to U16: Q1 = 57%, Q4 = 8%; U17 to U18: Q1 = 42%, Q4 = 14%).

Chapter 5 showed that relatively older (Q1 = 39%) U11 to U12 players were *moderately* ($P = 0.148$, ES = 2.01) advanced in terms of maturity in comparison to players' born later in the selection year (Q4). These findings might be considered somewhat unsurprising given that the decline in normative growth rate reaches its lowest since birth at approximately 11 years of age (Tanner et al., 1966), followed by a fast acceleration in growth nearing PHV pre-circa adolescents (approx. 12 years) (Tanner et al., 1966). Therefore, it might be speculated that relatively younger, U11 to U12 players' are at greater risk of being deselected (or overlooked for initial selection) from talent development programs due to their inferior stature related to the *moderate* (ES = 0.52) effect magnitude for estimated PHV between players' born in Q1 and Q4 ($P = 0.148$, ES = 0.52).

Subsequently, **Chapter 5** of this thesis confirms findings reported in the literature (Carling et al., 2009; Deprez et al., 2012), showing an obvious presence of the RAE that favoured players' who are born in the first three months of the domestic soccer selection year. The relatively older players' analysed in **Chapter 5** typically possessed enhanced maturity related anthropometric characteristics, materialising in to transient physical advantage over their peers players' born in the last three months (Q4) of the domestic soccer season. Therefore, providing further confirmation of the presence of the maturation-selection hypothesis by TD practitioners within elite youth soccer development centres in England, governed by the EPPP.

In addition, **Chapter 5** also demonstrated that players circa to PHV (U11 to U12) born in the first quarter (Q1) of the selection year were afforded *small* advantages for MSFT, CMJ and agility performance. However, these advantages were temporary and subsequently absent within older chronological age groups (U13 to 18). Therefore, leading to the assumption that TD practitioners involved in UK development centres sampled in this thesis tend to favour players who possess advanced anthropometric rather than physical characteristics *per se*. Therefore, to reduce the premature deselection of players' founded on temporary, maturity related physical phenotypes, it is recommended that TD practitioners should consider increasing the frequency of player maturity and physical phenotype monitoring across the Youth development phase of the EPPP associated to circa-PHV. As well having an awareness of the intricacies of player growth according to relative age and maturity status within the context of player (de)selection and role allocation. Leading to the recommendation that TD practitioners should continue to keep on open-minded regarding possible interventions that might alleviate such bias.

Such interventions might include the introduction of bi-annual age groupings, effectively reducing the likely magnitude of anthropometrical difference between players born at either end of the revised selection period. However, given the situational (extra staff, facilities and funding) and logistical (all clubs agreeing to conform) constraints, such intervention is likely considered unrealistic. Therefore, of particular pertinence to this thesis, is the work conducted by Mann and van Ginneken (2016). They demonstrated that TD practitioners' bias toward the selection of relatively older elite youth soccer players is removed by simply having assessed players wear shirts that are numbered to correspond to their age allowing scouts to make informed decisions regarding each player selection according to their age. Consequently, it is suggested that TD practitioners should engage in (and implement) more collaborative (between clubs and with academic researchers) experimental interventions which might reduce, if not remove the RAE bias shown within **Chapter 5** of this thesis.

Given that the maturity estimate equation (**Eq 1**.) used in this thesis is largely dependent upon anthropometric components and that the players sampled in **Chapter 7** achieved their PHV (~0.6 $cm \cdot month^{-1}$ (7.5 $cm \cdot year^{-1}$)) between the ages 10.7 and 15.2 years, a monthly measurment frequency is justified given the previously discussed limitations (such as measurment error) of the the predictive equation (see **Chapter 2, Section 7.2**) coupled with this accelerated phase of growth. Athough employing this measurement frequency is unlikely to surpass the SWC threshold set for stature (2.3 cm) established in **Chapter 4** of this thesis, a direct monthly measurement of player anthropometrics and estimate of APHV might be preferred given the limitations embroiled within the predictive equation. In addition to measurment frequency, TD practitoners should also be considerate of the variations in growth rates according to players' ethncity. Such consideration is of particular relevance in the context of the UK and is justified given the diverse demographic of some inner city communites. Whereby black, black British and Chineses ethnicities consitute to ~ 10 to 30% of the local poulation (Rogers, 2011) and that children of different ethnicities mature at different rates (Malina, Bouchard, et al., 2004) (as discussed in **Chapter 2**, (**Section 7.2**).

