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Anthropometrical, physical fitness and maturational characteristics in youth soccer: methodological issues and a longitudinal approach to talent identification and development

DIETER DEPREZ

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SAMENVATTING

Vanuit de literatuur wordt gesuggereerd dat in jeugdvoetbal de verantwoordelijken voor talentidentificatie, -ontwikkeling en -selectie longitudinaal en holistisch moeten benaderen, rekening houdend met de maturiteit en relatieve leeftijd van de jonge spelers. Het is reeds uitvoerig gebleken dat de voetbalsport systematisch laat mature en/of spelers die laat in het selectiejaar zijn geboren, uitsluit. Nochtans kunnen deze spelers net zo begaafd zijn als hun vroeg mature en/of 'vroeg' geboren medespelers. Vaak zijn er geen of onvoldoende objectieve criteria die de evaluatieprocessen kunnen ondersteunen. Dit proefschrift onderzocht de ontwikkeling van antropometrische kenmerken, fysieke fitheid en motorische coördinatie van jonge voetballers, en in het bijzonder de invloed van maturiteit en relatieve leeftijd op deze ontwikkeling doorheen de puberteit. Het onderzoek werd gesplitst in vier verschillende hoofdstukken. Het eerste hoofdstuk onderzocht (1) de betrouwbaarheid en validiteit van het intermitterende uithoudingsvermogen, gemeten via de Yo-Yo Intermittent Recovery test level 1 (YYIR1) in elite, sub- en niet-elite spelers (**studie 1**, n=228, 10-17 y; **studie 2**, n=36, 13-18 jaar), (2) de stabiliteit op korte en lange termijn van antropometrische kenmerken en de YYIR1 van 42 voetballers in de puberteit (**studie 3**), en (3) de overeenkomst tussen invasieve (bepalen skeletleeftijd) en niet-invasieve (schatten van de piekgroei leeftijd) methoden om enerzijds de volwassen gestalte te schatten, en anderzijds om spelers toe te wijzen in somatische maturiteitscategorieën in een gemengde sample van 160 Belgische en Braziliaanse elite spelers tussen 11 en 16 jaar (**studie 4**). Uit de resultaten van de eerste twee studies bleek dat de YYIR1 meer betrouwbaar is op elite niveau én op oudere leeftijd (U17-U19) in vergelijking met sub- en niet-elite spelers én op jongere leeftijd (U13-U15). Daarenboven, spelers met een relatief mindere YYIR1 prestatie op de leeftijd van 12 jaar zijn in staat om (weliswaar gedeeltelijk) de betere presteerders in te halen over een periode van vier jaar, wat de individualisering binnen het opleidingsproces noodzakelijk maakt (studie 3). Bovendien toonde de vierde studie aan dat zowel invasieve als niet-invasieve methoden om de volwassen gestalte te schatten sterk correleren. Echter, het categoriseren van spelers als vroeg, gemiddeld of laat matuur op basis van de piekgroei leeftijd is problematisch gebleken in elite jeugdvoetballers. Het tweede hoofdstuk richtte zich op de invloed van de relatieve leeftijd op zowel aërobe (YYIR1) (**studie 5**, n=606, U10-U19) als anaërobe prestatie-indicatoren (snelheid en explosiviteit) (**studie 6**, n=374, U13-U17). Een duidelijke oververtegenwoordiging van spelers die geboren zijn in het eerste deel van het selectiejaar werd gevonden in beide studies, hoewel de relatieve leeftijd zowel de aërobe als anaërobe prestaties niet beïnvloedde. Dit kan worden verklaard door het feit dat (1) selectieprocessen homogene spelers vormen op basis van aërobe en anaërobe prestaties reeds vóór de leeftijd van 10 jaar en (2) dit de variatie in maturiteitsstatus van de spelers binnen hetzelfde leeftijdscohort weerspiegelt. Het derde hoofdstuk onderzocht de longitudinale evolutie van de YYIR1 prestatie (**studie 7**, n=162, 11-14 y) en de explosieve kracht (**studie 8**, n=356, 11-14 y; **studie 9**, n=555, 7-20 y) via multi-level analyses. Daarnaast werden antropometrische, fysieke fitheid en motor coördinatie parameters retrospectief onderzocht om enerzijds

elite van drop-out spelers te onderscheiden, en anderzijds om de contractstatus en speeltijd op volwassen elite niveau te voorspellen (**studie 10**, n=388, 8-16 y). Algemeen benadrukten de resultaten uit dit hoofdstuk dat niet-specifieke motorische coördinatie sterk gerelateerd is met de ontwikkeling van aërobe en anaërobe prestaties en dat deze parameter toekomstige succesvolle en minder succesvolle jonge voetballers kan onderscheiden. Daarnaast maken meer explosieve spelers vanaf de leeftijd van 16 jaar meer kans op het krijgen van een professioneel contract en speelminuten binnen een professioneel volwassen elftal. Tot slot, het laatste hoofdstuk beschreef de positionele verschillen in antropometrische kenmerken, fysieke fitheid en motor coördinatie parameters in 744 jeugdvoetballers tussen 9 en 18 jaar (**studie 11**). Uit de resultaten bleek dat door de inherente antropometrische kenmerken en fysieke capaciteiten (snelheid, kracht, behendigheid) spelers in een bepaalde positie worden geselecteerd, en dat de periode rond piekgroei cruciaal kan zijn in dit selectieproces. Echter, de typische kenmerken voor de verschillende posities, zoals gebleken op volwassen leeftijd, zijn onvoldoende ontwikkeld bij jonge voetballers tussen de 8 en 14 jaar, hoewel de typische antropometrische kenmerken van doelmannen (groter en zwaarder) al manifest waren op jonge leeftijd. Kortom, de bovengenoemde studies in dit proefschrift benadrukken (1) het gebruik van de YYIR1 als een valide, betrouwbare en maturiteits-onafhankelijke tool om het intermitterende uithoudingsvermogen van spelers te beoordelen; (2) dat de selectieprocessen gericht zijn op de vorming van homogene spelersgroepen op basis van antropometrische kenmerken, maturiteit en fysieke fitheid, onafhankelijk van speelpositie; en (3) dat niet-specifieke motorische coördinatie essentieel is voor de ontwikkeling van fysieke fitheid en zou moeten geïmplementeerd worden in het trainingsproces.

SUMMARY

From the literature, it has been massively recommended that talent identification, development and selection processes in youth soccer should provide a longitudinal, holistic approach accounting for maturation and relative age. The sport of soccer systematically excludes those players who are later to mature and/or who are later born in the in the selection year, whilst these players might be as gifted as their earlier maturing and/or earlier born peers. There are often no or insufficient objective criteria that could support the evaluation process. The present thesis aimed to gain insight in young soccer players' development of anthropometrical characteristics, physical fitness and motor coordination parameters with respect to maturation and relative age. Therefore, the conducted research was divided into four different chapters. The first chapter investigated (1) test-retest reliability and validity of the intermittent endurance performance, assessed by the Yo-Yo Intermittent Recovery test level 1 (YYIR1) in elite, sub- and non-elite players (**study 1**, n=228, 10-17 y; **study 2**, n=36, 13-18 y), (2) the short- and long-term stability of anthropometrical characteristics and YYIR1 of 42 pubertal soccer players (**study 3**), and (3) the relationship between invasive (skeletal age) and non-invasive (estimation of age at peak height velocity) protocols to estimate adult stature on the one hand, and the agreement between methods assigning players to somatic maturity categories on the other in a mixed-sample of 160 Belgian and Brazilian elite players (**study 4**). Combining the results of the first two studies, the YYIR1 seems more reliable at elite level and at older ages (U17-U19) compared with sub-/non-elite level and at younger ages (U13-U15). Also, players with a relatively low YYIR1 performance at the age of 12 years are able to (however partially) catch-up the better performers over a four-year period, suggesting the need for individualization within the training process (study 3). Furthermore, the fourth study demonstrated that invasive and non-invasive protocols correspond well in estimating mature stature, although transforming estimated APHV into somatic maturity categories has proven to be problematic in elite youth soccer players. The second chapter focused on the influence of relative age on both aerobic (YYIR1) (**study 5**, n=606, U10-U19) and anaerobic performance measures (speed and explosive leg power) (**study 6**, n=374, U13-U17). A clear overrepresentation of players born in the first part of the selection year was found in both studies, although relative age did not confound aerobic as well as anaerobic performance measures. This might be explained by the fact that (1) the formation of homogenous players in terms of aerobic and anaerobic performances was already manifest before the age of 10 years, and (2) this reflects the variation in maturity status among players within the same age-cohort. The third chapter investigated the longitudinal development of the YYIR1 performance (**study 7**, n=162, 11-14 y) and explosive leg power (**study 8**, n=356, 11-14 y; **study 9**, n=555, 7-20 y) via multilevel analyses. Also, retrospective data were used to predict drop out, contract status and first-team playing time using anthropometrical, maturational, physical fitness and motor coordination characteristics (**study 10**, n=388, 8-16 y). Generally, the results highlighted that non-specific motor coordination contributed significantly to the development of aerobic and anaerobic performances, and that this parameter could distinguish between

future successful and less successful young soccer players. Further, young soccer players possessing higher levels of explosive leg power from the age of 16 years are more likely to sign a professional contract and are receiving more playing minutes at the professional adult level. The final chapter described differences in 744 youth soccer players' (9 to 18 y) anthropometrical characteristics and general fitness level through aerobic and anaerobic tests according to the playing position on the field (**study 11**). The results revealed that inherent anthropometrical and physical capacities (i.e., speed, power, agility) might select players in or reject players from certain positions, and the time around peak height velocity seems to be crucial in this selection process. However, the typical characteristics for the different playing positions at senior level are yet not fully developed among young soccer players between 8 and 14 years, although the typical anthropometrical characteristics of goalkeepers (i.e., taller and heavier) were already manifest at young age. In conclusion, the abovementioned studies in this thesis (1) emphasize the use of the YYIR1 as a valid, reliable and maturity-independent tool to assess a players' intermittent endurance capacity, (2) highlight that the selection process is focused on the formation of homogenous groups of players in terms of anthropometrical, maturational and physical fitness parameters, independent of playing position, and (3) that non-specific motor coordination is essential in the development of physical fitness measures and should be included in the training process.