In an attempt to further examine the influence of the maturation-selection hypothesis, **Chapter 6**, sought to explore the influence of this selection phenomena on playing position allocation of elite youth soccer players' in the UK. A similar study by Deprez, Fransen, et al. (2014) identified that Belgian elite youth soccer players' were characterised as exhibiting superior anthropometric and physical fitness attributes during age groups associated to pre and circa-adolescence. Showing that taller elite youth soccer players' are increasingly likely to be selected for goalkeeper or defensive outfield roles due to their anthropometric and physical advantages when competing with opposing players' in aerial contests (Buchheit et al., 2010a; Deprez, Fransen, et al., 2014; Malina et al., 2000).

Given the confirmation of the maturity-selection hypothesis within **Chapter 5**, it might be considered somewhat unsurprising that relatively older players' have also been shown to be selected for goalkeeper and defensive roles in elite youth soccer (Romann & Fuchslocher, 2013). However, given that current literature has sampled players from few different domestic and international (Carling et al., 2009) development centres (Deprez et al., 2013; Deprez, Fransen, et al., 2014; Hirose, 2009), findings likely reflect local talent identification philosophy. In addition, many studies have not distinguished between lateral and central derivatives of defensive and midfield playing positions (Deprez, Fransen, et al., 2014; Malina, Eisenmann, et al., 2004; Romann & Fuchslocher, 2013), therefore making inferences pertaining to playing position allocation of players residing in UK, elite youth soccer development programs difficult to formulate.

Having used a standardised battery of reliable (**Chapter 4**) anthropometric and physical fitness field-tests (**Chapter 3**), **Chapter 6** examined a broad sample of elite youth soccer players' residing within UK soccer TD centres to determine the influence of the maturation-selection hypothesis on playing position. This was achieved by examining the differences in relative age, anthropometry, maturity status, and physical fitness attributes associated to each positional role allocation throughout the EPPP 'Youth' and 'Professional' phases of development. U13 to U14 LD were identified as having been born significantly later in the selection year than CD, accompanied by GK and CD being advanced maturers versus other outfield players' for this age group.

Findings here confirm previous research (Deprez, Fransen, et al., 2014; Romann & Fuchslocher, 2013), stating that playing positions of elite youth soccer players' are often characterised by having enhanced maturity-related anthropometric attributes. Such findings are suggestive that the maturation-selection hypothesis established in **Chapter**

5 might act as a contributing factor to the tallest (and heaviest) players' being allocated GK and CD playing position, adhering to prior studies (Buchheit et al., 2010a; Deprez, Fransen, et al., 2014; Malina et al., 2000). However, given the reduced physical (Di Salvo et al., 2007) demand and specific technical nature of the playing position, it is somewhat unsurprising that GK displayed inferior endurance and sprint capacities versus their outfield team-mates at U13 to U14, but anaerobic phenotypes did not differ to outfield players' at U15 to U16 and U17 to U18. Therefore, it is plausible to suggest that the anthropometric rather than physical fitness characteristics *per se* are the primary determinants for GK role allocation during initial player selection (U13 to 14). This likely due to TD preference for GK who can dominate aerial duels and reduce the shot-target available to opposition players'.

With this in mind and to further enhance the physical qualities of GK, findings from this thesis justify the recommendation that early identification of physical fitness deficits (that are likely exhibited within the late Foundation, early Youth development phases as shown in **Chapter 6**) in GK (not exclusive to) should be remedied to improve long-term physical performance (Bergeron et al., 2015). Therefore suggestive that more specialised GK physical training should be integrated in to conditioning sessions that specifically focuses upon the development of aerobic and anaerobic capacities.

To this thesis best knowledge, the study presented in **Chapter 5** was the first to differentiate between central and lateral playing position characteristics of UK elite youth soccer players'. Although differences observed failed to reach statistical significance between central and lateral midfield roles in U13 to U14, LM tended to be faster sprinters versus CM at U15 to U16, a difference that was greater than the minimum threshold for SWC (**Chapter 4:** 10 m = 0.03 s; 20 m = 0.06 s) and attaining statistical significance at U17 to U18. These differences were also matched for U17 to U18 LD versus CD players'. Given that these between-playing position differences in sprint capacity were not evident pre-PHV, it can be speculated that these differences are unlikely to be a selection phenomenon. More a case of physical fitness characteristics that are autonomously developed according to the position-specific training and match demands of elite soccer (Di Salvo et al., 2007), which are trainable independent of maturity status (Wrigley et al., 2014).

Results reported in **Chapter 5** also suggested that the growth and physical fitness characteristics of UK elite youth soccer players' are individual-specific and moderated by maturity related growth curves. Therefore, it is recommended that TD practitioners should implement an individualised and 'plastic' approach to positional role assignment until complete player maturity is achieved. However, to ensure the effective role allocation of players' and enhance the management of player development centre resources, it might be considered essential for TD practitioners to understand the influence that the onset, tempo and cessation of somatic maturity and decimal age have upon physical phenotype development of elite youth soccer players' in the UK.