PART 1

General introduction and outline of the thesis

The general introduction consists of four major sections. In the first section, definitions of the key stages in the pursuit of excellence and different talent development concepts are presented. The second section summarizes the existing literature concerning talent identification in youth soccer through a systematic review. A major part of the present dissertation is related to the influence of maturation and relative age on anthropometrical and performance measures, which will be discussed in the third section. Finally, the general introduction ends with the summary of the objectives and research questions of the present thesis.

1. TALENT IDENTIFICATION AND DEVELOPMENT

1.1 Definitions

In soccer, the identification and development of youngsters with potential to reach the professional elite status has become tremendously important over the last two decades. In particular, the introduction of the *'Bosman Ruling'* in 1996 seems to be the trigger for professional soccer clubs to invest in the long-term development of (a small number of) gifted young soccer players. As this ruling precludes professional soccer clubs from withholding a player's registration at the completion of his contract (Williams & Reilly, 2000), the flow of players across national borders increased and caused inflationary pressure on wages and transfer fees, which in turn increased the rich-poor gap between successful and less successful clubs. In addition, the globalized access to soccer (e.g., the world cup tournament in 2006 had 27 billion accumulated viewers; Fédération International de Football Association; FIFA, 2007) has allowed the clubs to extend their international market segments, both in terms of value and labor access (Haugaasen & Jordet, 2012). As a consequence, the economic resources available increased significantly in recent decades, and have led to a highly polarized market. For example, in 2010, 25% of the total revenues in European soccer (€ 16 billion) were in the hands of only 20 clubs, and most of them were listed companies (Deloitte, 2010). Therefore, and especially for the (poorer) clubs in lower ranked countries who are less able to compete financially, it is necessary to develop their own gifted players to balance the in- and outflow of players to ensure stability in the performance, and to stay competitive in order to guarantee future sportive success.

As a consequence, sport scientists along with soccer federations, club directors, youth coaches and scouts tried to identify the key elements necessary to progress into an elite adult soccer player since two decades, and several developmental models were presented (Balyi & Hamilton, 2004; Gagné, 2004; Coté *et al.*, 2007a). Also, Russell (1998) and Williams and Franks (1998) distinguished four key stages in pursuit of excellence: 'talent *detection'*, 'talent *identification'* , 'talent *development'* and 'talent *selection'* (***Figure 1***). Talent *detection* refers to the discovery of potential athletes who are currently not involved in the sport in question. Compared to minority sports, talent detection is not a major problem in the sport of soccer due to its popularity and the large number of children who participate. Talent *identification* refers to the process of recognizing current participants with the potential to become elite players. Talent *development* implies that players are provided with a suitable learning environment to realize their potential. Talent identification has been viewed as part of talent development in which identification may occur at various stages in the process. Finally, talent *selection* involves the ongoing process of identifying players at various stages who demonstrate prerequisite levels of performance to be included for selection in a squad or team.

Despite the universally accepted terms for the latter key stages in the pursuit of excellence, less consensus is given to the term of *talent* itself. It is a complex item that nourishes the nature-nurture-debate. For example, when searching for the term ‘talent’ in the dictionary, it is defined as “a special natural ability or aptitude” (cf. nature), as well as “a capacity for achievement or success” (cf. nurture). This is well illustrated by Gagné (2000), who pointed out that talent has been used to describe two distinct things: on the one hand the natural abilities in any domain of human activity (= giftedness), and on the other hand the end product of systematically developed skills (= talent) to a level that the individual belongs to the top 10% of peers active in that domain. The latter description is closely related to the definition by Ommundsen (2009), who also highlighted the static or dynamic concept of talent. The static definition views talent as something you have inherited, which implies a focus on the performance level at an early age, while the dynamic definition regards talent as something you can develop. Lots of other definitions tried to cover the term, but unfortunately, there are no universally accepted criteria used to characterize the concept (Durand-Bush & Salmela, 2001). Rather, the talent concept should be described in terms of ‘potential’ to become an expert athlete (Russell, 1989; Williams & Reilly, 2000).

Many problems in talent identification and development processes have been described by others (Bartmus *et al.*, 1987; Williams & Reilly, 2000; Martindale *et al.*, 2005; Pearson *et al.*, 2006; Vaeyens *et al.*, 2008; Meylan *et al.*, 2010) and are here briefly summarized: (1) Reaching expertise is not dependent on one standard set of skills, but can be achieved in unique ways through different combinations of abilities (i.e., ‘compensation phenomenon’). (2) Important characteristics of success in adult performance could not automatically be extrapolated to youngsters, as children possessing these characteristics will not necessarily retain these attributes throughout their growth and maturation. (3) The dynamic nature of talent and its development cause the unstable, non-linear development of performance determinants (e.g., in function of timing and tempo of the adolescent growth spurt). (4) The majority of the studies still adopt an one-dimensional approach or concentrate on a combination of anthropometrical, physical or physiological performance characteristics, which has proven problematic in predicting future success in team ball sports. To counteract problems related to identification and development, the United Kingdom sport government body, responsible for promoting and supporting sport across the UK, implemented a 'talent *confirmation'* process which is a 3- to 6-month programme in which individuals identified as gifted are confronted with the training requirements of elite sports competition. The exposure to systematic training is designed to support and to validate the initial talent selection process (***Figure 1***).

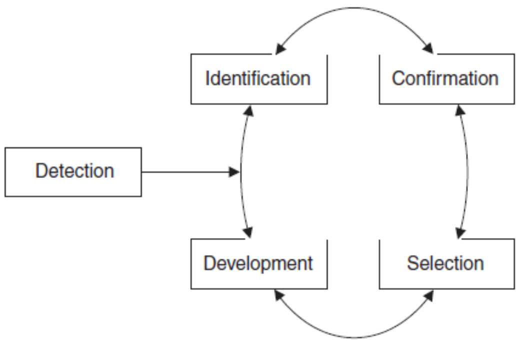

Figure 1 *Key stages in the talent identification and development process (Vaeyens et al., 2008).*

The identification and selection of gifted young soccer players have been linked to a coach's of talent scout's subjective, predetermined image of the ideal player (Williams & Reilly, 2000). However, it is now accepted, that when used in isolation, this approach can result in repetitive misjudgments in talent identification processes (Meylan *et al.*, 2010) and can lack consistency (Williams & Reilly, 2000). As such, over recent years, there has been an increasing emphasis in the use of science-based support systems offering a more holistic approach to talent identification in soccer (Reilly *et al.*, 2000). Performance measures entailing anthropometrical, physiological, psychological, sociological, technical and tactical skill have been used, either in isolation or in combination as predictors of expertise and talent development (***Figure 2***).

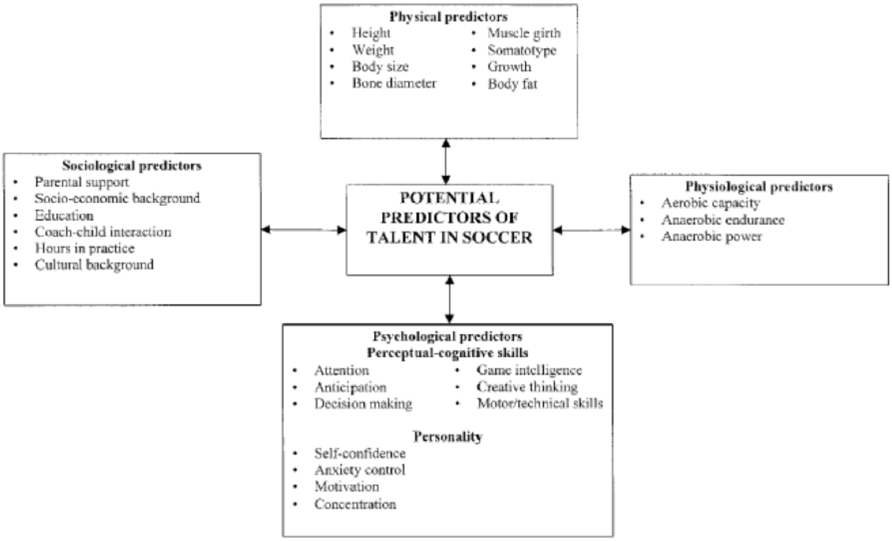

Figure 2 *Potential predictors of talent in soccer (Williams & Reilly, 2000).*

1.2 Reaching expertise in sport

1.2.1 Peak performance

The rush to produce young star performers seems not justified as there is a low predictive validity of junior performance standards for later success. For example, statistics from Bloom (1985) revealed that 90% of eventual world top 25 athletes did not shine supreme at younger ages. Also, Güllich, (2013) reported that the national soccer programme in Germany was characterized by sizeable turnovers at all ages (U15-U18) with repeated procedures of selection and de-selection instead of focus on the long-term development. Ironically, those players who are early selected based on present high-level performance may also be at disadvantage. While they improve initially, early achievers may be prone to premature drop out through competitive pressure (Moore *et al.*, 1998). While it is generally accepted that both genetics and environment play a part in expertise development, there is a considerable amount of research that highlights how expertise and skills associated with high level performance are improved and developed through training or experience (Ericsson, 2003). For example, Ward and Williams (2003) concluded that 'elite' soccer players as young as eight years had better skills due to extra opportunities rather than any genetic advantage. Such serendipitous early training can mask those with true potential, especially if large discrepancies exist between children's opportunities at early ages. Moreover, the age at peak performance for elite soccer occurs when players enter their mid- to late-twenties, so a long-term focus is compulsory to prepare future elite athletes (Martin, 1980; Schulz & Curnow, 1988;