To the authors' best knowledge, Philippaerts et al. (2006) longitudinal study of the physical and technical development in Belgian elite youth soccer players' is the only study to provide detail of player longitudinal physical development tempo relative to PHV. However, although informative, data presented by Philippaerts et al. (2006) is based on a modest number (n = 232) of soccer players participating within different competitive standards (elite, sub elite, amateur) of soccer governed by an overarching selection policy (The Ghent Youth Soccer Project). Therefore, it might be assumed that findings here are representative of both individual talent selection policies and of soccer player athletic development in general, rather than exclusively examining the development of elite adolescent players. This necessitates the need for comparable data of UK based elite youth soccer players' derived from multiple, domestic soccer development centres' that will ultimately provide TD practitioners with appropriate data identifying the onset, cessation of PHV, accompanied by the development trajectories of their players' relative to the decimal age and somatic maturity. Not only will such data permit TD practitioners to make more informed decisions regarding a players' development relative to their maturity, but such data will enable fitness coaches to prescribe and periodise athletic development programs of players around the onset and cessation on player PHV. Therefore, **Chapter 7** presented an analytical approach to estimate the onset, tempo and cessation of anthropometric and physical fitness characteristic development in a broad sample of elite youth soccer players' relative to their chronological and biological ages.

Using a standardised and reliable (**Chapter 4**) battery of anthropometric and physical fitness field tests, the main findings in **Chapter 7** reported that players' CMJ, agility and MSFT performance improved linearly from ~ 9 years before reducing in tempo at ages (CMJ: 15.2 years; Agility 15.8 years; MSFT; 16.4 years) circa-post PHV (CMJ: 0.6 years; agility 0.1 years; MSFT; 1.6 years). Findings in **Chapter 7** also reported that the peak development tempo of player CMJ (2.5 cm·year^{-1}), agility (-0.49 s·year^{-1}), and aerobic capacity (185 m·year^{-1}) development occur circa-APHV. These findings are comparable to those recorded for Belgian elite youth soccer players' (Philippaerts et al., 2006), showing that these fitness attributes also continue to develop at a slower rate (agility: -0.21 s·year^{-1}; CMJ: 1.3 cm·year^{-1}), if not decline (MSFT -38 m·year^{-1}) after PHV is achieved. Knowledge of 'slowing' annual development rates are particularly important to practitioners working with post-PHV players within the Youth and Professional development phases of the EPPP. Such consideration will help to ensure that the expectations and forecasts of players annual development expected by TD practitioners are realistic and relative to each players stage of maturity in order to help reduce the number of (de)selections of players for development programs based upon transient, maturity related physical phenotypes. With this in mind, it would be advantageous if the growth and development data collected as part of the EPPP mandate was collated, analysed, interpreted and fed back to TD practitioners, players and guardians to help nurture a better understanding of young soccer player development to a broader number of stakeholders.

However, **Chapter 7** also reported that the development of 10 and 20 m sprint speed to markedly improve by -0.07 and -0.14 $s \cdot year^{-1}$ respectively at decimal ages (11.8 to 15.8 years) spanning APHV (-1.8 to 1.3 YPHV). These data confirms findings by Mendez-Villanueva et al. (2010), who suggested that the presence of a transitional period spanning PHV that represents a period of notable increase in maximal sprint performance in comparison to a reduced development tempo circa-post PHV.

The identification of a period of marked improvement (identified in **Chapter 7**) for sprint speed development is of particular relevance, given that inferior sprint capacity can lead to the premature deselection of players from development programs, Such players' are typically less mature but maybe equally as technically gifted and are likely to match the sprint performance of their more mature counterparts once they have achieved an adult state of development (Deprez, Fransen, et al., 2015). Therefore, careful consideration of this phase of athletic development may limit the number of players selected for talent development programs based on transient superior sprint performance of players, typically afforded to more mature players. However, given that information pertaining to the training type and volume is absent in **Chapter 7,** it remains unclear whether the increased rate in sprint speed development across PHV reported in **Chapter 7** represents plausible justification to further investigate a 'window of opportunity' for sprint performance, or is merely a product of systematic training regime that is predetermined by individual genetics and growth curves (Buchheit & Mendez-Villanueva, 2013; Wrigley et al., 2014).

The International Olympic consensus statement on long-term youth athletic development (Bergeron et al., 2015) demands that athlete development frameworks should be holistic and representative of the multidimensional nature of athlete development and that 'best practice' should be realised for each development phase rather than prescriptions of training based on age and maturity based factors. Such sentiment is echoed by the British Association of Sport and Exercises Scientists (BASES), who state that a maturational threshold for enhanced sensitivity to athletic training is unlikely to exist but more so continue throughout childhood (BASES, 2014). Therefore, following government body recommendations (BASES, 2014), there is a necessity for controlled longitudinal investigation of elite youth athlete development to clarify the optimal training prescription that will elicit the greatest rates of development for these attributes across childhood and differing maturity status. For instance, contrasting effects of high intensity intermittent training (HIIT) have been demonstrated in female, adolescent soccer players (Wright, Hurst, & Taylor, 2016). Showing that HIIT had a *very likely moderate* improvement in endurance capacity for at-PHV (31% [90% CI ± 9.4%]) and post PHV (28% [90% CI ± 13%]) but decrements in repeated-sprint ability were most *likely very large* (6.5% [90% CI ± 3.2%) before-PHV. Although 'windows of opportunity' have in large been discredited (Ford et al., 2011; Lloyd & Oliver, 2012; Wrigley et al., 2014), such data is suggestive that TD practitioners should remain considerate of player maturity to ensure that training prescription is suitable (and safe) for the child's stage of development and intended training goals.

Findings also identified that the statistical model employed in **Chapter 7** showed greater strength and coefficient estimate precision for YPHV versus decimal age for both stature and body-mass. Therefore suggestive that TD practitioners should assess and consider player anthropometric development according to somatic maturity status rather that decimal age *per se*. In summary, findings in **Chapter 7** demonstrated evidence of an increased phase of sprint speed development, established during ages typically associated with the onset of PHV, accompanied by comprehensive data set of annual development tempos for anthropometric and physical fitness characteristics relative to chronological and somatic maturity in a broad sample of elite youth soccer. Although the inferences that can be made are somewhat restricted by the cross-sectional study design and limitations embroiled within the (Mirwald et al., 2002) (as discussed in **Chapter 2**, (**Section 7.2**), it is hoped that these data will provide TD practitioners with a guide of when the influence of maturity will onset, peak and subside on physical phenotype development so that informed decisions can be made regarding the suitability of training prescription and development trajectories for players.

It is assumed that the data presented in **Chapters 4 to 8** of this thesis will offer valuable insight and guide for TD practitioners during the monitoring, analysis and interpretation of elite youth soccer player physical phenotypes development. It is also hoped that this thesis will enable TD practitioners to better understand the intricacies between somatic maturity, relative age and the physical development of players' that contribute toward the maturation-selection hypothesis. This understanding will enable TD practitioners to better forecast the physical and anthropometric development trajectories of players', which will ultimately enable practitioners to deploy effective recruitment policies and better manage development centre resources when considering player potential

8.2 Limitations

The general aim of this thesis was to assess the extent of the maturation-selection hypothesis on recruitment and playing position allocation of players' within the EPPP, In addition, the present thesis also sought to examine the influence of somatic maturity status and relative age on player anthropometric and physical fitness development and positional role allocation as they navigate the EPPP.

As discussed in **Chapter 2**, soccer match-play can be characterized as prolonged, high intensity, intermittent match activity, lasting 90-min that is interspersed by periods of low intensity activity that taxes there aerobic and anaerobic energy systems (Di Salvo et al., 2007; Mohr et al., 2003). Therefore, general consensus is that elite youth soccer players' should be able to perform a number of soccer specific performance attributes such as sprinting, agility, endurance and power. Although the standardised battery of field-tests (**Chapter 3**) implemented in this thesis were proven as reliable (**Chapter 4**) methods for the assessment of such physical fitness qualities, the absence of other measures of players' physical fitness (strength, flexibility, movement-efficiency), psycho-social and technical (passing, shooting, dribbling) attributes (as recommended within holistic TD programs (Reilly, Williams, et al., 2000; Unnithan et al., 2012)) is acknowledged as limitation within this thesis.

Given that technical characteristics can discriminate between 'selected' and 'deselected' players' when considered in conjunction with physical characteristics (Huijgen et al., 2010), the absence of a measure of technical ability within this thesis might be considered as a major limiting factor for the inferences that can be made to the wider TD process within UK elite youth soccer. Although the Loughborough Soccer Passing Test (Ali et al., 2007) is highly cited in pertinent literature (Foskett, Ali, & Gant, 2009; Impellizzeri et al., 2008; Rampinini et al., 2008; Skinner, Hustler, Bergsteinova, & Buskirk, 1973) as a recognized method for assessing soccer technical qualities, there is seemingly a lack of consensus on a uniform method for examining soccer players' technical qualities. That said, a multivariate analysis of individual variation in soccer skill using the University of Queensland Football Skill Assessment Protocol (passing [over 20m], lofted passing [over 35m], wall-passing, shooting accuracy [over 20m]), dribbling speed and juggling ability) has shown promising evidence to support the use of a comprehensive battery of soccer specific technical field tests as a tool for talent identification (Wilson et al., 2016), although this work is still in its infancy. Therefore, the absence of an ecologically valid technical soccer test that accurately reflects the stochastic nature of soccer match-play is likely responsible for the lack of a uniformed measure of technical ability within the national monitoring initiatives (such as the EPPP).