Bloomfield *et al.*, 2005). An analysis of age in four prominent soccer competitions (i.e., Spanish, German, Italian and English leagues) revealed a mean age of 26.4 ± 4.4 years, with a positional gradient from oldest to youngest in goalkeepers > defenders > midfielders > forwards (Bloomfield *et al.*, 2005). As such, a long-term project requires effective coordination and once operationalized, these long-term goals must direct and integrate a wide variety of important factors to ensure processes are effective in helping our youngsters achieve their long-term potential (Martindale *et al.*, 2005).

1.2.2 Talent development concepts

In providing answers to how one can reach expert performance, different talent development concepts were presented in the literature. Since the early 1990s, one of the first research group conducting the search for athletic talent was Ericsson and colleagues (1993). Through an extensive review of the expertise literature, Ericsson *et al.* (1993) concluded that the role of nurture in the development of exceptional performance has repeatedly been delegated to a subsidiary place in explanation of expertise, even though the evidence for genetic factors (i.e., nature) is somewhat misleading. Subsequently, they proposed and empirically examined within the music domain a theory of expertise based on their key concept, ‘deliberate practice’. They defined deliberate practice as any activity designed to improve current performance that is effortful and not inherently enjoyable. Within their theory, experts spend typically around 10 years or 10.000 hours in deliberate practice to attain exceptional performance. The focus is not on the type and content of training and/or play (quality), but on a minimum of 10 years (~ 10.000 hours) engagement in deliberate practice (quantity).

Côté *et al.* (2007a) introduced the term deliberate play. It was defined as an unstructured activity focused on having fun. Deliberate play allows a child to experiment with various forms of movement in a stress-free environment that could be most conductive to learning. Also, deliberate play permits the development of social attitudes, encourages the child to be with others, and gives a child specific goals to work towards. Through play, the child grows, and growth acts as a stimulus to play-change and later involvement in more structured deliberate practice activities (Côté *et al.*, 2007a). More specific to soccer, Ford *et al.* (2009) advocated that young soccer players have to sustain a high amount of hours in deliberate practice, but also have to engage in playful soccer activities (sport-specific deliberate play). This is closely related to the ongoing debate whether an athlete must sample different sports during childhood (early diversification ~ Côté *et al.*, 2007a) or must focus solely on one sport at young age (early specialization ~ Ericsson *et al.*, 1993). To provide an optimal environment for youth athletes’ lifelong involvement in sport or even for future success in elite participation, Côté and Fraser-Thomas (2007b) outlined a conceptual framework knows as the Developmental Model of Sport Participation (DMSP), presented in ***Figure 3***. This model outlined a second pathway, next to early specialization, to skill acquisition: the early diversification pathway. This pathway involves that athletes progress through three consecutive stages of development: the sampling (6 to 12 years), specializing (13 to 15 years) and investment years (from 16 years on). The emphasis on fun and motor development skills during the sampling years (childhood) was advised, as this approach generally leads to less drop-out, continued sport participation and even elite performance into adulthood. However, several studies demonstrated that the absence of sampling during childhood also can lead to future adult expert performance, even when these players started their soccer careers as young as 5.5 years (Helsen *et al.*, 1998b; Ward *et al.*, 2007; Ford *et al.*, 2009). The study by Ford *et al.* (2009) also demonstrated that during the sampling years elite and sub-elite players had a similar amount of hours in deliberate practice, but elite players spent significantly more time in deliberate play. Based on these findings, neither the early diversification nor the early specialization pathway was fully supported (Ford *et al.*, 2009). It was suggested that young soccer players who want to excel in adulthood should be allocated to soccer at young age and should sustain a high amount of hours in deliberate practice, but also (and especially) must engage in playful soccer activities at younger age.

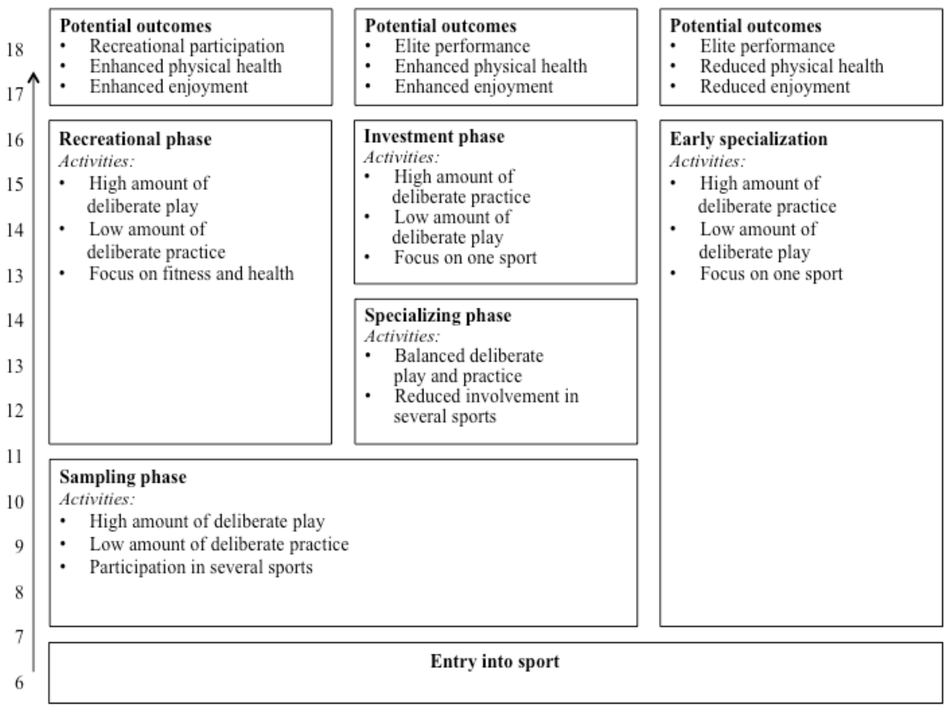

Figure 3 *The developmental Model of Sport Participation (Côté & Fraser-Thomas, 2007).*

In an attempt to describe an integrated multidimensional model of talent and in response to the ambiguity caused by the 'one term fits all' use of talent, Gagné (1993; 2004) suggested a clear distinction between outstanding natural abilities ('*giftedness'*) and an end product of systematically developed skills which define expertise ('*talent'*) via the Differentiated Model of Giftedness and Talent (DMGT) (***Figure 4***). This developmental sequence constitutes the heart of the DMGT. Three types of catalysts help or hinder that process: (1) interpersonal catalysts, like personal traits and self-management processes; (2) environmental catalysts, like socio-demographic factors, psychological influences (e.g., from parents, teachers, or peers), or special talent development facilities and programs; and (3) chance. In the model, chance is clearly linked to natural abilities, intrapersonal and environmental catalysts. The DMGT includes a 5-level metric-based system to operationalize the prevalence of gifted individuals, with a basic 'top 10 per cent' threshold for mild giftedness or talent, through successive 10 per cent cuts for moderate, high, exceptional and extreme levels.