In addition, the choice of soccer technical assessment is primarily dependent on situational factors such as cost, available time, space, number of players' and experienced practitioners to operate the tests (Ali, 2011). These factors might in part offer explanation for the absence of player technical ability measures within the test battery chosen by clubs to satisfy the EPPP physical testing mandate upon which this thesis was largely dependent. That being said, given the strong presence of the maturation-selection with UK elite youth soccer development centers established within **Chapters 5** and **6** of this thesis, it is recommended that an individual assessment of player technical ability within a match-play or training environment might ensure that equally technically gifted players are not deselected based on transient, enhanced maturity related physical phenotypes.

In addition, it also acknowledged that the fitness test battery deployed in the present thesis may not be wholly representative of the fitness test battery presently used within the EPPP (in particular the absence of the YYIRT; Bangsbo et al. (2008)). However, given that the justifications outlined in **Chapter 2** of this thesis, the composition of the test battery was chosen on the basis that they met the specific validity and reliability criteria, whilst also being cost efficient and satisfying logistical constraints of the multiple clubs involved within the series of research studies within this thesis. Therefore, given that the EPPP was in its infancy during the timing of data collection, the composition of the deployed fitness test battery was deemed suitable by the Football League to fulfil the requirements of the EPPP mandate for physical benchmarking of players' (The English Premier League, 2011). As discussed in **Chapter 2**, the assessment of skeletal maturity using radiology based methods is largely considered as the criterion measure of biological maturity (Greulich & Pyle, 1959; Roche et al., 1988; Tanner & Whitehouse, 1962). However, given the expensive diagnostic equipment and expert clinical knowledge required to establish player skeletal maturity, it is intuitive that EPPP legislation (The English Premier League, 2011) mandates the use of a cross-validated (Bailey et al., 1999), non-invasive, estimation of player somatic maturity (Mirwald et al., 2002), calculated using anthropometric measures that are collected as part of the EPPP systematic test battery.

Identified in **Chapter 2** (**section 2.7.2**), the longitudinal accuracy of the estimation of somatic maturity method implemented in the present thesis has been questioned (Deprez, Fransen, et al., 2014; Malina & Kozieł, 2014). Whereby a validation study of the predictive equation used to estimate somatic maturity status (Mirwald et al., 2002) conducted by Malina and Kozieł (2014) showed that although the equation possessed adequate accuracy for estimating somatic maturity circa APHV (± 0.21), the variance in measurement accuracy was influenced by decimal age and maturity status at either end of the equation range (-3 YPHV: -0.32 years; +3 YPHV: +0.56 years). However, it is assumed that the cross-sectional nature of the research studies presented in **Chapters 5 and 6** somewhat attenuates the confounding influence of decimal age on the APHV prediction given that the purpose theses chapters were to examine the differences between players of varying relative ages and positional roles according to maturity within biannual age groupings.

It is acknowledged that the predictive equation (Mirwald et al., 2002) used within this thesis likely overestimated the APHV for players over the age of 16 years with **Chapters 5**, **6** and **7.** For instance, this is particularly identifiable in **Tables 12 to 14** where APHV is somewhat overestimated and associated inferences were tempered. That being said, given the large, multi-development centre design of this thesis, it is believed that estimation of somatic maturity procedure was the only viable method of attaining measurements of maturity status within a broad sample of UK elite youth soccer development programs during the time of data collection. However, since data collection completion of this thesis, a modified predictive maturity equation (Moore et al., 2015) has been developed. Moore et al. (2015) model out performs the Mirwald et al. (2002) equation, reporting that 90% of predictions being ± 1 year of secondary external samples taken from the Healthy Bone Study III (n = 81 [boys: n = 42], 8.9 to 18.9 years) and Harpenden Growth Study (n =151 [boys: n = 79], 7.5 to 17.5 years) (cited in Moore et al. (2015)). Therefore, suggesting that some inferences regarding elite youth soccer player athletic development and performance according to estimated somatic maturity (having used the (Mirwald et al., 2002)) in this thesis and indeed previous literature (Buchheit et al., 2010a; Deprez et al., 2013; Deprez, Fransen, et al., 2014; Lovell et al., 2015; Mendez-Villanueva et al., 2011; Mendez-Villanueva et al., 2010; Mendez-Villanueva et al., 2012) may need to be tempered somewhat.

Lastly, although the broad sample of players examined within the present thesis is largely considered a strength of the research design, it might also be perceived as a source of weakness given that variables such as training volume, intensity and modality were not controlled for, which likely confounds findings somewhat. Therefore, although the findings presented within this thesis provide comprehensive age and playing position benchmark data according to maturity status and relative age, accompanied by estimated annual rates of physical phenotype development for elite you soccer players, TD practitioners should understand the limitations in association to the cross-sectional nature of this thesis when interpreting their own player data within the context of this thesis

8.3 Future Research Recommendations

A main aim of this thesis to examine the extent in which maturity related physical phenotypes of UK, elite youth soccer influence the selection, playing role allocation and development of elite youth soccer players' as they navigate the EPPP. As discussed in **Chapter 7** of this thesis, with exception of sprint performance characteristics, the cross-section of elite youth soccer players' sampled showed a tendency to continually develop physically in a linear fashion from ~9 years, before reducing in tempo circa-post PHV. However, the cross-sectional nature of experimental design in **Chapter 7** somewhat limits the inferences that can be drawn regarding the LTAD of elite youth soccer players'. As cited in **Chapter 7**, only Philippaerts et al. (2006) have longitudinally monitored and assessed the physical development of elite youth soccer players' using a comprehensive, standardised battery of anthropometric and physical fitness field-tests. Therefore, as advocated by the British Association of Exercise Scientists (BASES) expert statement on the 'Trainability during Childhood and Adolescence' (BASES, 2014), there is necessity for future longitudinal designed research studies to include control groups of subjects so that the maturational threshold in the development of child physical phenotypes can be further examined. Such research may offer further scientific explanation of the underlying mechanisms of athletic adaptation across different stages of player maturation (BASES, 2014) and ultimately contribute toward the further develop of elite youth soccer players who are eligible for senior domestic and international representation

In addition to longitudinal study design examining the physical and athletic development of elite youth soccer players, there is a void in the literature that examines the evolution of positional role allocation. To date, many studies (including **Chapter 6**) have well described the relative age and maturity related physical and anthropometric phenotypes of elite youth soccer players according to playing position (Buchheit et al., 2010a; Deprez, Fransen, et al., 2014; Romann & Fuchslocher, 2013). However, there is a lack of longitudinal, empirical, data examining the evolution of elite youth soccer player positional role allocation. Such investigatory work would likely permit TD practitioners and national governing bodies to better understand how young soccer players develop (technically, tactically, physically and mentally) across the EPPP relative to their final primary playing position once a senior level has been achieved. Such research is likely to increase the efficiency of youth development investment in the professional soccer pyramid in England. (The English Premier League, 2011).

In addition, **Chapter 7** of this thesis reported evidence of an 'increased' phase of sprint speed development (10m: -0.07 $s \cdot year^{-1}$; 20m: -0.14 $s \cdot year^{-1}$) that onsets at decimal ages (11.8 to 15.8 years) spanning PHV (-1.8 to 1.3 YPHV), similar to those advocated by the Balyi (2004) LTAD model. Although it is suggested that maturity might be influential on increasing the rate of sprint speed development in highly trained soccer players (Mendez-Villanueva et al., 2011) and appealing to confirm the ideology of a 'window of opportunity' for speed development within this thesis, it remains somewhat unclear if the magnitude of sprint speed development was significantly enhanced beyond the rate of each players natural development. In addition, it is also unknown if the increased rate of speed development outlined in **Chapter 7** was an outcome from specific sprint speed training intervention, prescribed pre- to circa-PHV. Alternatively, it is equally plausible that any training effect was a direct result of players' enhanced capacity to perform a higher training dose circa-post PHV, rather than physiological changes related to the onset of puberty (BASES, 2014).

As discussed in **Chapter 7**, compelling evidence does exist to suggest that prescription of HIIT pre and post PHV elicited *very likely moderate* improvements in endurance capacity within female adolescent soccer players. Although, HIIT was also identified as having a harmful effect on repeated-sprint ability before and at PHV.

Similarly, Lloyd, Radnor, De Ste Croix, and Cronin (2015) also showed that implementing 6 weeks of plyometric training elicited greater changes in both squat jump and running acceleration performance in pre PHV in adolescent boys when compared with the post-PHV peers. However, other training responses to traditional strength and combined training demonstrated an absence of any significant and clinically meaningful change between pre and post-PHV boys. Indicative that plyometric training might be an effective training prescription to improve jumping performance for pre PHV boys. Therefore, considering such training intervention studies, and in agreement with the BASES (2014) expert statement on trainability during childhood and adolescence, future research is required to further examine the timing, mode and impact (positive and negative) of specific training prescription on the physical fitness characteristics of elite youth soccer players, at different stages of their development across PHV. With particular reference to the efficacy of implementing specific athletic conditioning sessions according to somatic maturity offset (bio-banding).