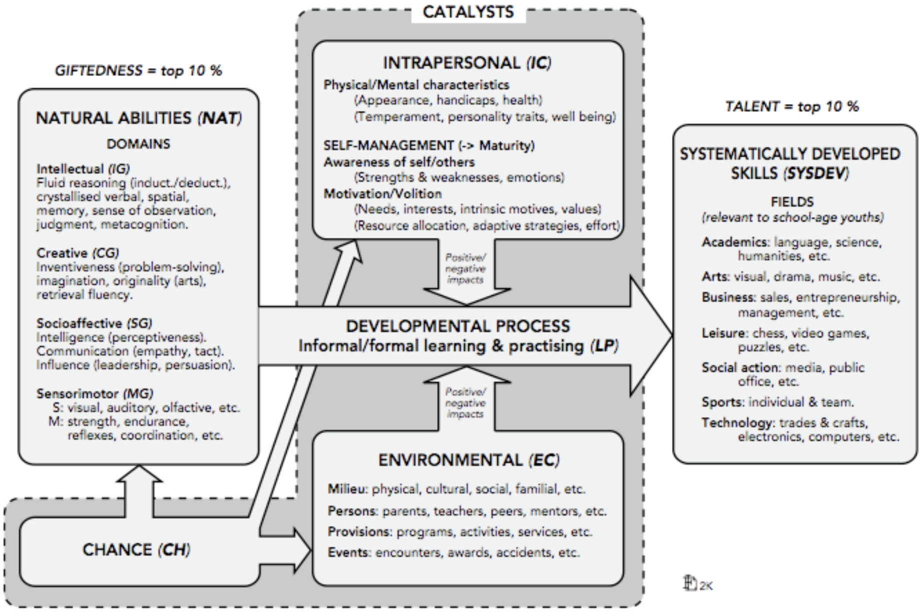

Figure 4 *Differentiated Model of Giftedness and Talent (Gagné, 2004).*

A more practical approach was presented by Balyi and Hamilton (2004), who described that athletic development from childhood into adulthood is characterized by certain sensitive periods of accelerated adaptation ('*windows of opportunity'*) to speed, motor competence, strength, endurance and suppleness, associated with growth and maturation (PHV) (the 'Long Term Athlete Development model'; LTAD, see ***Figure 5***). During so-called critical periods accelerated adaptations will occur if the proper volume, intensity and frequency of exercises are implemented. For example, for boys, a first accelerated adaptation for speed occurs between 7 and 9 years, whilst for motor coordination, the accelerated period falls between 9 and 12 years. However, the LTAD model was recently criticized by Ford and colleagues (2011), given the lack of empirical evidence for the LTAD model due to the large number of physiological factors that influence performance. Therefore, the authors support a more individualized approach with certain periods of '*training emphasis*', along the training process to advance all fitness components during childhood and adolescence.

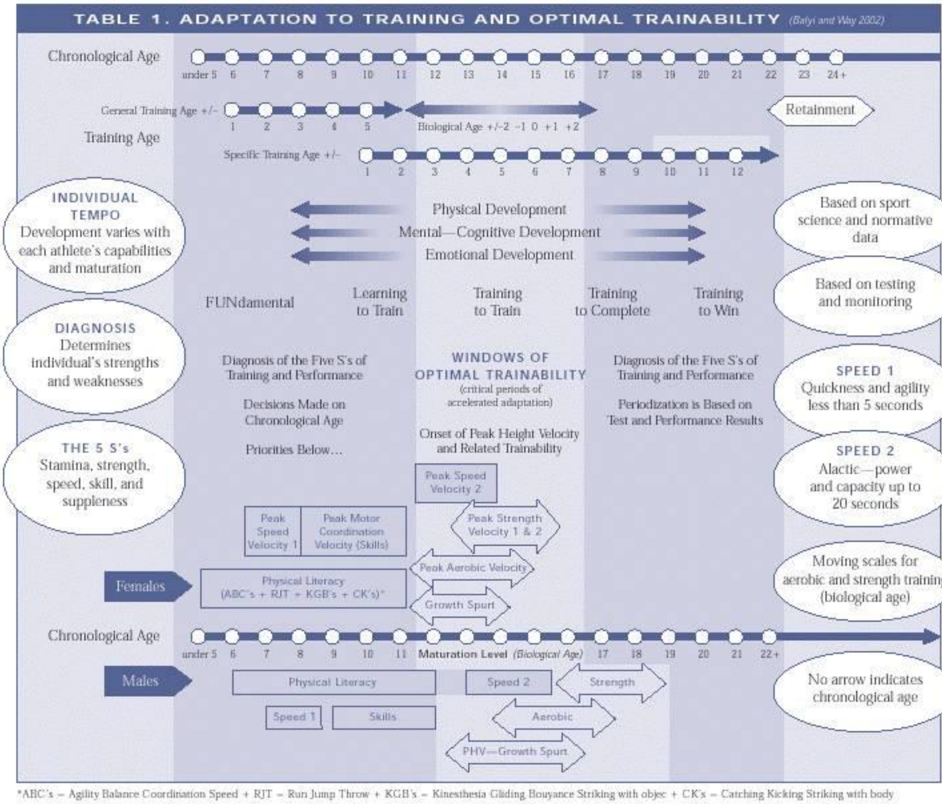

Figure 5 *The Long-Term Athlete Development model (Balyi & Hamilton, 2004).*

2. TALENT IDENTIFICATION IN YOUTH SOCCER: A SYSTEMATIC REVIEW

As part of the present general introduction section, we conducted a systematic search through the literature according to the framework of potential predictors of talent in soccer as presented in ***Figure 2*** (Williams & Reilly, 2000). The systematic collection of such measures (i.e., physical, physiological, psychological and sociological predictors), particularly from childhood through adolescence, would ensure that coaches are better informed about how these factors affect the development of young soccer players. The systematic search was directed through searching the electronic research databases PubMed, Web of Science and SPORTDiscus in the period February-March, 2014. Key search terms used included 'talent', 'talent identification', 'talent development', 'talent selection', 'youth', 'skill', 'soccer' and 'football', and were used in various combinations. From a total of 5.445 studies, 343 studies were retained for further screening. A total of 164 studies (original studies, n = 144; reviews, n = 20) was found relevant as all these studies focused on at least one domain of potential predictors of talent in youth soccer (***Table 1***), and each potential predictor will be discussed separately. Obviously, more recent literature (i.e., published after February-March 2014) was addressed where appropriate in the current dissertation.

Table 1 *Overview of selected papers (only original studies included, n=144) obtained through a systematic search according to predictor variable and study design.*

	Physical	Physiological	Psychological	Sociological	n
Uni-dimensional	5	16	23	11	**55**
Multi-dimensional	x	x	x	x	*7*
	x	x	x		*11*
	x	x		x	*15*
	x		x	x	*1*
		x	x	x	*2*
	x	x			*32*
	x		x		*1*
	x			x	*1*
		x	x		*3*
		x		x	*1*
			x	x	*15*
Total					**89**

2.1 *Physical predictors*

The average heights and weights of young soccer players from Europe and North America tend to fluctuate above and below reference medians for non-athletic youth from childhood to mid-adolescence (about 8 to 14 years). However, in later adolescence (15+ years), average heights approximates, on average, the reference medians, whereas weights are above the reference medians reflecting the higher lean body mass in soccer players (Malina *et al.*, 2000). This trend suggests more mass-for-height and is consistent with the lower mean ectomorphy of soccer players compared to non-athletic males of the same age (Malina *et al.*, 2000). Also, a recent study in professional Brazilian youth soccer players (15 to 17 years) showed that, in general, players were classified as balanced mesomorphs, featuring a predominance of a muscle skeletal component and a balance of fat and linearity components (Fidelix *et al.*, 2014).

Many studies already described that talent identification and selection processes tend to advantage players who are more advanced or on time in maturity status (Figueiredo *et al.*, 2009a; Hirose, 2009; Malina, 2011). In adolescence, being advanced in biological maturation is related to larger body size dimensions (Malina *et al.*, 2000), which in turn lead to better performances in speed, explosive leg power and agility (Malina *et al.*, 2000; 2004a; 2004b; Figueiredo *et al.*, 2009b; 2010b; Coelho-e-Silva *et al.*, 2010; Carling *et al.*, 2012; Lago-Peñas *et al.*, 2014). For example, Wong *et al.* (2009a) showed that anthropometry (height, body mass and BMI) is positively related to measures of speed, explosive leg power, endurance and soccer-specific dribbling in seventy U14 Chinese players. Recently, several studies demonstrated that stature and body mass, and more specifically larger amounts of lean body mass, may improve explosive leg power and speed, and this relationship seems to be stronger with longer running distances (Amonette *et al.*, 2014; Lago-Peñas *et al.*, 2014). This suggests that coaches select young players according to their anthropometry for short-term benefits and does not justify such practice in the long-term process of player development. Therefore, coaches may need to provide opportunities for or perhaps protect smaller, skilled players during the adolescent years. Shortness may be transient, to some extent, as size differences between boys at the extremes of maturity is generally reduced as all boys eventually reach maturity in late adolescence (Williams and Reilly, 2000; Malina *et al.*, 2004b; Figueiredo *et al.*, 2010b). A statistical technique (i.e., introducing *covariates*) could provide researches to control for anthropometrical and maturational characteristics in the evaluation of young soccer players, although not this is not feasible for youth coaches and talent scouts in practice. For example, when statistically controlling for maturational status (i.e., age at peak height velocity and skeletal age, respectively), differences in anthropometry (Fragoso *et al.*, 2014), and physical fitness and motor coordination parameters (Vandendriessche *et al.*, 2012a) faded out between birth semesters in elite U15 players, and between international U16-U17 players contrasting in maturity status, respectively. However to date, selection policies are still likely to favour players with increased body dimensions during adolescence.

As anthropometrical characteristics are related to better performances in speed and explosive leg power, it could be expected that players with larger body size dimensions are more presented at higher levels of competition. However, the literature does not consistently confirm this hypothesis as anthropometrical and somatotype profiles of soccer players can be specific to the clubs where they train because these characteristics may vary according to the club size, geographical location, training and monitoring conditions (e.g., specialized training, nutritionists, etc.), among others (Fidelix *et al.*, 2014). For example, Vaeyens *et al.* (2006) and Le Gall *et al.* (2010) found no differences in anthropometry between elite, sub-elite and non-elite Flemish soccer players (U13-U16), and between future international, professional and amateur French soccer players (U14-U15), respectively. In contrast, both cross-sectional and longitudinal data revealed that young soccer players at higher levels of competition demonstrated larger body size dimensions (Figueiredo *et al.*, 2009a; Coelho-e-Silva *et al.*, 2010; Carling *et al.*, 2012; Rebelo *et al.*, 2013). Moreover, players dropping out of the sport tend to have smaller body dimensions and are more late to mature (Malina *et al.*, 2000; Figueiredo *et al.*, 2010b).

Several studies reported position-related differences in body size dimensions at different ages, and on average, goalkeepers and defenders were the tallest and heaviest compared to midfielders and forwards (Malina *et al.*, 2000; Gil *et al.*, 2007a; Wong *et al.*, 2009a; Lago-Peñas *et al.*, 2011; 2014; Rebelo *et al.*, 2013). Bigger boys are often selected for these positions, sometimes from a very young age, as activities often involve body contact with opposing players, as well as aerial duels to sustain long ball passes and crosses. Also, goalkeepers presented the highest adiposity, in terms of skinfolds and fat percentage (Malina *et al.*, 2000; Gil *et al.*, 2007a). Even though the physiological and energetic demands of goalkeepers are different from outfield players, fat quantity should not exceed 11.5-12% for soccer players, irrespective of his playing position. And it should not exceed 14% for a young sedentary man (Gil *et al.*, 2007a). On occasion, in non-elite soccer teams, especially in the younger ones, heavier and bigger boys are selected as goalkeepers, no due to the fact that they have better skills for this position but rather, because they are not as fit as the rest of the players. Moreover, goalkeepers themselves frequently do not train as hard as the rest of the team because they think that their post does not require such a high demand. Also, amongst 19 Portuguese, national youth team players aged 15-16 years, defenders and forwards are more advanced in maturity status compared to midfielders, although a trend ($p=0.18$) was suggested from forwards (shortest, 1.70 m) over midfielders (1.75 m) to defenders (tallest, 1.77 m) (Malina *et al.*, 2000). These findings contrasts the general trend in height and weight amongst Portuguese players 13-15 years of age by positions, which showed that, on average, forwards were the tallest and heaviest compared to defenders and midfielders (smallest and leanest) (Malina *et al.*, 2004a). Additionally, in 70 Chinese U14 players, forwards were significantly lighter (43.9 kg, 1.56 m) and shorter compared with goalkeepers (54.6 kg, 1.69 m), defenders (56.2 kg, 1.67 m) and midfielders (52.2 kg, 1.65 m) (Wong *et al.*, 2009a). Similarly, a study by Lago-Peñas *et al.* (2011) showed that goalkeepers and central defenders were taller and heavier, and had higher endomorphic component values compared to external defenders, central and wide midfielders and forwards. Therefore, the development of anthropometrical (and physical and physiological) characteristics, required for an elite soccer match, might not be fully evolved in young soccer players, since they experienced formal training for just a few years with lower game intensity and shorter match duration. As a consequence, the selection of young players for a specific playing position based on their anthropometrical (and physical and physiological profile) might not be appropriate. A general overview of anthropometrical characteristics (i.e., stature and weight) and the distribution of maturity groups in youth soccer players was provided at the end of the present dissertation (appendix 1 and appendix 2).

Generally, anthropometrical predispostions might select or reject players in or from certain positions, already from a young age (see above). Many coaches translate adult soccer straight into youth soccer without considering individualized, long-term youth development. However, when approaching full maturity status, specific anthropometrical characteristics are inherent to the specific demands of the position on the field. ***Table 2*** provides an overview of the anthropometrical characteristics of adult soccer players which might be helpful for the selection or redirection of players into certain positions in late adolescence.

Table 2 *Anthropometrical profile of professional adult soccer players from Belgium (Boone et al., 2011) and Denmark (Bangsbo, 1994).*

Study	Parameter	n	GK	n	CB	n	FB	n	MF	n	FW
Boone *et al.* [2011]	Stature	17	188.2 ± 4.5	60	186.4 ± 4.3	82	179.3 ± 4.8	68	181.3 ± 4.1	62	183.5 ± 6.7
	Weight	17	84.2 ± 5.2	60	82.5 ± 5.0	82	73.4 ± 6.4	68	76.7 ± 5.1	62	78.6 ± 4.8
Bangsbo [1994]	Stature	5	1.90 ± 0.06	13	1.89 ± 0.04	12	1.79 ± 0.06	21	1.77 ± 0.06	14	1.78 ± 0.07
	Weight	5	87.8 ± 8.0	13	87.5 ± 2.5	12	72.1 ± 10.0	21	74.0 ± 8.0	14	73.9 ± 3.1

GK= goalkeeper, CB= center back, FB= full back, MF= midfielder, FW= forward

2.2 *Physiological predictors*

Physiological key predictors of youth soccer players, such as endurance, speed, and explosive leg power have been massively studied in the past decades. Amongst these predictors, and according to the framework of Williams and Reilly (2000), aerobic and anaerobic characteristics have been reported solely or in combination to establish standards or to differentiate players in the talent identification process. To provide a clear overview, aerobic and anaerobic characteristics will be discussed separately and were summarized in two different tables at the end of the dissertation (appendix 3 and appendix 4).

2.2.1 Aerobic characteristics

The ability to quickly recover from high-intensive actions during a soccer game, is related to an increased aerobic fitness (Bangsbo *et al.*, 2008), although a good aerobic capacity does not necessary determine good overall performance in soccer (~'*compensation phenomenon'*) (Bartmus *et al.*, 1987; Reilly *et al.*, 2001). Nevertheless, the consistent observation of mean VO_2max-values between 55 and 65 $ml.kg.min^{-1}$ for young soccer players and more in youth elite teams suggests the existence of a threshold below which an individual player is unlikely to perform successfully in top-class temporary soccer (Bunc & Psotta, 2001; Reilly *et al.*, 2001; Hansen & Klausen, 2004; Gravina *et al.*, 2008; Carling *et al.*, 2009; 2012; Wong & Wong, 2009; Le Gall *et al.*, 2010). For example, research in Belgian adult professional soccer players (n=289) revealed an overall VO_2max of 57.7 ± 4.7 $ml.kg.min^{-1}$, with higher values for full backs (62.2 ± 2.7 $ml.kg.min^{-1}$) and central midfielders (60.4 ± 2.8 $ml.kg.min^{-1}$) compared with goalkeepers (52.1 ± 5.0 $ml.kg.min^{-1}$), central defenders (55.6 ± 3.5 $ml.kg.min^{-1}$) and forwards (56.8 ± 3.1 $ml.kg.min^{-1}$) due to the specific positional demands (Boone *et al.*, 2012). Field tests measuring aerobic endurance in adult soccer players have also been extensively studied en benchmarks for these tests exist as well. For example, a review by Bangsbo *et al*. (2008) reported values for the intermittent recovery test level 1 from 1810 m (moderately trained players) to 2420 m (professional players). These data in adult players could guide talent development programs and provides more insight in differences between youth and adult players.

In a longitudinal sample of Danish players aged 10 to 13 years, elite players (61.2 $ml.kg.min^{-1}$) consistently showed higher VO_2max-values compared to their non-elite peers (55.1 $ml.kg.min^{-1}$) for almost four consecutive years (Hansen & Klausen, 2004). Other longitudinal observations in 453 young athletes, aged 8 to 16 years in four different sports suggested that in athletes, the increase in absolute VO_2max with advancing pubertal development is caused by an increase in the metabolic capacity, but that training before puberty was having little if any effect on aerobic power (Baxter-Jones *et al.*, 1993). Other studies reported better aerobic performance with increasing chronological age, although the relative VO_2max remained rather stable (Figueiredo *et al.*, 2009b; Roesher *et al.*, 2010; Markovic &

Mikulic, 2011). Moreover, it has been shown that in 160 Flemish youth soccer players, aged 10-13 years (Ghent Youth Soccer Project), aerobic endurance assessed by the endurance shuttle run is an important discriminating characteristic between elite and sub-/non-elite players near the end of puberty (U15-U16) in favour of elite players (Vaeyens *et al.*, 2006). Also, future elite Portuguese players between 11 and 14 years performed better on the yo-yo intermittent endurance test compared with future club and drop-out players after a two-year follow-up period (Figueiredo *et al.*, 2009b). A study with 83 Portuguese soccer players, aged 11-13 years, revealed that the development of aerobic performance was significantly related to chronological age, biological development, and volume of training (Valente-dos-Santos *et al.*, 2012a). However, the development of aerobic power by chronological age decreased after the end of puberty (~15 y), which is in accordance with findings from Roesher *et al.* (2010). Although, from the age of 15 years, the gap between future professional and non-professional players becomes larger and from this age, intermittent endurance performance might be one of the indicators in the identification and selection of potential top players (Roesher *et al.*, 2010). Even at the age of 19 years, differences in yo-yo intermittent endurance test performance were found between elite and non-elite Portuguese players (Rebelo *et al.*, 2013). Altogether, these findings suggest that more experience, better quality of training (e.g., volume and intensity) and genetic factors might have been advantageous for players performing at the highest youth levels.