As discussed in **Section 8.2**, the absence of a measure of player technical skill is considered a limitation of this thesis, as player technical attributes can distinguish between those players ‘selected’ and ‘deselected’ for specialist development programs (Huijgen et al., 2010), such as the EPPP (The English Premier League, 2011). Similarly to the assertions made in **Chapter 7**, longitudinal (7 years) analysis of elite youth soccer player technical and sprint development (shuttle sprint and dribble Test and the slalom sprint and dribble test) identified a rapid improvement in player sprinting development circa-PHV, but this was in contrast to dribble performance, which only improved considerably during ages (16 years) associated to post-PHV (Huijgen et al., 2010). Huijgen (2013), also demonstrated that longitudinal analysis of a similar group of elite youth soccer players identified that the amalgamation of speed and accuracy in soccer skills might be more important than speed alone when deciding on players to be selected for talent development programs.

Given that technical skill, is likely to be a primary determining factor for the selection of players for talent development programs, there is an absence of literature that examines the technical (dribbling, passing, shooting) development of UK elite youth soccer players. This is probably likely due to the lack of consensus on a uniform method for examining soccer players' technical qualities (discussed in **Section 8.2**). That being said, the soccer technical test battery devised by Russell, Benton, and Kingsley (2010), does report promise of being a valid and reliable method of quantifying player passing (CV = 6.5%), shooting (CV = 6.9%) and dribbling (CV = 2.4%) capacities. However, it might be argued that a more holistic, multivariate approach to assessing soccer technical ability is required such as the earlier mentioned (**Chapter 8, Section 8.2**) University of Queensland Football Skill Assessment Protocol (passing [over 20m], lofted passing [over 35m], wall-passing, shooting accuracy [over 20m]), dribbling speed and juggling ability). Such test batteries might permit future research design to examine the longitudinal, technical development of elite youth soccer player according relative age, maturity status and playing position that will reduce the premature deselection of equally talented soccer players who are relatively younger and less mature from the EPPP.

Lastly, given the outlined limitations (Deprez, Fransen, et al., 2014; Malina & Kozieł, 2014) associated to the maturity predictive equation (Mirwald et al., 2002) (summarized in **Section 8.2)**, it is likely that the predicted APHV for players both 3 years to, and post PHV are under and overestimated in previous pertinent literature (Buchheit et al., 2010a; Deprez et al., 2013; Deprez, Fransen, et al., 2014; Lovell et al., 2015; Mendez-Villanueva et al., 2011; Mendez-Villanueva et al., 2010; Mendez-Villanueva et al., 2012) and in **Chapters 5**, **6** and **7** of this thesis respectively. Therefore, there is necessity for future research design to either employ the redeveloped maturity estimate equation (Moore et al., 2015) or implement alternative and reliable methods (DXA-derived from hand scans (Romann & Fuchslocher, 2016)) suitable for application within applied environments that can evaluate, benchmark and predict the athletic development of elite youth soccer players relative to maturity status.

8.4 Conclusions

Established in **Chapter 4**, the standardised battery of anthropometric, maturity and physical fitness field-tests deployed by a selection of UK elite youth soccer development centres between 2011 to 2015 as part of the EPPP (The English Premier League, 2011) observed high levels of short-term reliability and are capable of monitoring changes in elite youth soccer player athletic development, growth and maturity. The practical application of minimum threshold for SWC for player development presented in **Chapter 4** of this thesis will enable TD practitioners' to contextualise player development and is concluded as a worthwhile venture for elite youth soccer practitioners.

Findings in **Chapter 5** of this thesis have confirmed the presence of a clear birth distribution bias that favours the selection of players' for UK elite soccer development centres, who are born earlier in the selection year. It is likely that these players' possess enhanced maturity related anthropometric characteristics and will have *small*, yet transient physical advantages over players' born later in the selection year. Therefore, it can be concluded that the advanced anthropometric characteristics of relatively older, Youth development phase soccer players' clearly confirms the maturation-selection hypothesis (Cobley et al., 2009; Helsen et al., 2005) by TD practitioners in UK elite youth soccer development centres governed by the EPPP. As shown in **Chapter 6**, it can be concluded that the maturation-selection hypothesis extended to the allocation of elite youth player playing positions, identifying that irrespective of decimal age group, specific anthropometrical attributes (enhanced stature and to a lesser extent body-mass) characterised defensive playing positions in UK elite youth soccer development programmes. Findings from this thesis strongly suggest that transient body size advantages conferred by relative age and maturity status, influence positional role allocation in existing, EPPP youth soccer programmes.