On the other hand, contrasting observations revealed no differences in aerobic performance between players of different levels, especially in late adolescence (Visscher *et al.*, 2006; Gil *et al.*, 2007a; 2007b; Gravina *et al.*, 2008; Coelho-e-Silva *et al.*, 2010; Lago-Peñas *et al.*, 2011; Gonaus & Müller, 2012). The possibility exists that multiple selection procedures in pre-adolescence and systematic training during adolescence may result in a 'physically' more homogenous group of players in late adolescence. Thus, the differentiating potential of aerobic performance may decrease with age, indicating that in late adolescence, when the late maturing players caught up with the early maturing players, other aspects such as psychological, technical or tactical skills would probably become more powerful in distinguishing between future successful and non-successful players (Rösch *et al.*, 2000; Williams and Reilly, 2000; Gil *et al.*, 2007a; Gonaus & Müller, 2012).

Recently, two studies investigated the changes in aerobic performance over a time period of 10 years in 13-year-old French soccer players entering an elite soccer academy between 1992 and 2003, and in elite Dutch soccer players between 2000 and 2010 in several age groups, respectively (Carling *et al.*, 2012; Elferink-Gemser *et al.*, 2012). Although the game of soccer is constantly evolving, resulting in increased physical demands in professional soccer, changes in aerobic performances in the 13-year-old players who entered the French academy over ten years was not noticeable (Carling *et al.*, 2012). The results suggest a lack of change in selection philosophies and practices of coaches involved in recruiting players for the academy, which in turn is reflected in consistency of specific evaluation criteria employed over the decade considered. In contrast, the Dutch study showed improvements in aerobic performance from 2000 to 2010 of around 50% in all age groups (Elferink-Gemser *et al.*, 2012). A possible explanation is the increased quantity and quality of training over the years. Also, when identifying, developing and selecting youngsters, coaches have to be aware that the current level of soccer and its underlying performance characteristics are improving over time. Taken both results together, the use of specific field tests to assess aerobic performance (i.e., 20m continuous progressive track run vs. interval shuttle run test in the French and Dutch study, respectively) and differences in competition levels at the professional level might account for these discrepancies in selection policies and aerobic performance over time and should be considered in future talent identification programs.

Several studies examined underlying factors determining aerobic performance. For example, a study by Moreira *et al.* (2013) investigated the contribution of salivary testosterone concentration, years from peak height velocity and anthropometry on aerobic fitness in 45 elite soccer players, aged 12 years. Although minor, the salivary testosterone concentration was the primary and single contributor to the variance in aerobic performance (21.3%), however no difference was found between players with low and high levels (median-split) of salivary testosterone concentration. Moreover, a study in Portuguese soccer players, aged 11 to 12 years, investigating differences in functional capacities between the skeletally most (n=8) and least (n=8) mature players, revealed that the least mature players had the better aerobic fitness (Figueiredo *et al.*, 2010b). Other longitudinal observations and correlation studies found that chronological age (Figueiredo *et al.*, 2009a; Roesher *et al.*, 2010; Valente-dos-Santos *et al.*, 2012a), height (Wong *et al.*, 2009a), maturity indicators (i.e., testicular volume, serum testosterone levels, skeletal age, stage of pubic hair) (Hansen & Klausen, 2004; Malina *et al.*, 2004a; Valente-dos-Santos *et al.*, 2012a) and training volume (Malina *et al.*, 2004a; Figueiredo *et al.*, 2010a; Valente-dos-Santos *et al.*, 2012a) positively, and sum of skinfolds (Figueiredo *et al.*, 2010a) negatively contributed to the aerobic fitness in young soccer players. Although for elite players within the same chronological age group, no differences were found between the youngest and the oldest, which might reflect the homogeneity in terms of aerobic performance (Malina *et al.*, 2004a; Carling *et al.*, 2009). Of particular interest for coaches and trainers involved in youth soccer, Philippaerts *et al.* (2006) found that the estimated velocity curves for the cardiorespiratory endurance indicated peak gains coincident with peak height velocity. After peak height velocity, the rate of improvement in aerobic fitness decreased which is in accordance with the findings from Valente-dos-Santos *et al.* (2012a). However, the latter study suggests a more complex relation between skeletal age and aerobic performance. Specifically, the development of the aerobic performance proceeds nearly linearly between 10 and 18 years of age, which stresses again the need for individualization in the development of youth soccer players.

Finally, few studies investigated the differences in aerobic performance between the positional roles within elite youth soccer teams of different chronological ages. In general, goalkeepers demonstrate the lowest, whereas defenders, midfielders and forwards demonstrate higher and similar aerobic performances expressed as estimated relative VO_2max or as running distance in field tests (i.e., yo-yo intermittent endurance test level 1 and level 2, yo-yo intermittent recovery test level 1, Astrand test) (Malina *et al.*, 2004a; Gil *et al.*, 2007b; 2014; Coelho-e-Silva *et al.*, 2010; Lago-Peñas *et al.*, 2011). Another study showed that center backs had the lowest yo-yo intermittent recovery test level 1 performance compared with central and wide midfielders, and forwards, but not with full backs, although differences between center backs and the other positions were relatively low (± 200-300 m which corresponds to approximately 5 to 8 running bouts) (Markovic & Mikulic, 2011). These results suggest that elite players possess similar aerobic endurance characteristics, no matter what position they play in, and almost proves the existence of a certain threshold below which players are unlikely to perform successfully (Reilly *et al.*, 2001).

2.2.2 Anaerobic characteristics

During a soccer match, energy delivery is dominated by aerobic metabolism. However, explosive actions (short sprints, tackles, jumps and duel play) are covered by means of anaerobic metabolism, and are often considered crucial for match outcome (Bangsbo, 1994). Anaerobic performance measures have been used in talent identification programs for young soccer players to predict both short-term (Le Gall *et al.*, 2010) and long-term (Gonaus & Müller, 2012) competition level. Within the field of (youth) soccer, several protocols have been used to evaluate anaerobic performance which generally could be divided, when overviewing the literature, into three anaerobic performance categories: jump performances (which will be referred to as 'explosive leg power' throughout the present thesis) (e.g. countermovement jump, squat jump, drop jump, standing broad jump) (Hansen *et al.*, 1999; Malina *et al.*, 2004a; 2007; Vanderford *et al.*, 2004; Vaeyens *et al.*, 2006; Gil *et al.*, 2007a; 2007b; Nedeljkovic *et al.*, 2007; Gravina *et al.*, 2008; Baldari *et al.*, 2009; Carling *et al.*, 2009; Figueiredo *et al.*, 2009a; 2010a; 2010b; Wong *et al.*, 2009a; Wong & Wong, 2009b; Coelho-e-Silva *et al.*, 2010; Fernandez-Gonzalo *et al.*, 2010; Le Gall *et al.*, 2010; Vanttinen *et al.*, 2010; Lago-Peñas *et al.*, 2011; Quagliarella *et al.*, 2011; Gonaus & Müller, 2012; Valente-dos-Santos *et al.*, 2012d; Vandendriessche *et al.*, 2012a; Moreira *et al.*, 2013; Rebelo *et al.*, 2013), muscle strength characteristics (e.g., knee extensors and flexors, hip extensors and flexors, upper limb power) (Hansen *et al.*, 1999; Vaeyens *et al.*, 2006; Nedeljkovic *et al.*, 2007; Carling *et al.*, 2009; 2012; Fernandez-Gonzalo *et al.*, 2010; Le Gall *et al.*, 2010; Gonaus & Müller, 2012; Rebelo *et al.*, 2013) and sprint performances (e.g., agility shuttle run, linear sprint, repeated sprint ability) (Vanderford *et al.*, 2004; Vaeyens *et al.*, 2006; Gil *et al.*, 2007a; 2007b; Malina *et al.*, 2007; Nedeljkovic *et al.*, 2007; Gravina *et al.*, 2008; Carling *et al.*, 2009; 2012; Figueiredo *et al.*, 2009a; 2010a; 2010b; Wong *et al.*, 2009a; Wong & Wong, 2009b; Coelho-e-Silva *et al.*, 2010; Le Gall *et al.*, 2010;

Vanttinen *et al.*, 2010; Lago-Peñas *et al.*, 2011; Gonaus & Müller, 2012; Valente-dos-Santos *et al.*, 2012a; 2012c; 2012d; Vandendriessche *et al.*, 2012a; Rebelo *et al.*, 2013). For an extensive summary of these characteristics in adult soccer players, we refer to a review of Stolen *et al*. (2005).

Anaerobic performances are influenced by chronological age. Moreover, jumping performances (such as vertical jump and standing long jump) improve linearly from 5 until 18 years of age in normally growing boys, and until 14 years of age in girls (Malina *et al.*, 2004b). For example, outcomes on the countermovement jump (CMJ) without arm-swing ranged from 26.5 ± 6.2 cm to 40.2 ± 5.5 cm in U10 elite soccer players from Spain (n=15) (Fernandez-Gonzalo *et al.*, 2010) and U18 drafted national youth team soccer players in Austria (n=136) (Gonaus & Müller, 2012), respectively. However, anaerobic performance characteristics vary across levels and countries, and it seems possible that younger players outperform older players (e.g., CMJ: elite U16 from Belgium, 44.7 ± 5.0 cm *vs*. CMJ: elite U18 from Serbia and Montenegro, 37.7 ± 3.9 cm) (Vaeyens *et al.*, 2006; Nedeljkovic *et al.*, 2007). Cross-cultural differences in quality of training, practice hours, quality of coaching and level of players may account for these discrepancies. Individual and longitudinal monitoring of promising young soccer players shows once more valuable in their evaluation.

Furthermore, in young male soccer players, strength-related motor performances (such as vertical and standing long jump) improve with increasing body size dimensions (i.e., stature and body size) and sexual maturity (Malina *et al.*, 2004a; Baldari *et al.*, 2009). For example, Philippaerts and colleagues (2006) showed the highest rate of improvements for anaerobic performances at the time of peak height velocity and remained positive for at least 6 to 18 months after peak height velocity. Also, in pre-adolescent Brazilian players, salivary testosterone concentration and years form peak height velocity accounted for 42.88% of the variance in CMJ performance and the high-testosterone jumped significant higher compared to the low-testosterone group (Moreira *et al.*, 2013). More mature players benefit from the hormonal changes occurring during puberty (e.g., increase in serum testosterone) which stimulates muscle growth and strength. Similarly, being advanced in maturity status (Malina *et al.*, 2004a; Vaeyens *et al.*, 2006; Figueiredo *et al.*, 2009b; 2010a; 2010b; Valente-dos-Santos *et al.*, 2012b; 2012c; Vandendriessche *et al.*, 2012a), having larger body size dimensions (Malina *et al.*, 2004a; Figueiredo *et al.*, 2010a; 2010b; Valente-dos-Santos *et al.*, 2012a), and having more experience (Malina *et al.*, 2004a; Figueiredo *et al.*, 2010a; Valente-dos-Santos *et al.*, 2012b) also contribute to better anaerobic performances. Furthermore, elite players were stronger than non-elite players independent of testosterone concentration, even when corrected for body size, indicating that being an elite player per se affected the development of strength (Hansen *et al.*, 1999). The reason for this may be a larger relative increase in muscle mass for the elite players and thus a larger cross-sectional area of the muscles.

Amongst 128 Portuguese youth soccer players, aged 13-14 years, regional players in all positions (defender, midfielder, forward) performed better in squat jump and sprint tests compared with local peers which is probably reflected in the larger body size and advanced maturity status in the regional players (Coelho-e-Silva *et al.*, 2010). Although, no statistical differences were clear when players were pooled together. Similarly, differences between elite and non-elite field positions existed in Portuguese U19 players (Rebelo *et al.*, 2013). For example, elite goalkeepers were largely differentiated from non-elite goalkeepers, not only in stature and body mass, but also in vertical jump and sprint performance, and they showed higher levels of lower-limb strength. Also, elite central defenders presented larger body size dimensions and better vertical jump performance compared to their non-elite peers, which is in line with the findings of Lago-Peñas et al (2011). The observations are generally consistent with coach expectations for players in this position, as activities of central defenders often involve body contact with opposing players, as well as aerial duels to sustain long ball passes and crosses. These positional differences may be due to differences in experience and training time.

Furthermore, in Spanish non-elite youth soccer teams, aged 17 years on average, forwards were the fastest in the 30 m flat sprint and most powerful in jump tests (Gil *et al.*, 2007a). Velocity and power are some of the most important characteristics of the forwards during a soccer match and coaches and trainers may select stronger soccer players with the best physiological profile for the forwards group, reflecting the belief that the success of match depends primarily on this particular groups of soccer players. In the defenders group, one of the discriminating variables was the power of the lower legs. In this position, players must be able to jump high in order to stop the ball going into the goal. On the other hand, no statistical differences in jump performances between positions (goalkeepers, defenders, midfielders and forwards) in 70 U14 Chinese players were presented (Wong *et al.*, 2009a), which is similar to the findings of Malina *et al.* (2004a). Also, no positional differences in sprint performances (10 m and 30 m sprint) were found (Malina *et al.*, 2004a; Wong *et al.*, 2009a). Although, goalkeepers were the second fastest on the 10 m sprint which might be due to the fact that goalkeepers normally sprint for 1 to 12m (Bangsbo & Michalsik, 2002), and therefore, the 30 m sprint is probably not the most appropriate test to evaluate goalkeepers. Forwards were the slowest on the 30 m sprint (Wong *et al.*, 2009a), which contrasts a study by Malina *et al.* (2004a) where forwards were the fastest on the 30 m sprint, although positional differences in both studies were not significant.

Finally, anaerobic performance characteristics were able to discriminate between future successful and less successful youth soccer players (Figueiredo *et al.*, 2009a; Le Gall *et al.*, 2010). For example, future players playing at elite level after a two-year follow-up period, presented better sprint and jump performances compared to players classified as drop-outs amongst 159 Portuguese soccer players (Figueiredo *et al.*, 2009a). These differences measured at the baseline were explicitly present in the older age group (13-14 years) compared to the younger one (11-12 years). Chronological age or skeletal maturity did not differ between elite and drop-out players aged 11-12 years, but elite players aged 13-14 years were older both chronologically and skeletally. As mentioned before, increased body size dimensions and advanced maturity status are related to better performances in strength related tasks, especially in the years of mid-puberty (13-15 years) (Malina *et al.*, 2004b).

2.3 Psychological and sociological predictors

Williams and Reilly (2000) categorized the psychological predictors associated with gifted young soccer players into (1) perceptual-cognitive skills (e.g., attention, anticipation, decision-making, game intelligence, creative thinking and motor/technical skills) and (2) measures of personality (e.g., self-confidence, anxiety control, motivation and concentration) (***Figure 2***). Perceptual-cognitive skill refers to the ability to identify and acquire environmental information for integration with existing knowledge such that appropriate responses can be selected and executed (Marteniuk, 1976). The first part of this definition stresses the recognition and cognitive processing of information, whilst the second part highlights the ability to effectively execute appropriate responses. Also, according to sociologists, the environmental factors are more important than the genetic influences in the 'nurturing' of gifted athletes. Supportive parents, stimulating and permissive coaches, and the dedication and commitment to spend numerous hours practicing skill are the real determinants of excellence (Williams & Reilly, 2000). The psychological and sociological characteristics of young soccer players were not the main focus of the present dissertation, and therefore this will be discussed briefly in the next paragraph. Although, as we considered the motor and technical skills as 'psychological' characteristics (Williams & Reilly, 2000; see ***Figure 2***), and the fact that we included such measures as part of the present talent identification dissertation, a more in-depth discussion will be presented further on this section.

It is well-known that top athletes have to be mentally in a good shape in order to perform at the highest level, especially within individualized sports such as tennis, golf or athletics. Also, the roles of the parents, coaches, peers, etc. could play a crucial part in the further development of gifted athletes. Particular for soccer, players who perceived their fathers as being more involved in their soccer participation and exerting lower amounts of pressure to perform had more positive psychosocial responses (Babkes & Weiss, 1999). Moreover, parents perceived as positive exercise role models, who had more positive beliefs about their child's competency, and who gave more frequent positive responses to performance successes were associated with athletes who had higher perceived competence, enjoyment and intrinsic motivation (Ebbeck & Becker, 1994; Babkes & Weiss., 1999). This stresses the need for an emotional and social supportive environment, besides the orientation on specialization and expertise (Gonçalves *et al.*, 2014). Besides, higher levels of physical fitness seems associated with a higher socio-economic status, living conditions, parental activity, and opportunities for physical activity and practice (Goodway & Smith, 2005; Vandendriessche *et al.*, 2012b).

Furthermore, other psychological outcomes such as ego and task orientations, decision-making (i.e., tactical) skills (via real images or inventories) and visual search behavior could aid the talent identification and development process. The general trend emerged from the literature that higher levels of competition are associated with a higher ego orientation (compared with task orientation) (Coelho-e-Silva *et al.*, 2010; Figueiredo *et al.*, 2010b), and with more accurate and faster decisions with more goal-oriented search strategies (Elferink-Gemser *et al.*, 2004; Vaeyens *et al.*, 2007a; 2007b; Del Campo *et al.*, 2010; Savelsbergh *et al.*, 2010; Kannekens *et al.*, 2011).

As the present dissertation considers motor coordination and technical skills as potential *psychological* characteristics of gifted young soccer (***Figure 2***), we discuss these specific items in this paragraph, although many studies are categorizing these specific outcomes under physical fitness. The main reason for considering motor coordination as a psychological predictor (i.e., perceptual-cognitive skill) is the fact that movements of several limbs or body parts are combined in a manner that is well timed, smooth, and efficient with respect to the intended goal. This involves the integration of proprioceptive information detailing the position and movement of the musculoskeletal system with the neural processes in the brain and spinal cord which control, plan, and relay motor commands. The cerebellum plays a critical role in this neural control of movement and damage to this part of the brain or its connecting structures and pathways results in impairment of coordination. Several studies have reported the importance of including motor coordination in development programs and selection processes in elite gymnasts and soccer players (Vandendriessche *et al.*, 2012a; Vandorpe *et al.*, 2012). It has been shown that a better baseline motor coordination is advantageous in physical fitness outcomes compared to those with low baseline motor coordination levels, even after a two- or five-year follow-up, respectively (Hands, 2008; Fransen *et al.*, 2014). The importance of the inclusion of non-specific and soccer-specific motor coordination skills in the identification and selection of Belgian international soccer players (15 to 16 years) has been described elsewhere (Vandendriessche *et al.*, 2012a). Moreover, talent development programs often adopt a one-dimensional approach or include a combination of morphological and physical tests (e.g. speed, endurance and power) which are sensitive to differences in maturation (Malina *et al.*, 2004b); Vaeyens *et al.*, 2006). Yet, motor coordination tasks are not related to biological maturity, and are therefore recommended as assessment tools in talent identification and development programs which in turn might prevent drop out of late maturing promising players (Malina *et al.*, 2005; Pearson *et al.*, 2006; Coelho-e-Silva *et al.*, 2010; Vandendriessche *et al.*, 2012a).