Given the findings presented in **Chapter 7**, it is concluded that the applied statistical model strength and coefficient estimate precision for presented data were somewhat higher in YPHV versus decimal age for both stature and body-mass and were absent for the development of CMJ, agility and MSFT physical fitness attributes. Therefore, TD practitioners should consider using somatic maturity as the independent variable when longitudinally assessing the development of anthropometric characteristics. However, likely to be of increasing practical relevance for TD practitioners is that **Chapter 7** establishing that sprint performance development increased across decimal ages (11.8 to 15.8 years) spanning PHV (-1.8 to 1.3 YPHV). This can be considered a key finding, given that the sprint qualities of elite youth soccer players have been shown to discriminate between those players who are selected and deselected from elite development programs (Deprez, Fransen, et al., 2015). Such selection policy threatens to reduce the number of equally talented players, who are eligible for senior domestic and national representation by deselecting them from talent programs (such as the EPPP) based on transient, inferior physical anaerobic qualities.

This thesis has established benchmarks for annual development tempo for anthropometric and physical fitness characteristics relative to chronological age and somatic maturity in a broad sample of elite youth soccer. This information will provide further understanding for elite youth soccer TD practitioners regarding the future physical and anthropometric development trajectories of their players' as they navigate through the EPPP. Findings from this thesis will permit soccer TD practitioners to better forecast rate of players' anthropometric and physical fitness characteristics development at an early stage of their development and allow practitioners to adopt a 'plastic' approach to positional role assignment and the deselection of players' until complete maturity is achieved. Findings here will ultimately contribute to facilitate the effective management of development centre resources when considering player potential.

8.6 Practical Applications

To further enhance the accurate assessment of player development, TD criteria and retention policies in which players' are benchmarked, this thesis has produced four practical recommendations for TD practitioners to consider. It is hoped that these recommendations will likely contribute to reduce the number of premature deselections of players' based on short-termt, maturity related characteristics and strengthening the pool of young players' available senior club and national selections:

1. TD practitioners should consider establishing a rigorous testing protocol for all field-tests, accompanied by between and within-practitioner variation and SWC for anthropometric measures that will allow for statistically based assumptions regarding each player's current development status and trajectory.

2. Not only should TD practitioners be considerate of the obvious birth distribution bias that favours the selection of players' who are born earlier in the soccer selection (September to November) year, who possess enhanced maturity related anthropometric characteristics, practitioners should actively engage in experimental interventions that might reduce subsequent selection bias.

3. TD practitioners should be cognisant that physical development trajectories of elite youth soccer players are individual-specific and moderated by biological maturity and selectors should adopt a ‘plastic’ approach to positional role assignment (and indeed deselection of players’) until complete maturity is achieved.

4. It is recommended that the estimated development data presented in **Chapter 7** should be applied by TD practitioners to permit improved forecasting of players’ rate of anthropometric and physical fitness (in particular sprint development) characteristics development at an early stage of their development and facilitate the effective management of development centre resources when considering player potential.

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Chapter 10. Appendix

9.1 Appendix 1: Disclosure and Barring Service Certification

STRICTLY PRIVATE AND CONFIDENTIAL

CHRISTOPHER MCLAREN-TOWLSON
31 MIDDLEBROOK ROAD
BAGTHORPE
NOTTINGHAM
NOTTINGHAMSHIRE
NG165HA

11078001

Disclosure & Barring Service

Enhanced Certificate
Page 1 of 2

Certificate Number 001426585492

Date of Issue: 21 NOVEMBER 2013

Applicant Personal Details

Surname: MCLAREN-TOWLSON
Forename(s): CHRISTOPHER PHILIP
Other Names: TOWLSON, CHRISTOPHER
Date of Birth: 01 MARCH 1983
Place of Birth: NOTTINGHAM
Gender: MALE

Employment Details

Position applied for:
CHILD AND ADULT WORKFORCE RESEARCHER

Name of Employer:
UNIVERSITY OF HULL

Countersignatory Details

Registered Person/Body:
UNIVERSITY OF HULL

Countersignatory:
PHILIP MARSHALL

Police Records of Convictions, Cautions, Reprimands and Warnings
NONE RECORDED

Information from the list held under Section 142 of the Education Act 2002
NONE RECORDED

DBS Children's Barred List information
NONE RECORDED

DBS Adults' Barred List information
NONE RECORDED

Other relevant information disclosed at the Chief Police Officer(s) discretion
NONE RECORDED

Enhanced Certificate
This document is an Enhanced Criminal Record Certificate within the meaning of sections 113B and 116 of the Police Act 1997.

THIS CERTIFICATE IS NOT EVIDENCE OF IDENTITY
DBS Disclosure and Barring Service, PO Box 165, Liverpool, L69 3JD Helpline: 0870 90 90 811

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