Besides, many others have used soccer-specific motor coordination (i.e., technical) skills (e.g., shooting, dribbling, juggling, etc.) in talent identification and development programs in order to distinguish between levels of competition or positional role on the field. For example, recently, a study in German youth soccer showed that dribbling and juggling differentiated the most among players of different performance levels (Höner *et al.*, 2014). Also, Rebelo *et al.* (2014) showed that it was possible to correctly classify playing position (goalkeepers versus outfield players) based on three and four technical skills (i.e., passing, shooting, dribbling and ball control) in U13-U15 and U17-U19 youth soccer players, respectively. In summary, reviewing the literature with respect to soccer-specific skills, it emerged from most studies that better technical skills are related to an increase of age (Rösch *et al.*, 2000; Huijgen *et al.*, 2010; Vanttinen *et al.*, 2010) and stature (Valente-dos-Santos *et al.*, 2014a; 2014b), a higher lean body mass (Huijgen *et al.*, 2010; Valente-dos-Santos *et al.*, 2014a; 2014b), more experience and to playing position (Huijgen *et al.*, 2010; Rebelo *et al.*, 2013; Valente-dos-Santos *et al.*, 2014a; 2014b), a higher level of competition (Rösch *et al.*, 2000; Vaeyens *et al.*, 2006; Figueiredo *et al.*, 2009a; Coelho-e-Silva *et al.*, 2010; Rebelo *et al.*, 2013; Waldron & Murphy, 2013; Le Moal *et al.*, 2014), but are not related to biological maturation (Malina *et al.*, 2007; Figueiredo *et al.*, 2009b; 2010a). However, some contrasting results stated that a shorter stature contributes to better technical skills (Malina *et al.*, 2007) and that players with more game experience do not display better technical skills (Vanderford *et al.*, 2004). It should be understood that outcome measures depend on the type technical skill assessed. For example, heavier, more mature players are more in advantage in shooting but not in dribbling skills (Wong *et al.*, 2009a).

2.4 Test battery

2.4.1 Longitudinal and holistic approach

It was initially suggested by Williams and Reilly (2000) that talent identification programs preferably adopt a multidisciplinary approach (***Figure 2***). Longitudinal research of this nature would also contribute to determine the predictive utility of these tests with young players. This more structured and holistic approach would account for a greater proportion of the variance between talented and less talented players, promoting greater accuracy and improved understanding of the talent identification process. A comprehensive database is required to develop a criterion-based model or `talent profile' that may help predict future performance. Results can guide the strength and conditioning training program leading to more successful and objective attainment (Walker & Turner, 2009). Moreover, different factors may predict performance at various ages and, consequently, any such model would need to be age-specific. In this light, a perfect model is likely to account for the effect of maturation on physical and physiological outcomes as maturation makes prediction of adult performance difficult (Pearson *et al.*, 2006).

While laboratory tests can, and have been used to evaluate the performance characteristics of soccer players (Tumilty, 1993), in many respects field-based methods are more suited to soccer as they are ecologically valid, allow the testing of large numbers of performers simultaneously and quickly, are generally cheaper, easier to administer and can be used by practitioners as well as researchers, given appropriate care and training (Alricsson *et al.*, 2001; Svenson & Drust, 2005). Many field test batteries were presented in the literature, however most of them still focus on one or two potential predictors of soccer talent, despite the recommendations for a more holistic approach (Williams & Reilly, 2000; Pearson *et al.*, 2006).

2.4.2 Validity, reliability and sensitivity

Despite statements that tests found to be valid and reliable in adult players, are appropriate for use in younger players, tests cannot be administered in young players with confidence until their validity and reliability is specifically demonstrated such individuals. In a comprehensive review by Currell and Jeukendrup (2008), three types of validity were addressed (i.e., logical, criterion and construct validity). Basically, a researcher or coach want to know whether an administered test measures what it sets out to measure. Logical validity refers to what happens in the 'real situation', for example a soccer skill test with high logical validity would attempt to measure aspects of soccer skill that would be typically found during a soccer game, although this is very difficult to assess (Ali, 2011). In contrast, criterion validity allows for an objective measure of validity. It involves using a performance protocol to subsequently predict performance (i.e., predictive validity) or that the performance protocol is correlated with a criterion measure (i.e., criterion validity) (Currell & Jeukendrup, 2008). However, the most common used measure of validity in sports performance is construct validity. A test with good construct validity will able to distinguish between levels of players or age groups. Reliability or test–retest repeatability is the degree to which a measurement instrument consistently measures whatever it measures (Hopkins, 2000). A reliable skills test would therefore give comparable results for a player over repeated trials (on the same day) or over many testing sessions (different days), providing the same physical and environmental conditions were being met. Finally, a sensitive test is one that can detect small but important changes in performance (Currell & Jeukendrup, 2008). Therefore, a test with a low within-subject coefficient of variation will be able to detect smaller changes in soccer skill between groups or over time. For a more detailed description of validity, reliability and sensitivity when measuring sports performance, I refer to the review by Currell and Jeukendrup (2008).

2.4.3 Multi-disciplinary test battery

In order to anwer the research questions in the present disseratation (see further, point 4. *Objectives and outline of the thesis*), we developed a multi-disciplinary test battery, that will be discussed more in detail in the different chapters further on. Below, a general overview of the test battery administered in the present dissertation.

Table 2 *Overview of the test battery.*

Predictor	Parameter	Test / Measurement
Physical	Anthropometry	Stature (cm)
		Weight (kg)
		Body fat (%)
		Sitting height (cm)
	Maturity status	Maturity offset (y)
Physiological	Flexibility	Sit-and-Reach (cm)
	Endurance	Yo-Yo intermittent recovery test level 1 (m)
	Speed	5m, 10m, 20m, and 30m sprint (s)
	Strength	Counter movement jump (cm)
		Standing broad jump (cm)
	Agility speed	T-test (s)
Psychological	Motor coordination	Moving boxes (n)
		UGent dribbling test (s)

One of the aims of the present dissertation was to investigatie the reliability and validity of both the Yo-Yo intermittent recovery test level 1 and the maturity offset protocol (see Part 2, Chapter 1). All other tests used, were checked for their reliability and validity, and a brief overview of these measures are described the methods section of study 11 (Chapter 4). This test battery was longitudinally applied and the results are described in Chapter 3.

3. MATURATION AND RELATIVE AGE EFFECT

3.1 Maturation

The sport of soccer seems to favour players who are average or advanced in maturity status (Malina *et al.*, 2000; 2007; 2010; 2012; Figueiredo *et al.*, 2009b; Hirose, 2009; Coelho-e-Silva *et al.*, 2010; Carling *et al.*, 2012; Hirose & Hirano, 2012; Valente-dos-Santos *et al.*, 2012a; 2012b; 2012d) and suggest that coaches select players for immediate competitive success and not for eventual success at higher levels of competition (Malina *et al.*, 2004a; Figueiredo *et al.*, 2009a; 2009b; Valente-dos-Santos *et al.*, 2012a). Although, younger elite players (i.e., 11-12 years) spanning the skeletal maturity spectrum from late (delayed) to early (advanced) were represented, as age and presumably experience increase, players advanced and average in maturity status seem to dominate (elite) soccer (Malina *et al.*, 2000; Figueiredo *et al.*, 2009a; Hirose, 2009; Malina *et al.*, 2010; 2012; Hirose & Hirano, 2012; Valente-dos-Santos *et al.*, 2012a; 2012b; 2012d). More mature soccer players have larger body size dimensions and demonstrate more speed and power compared to their less mature peers, which is the main reason to exclude the latter players (Malina *et al.*, 2000; 2004a; Figueiredo *et al.*, 2009b; 2010b; Coelho-e-Silva *et al.*, 2010; Carling *et al.*, 2012; Vandendriessche *et al.*, 2012a).

As a whole, talent identification and selection structures appear to be heavily influenced by body size and maturity and perhaps not adult potential (Carling *et al.*, 2012). This short-term selection policy in early puberty is detrimental for gifted, late maturing players who drop out along the developmental process and therefore never receive a chance again to expose their talents at older ages. For example, Figueiredo *et al.* (2009b) illustrated that Portuguese soccer players (aged 13-14 years at baseline) who stayed at or moved up to elite level were skeletally older (15.3 years) compared with players who dropped out (14.0 years) after a two-year follow-up period. Also, in this study, among the drop-out players, 13.3% were advanced in maturity status, against 42.9% of the players who stayed at elite level. Nevertheless, some players later in maturing may be as skilled as players advanced in maturation although their body size and power are quite different (Figueiredo *et al.*, 2010b). It has been reported that players at the extremes of height and skeletal maturity differ in speed and power, although they did not differ in aerobic endurance and in soccer-specific skills (Figueiredo *et al.*, 2010b). Small and late maturing players will eventually close the gap in size and power and may need to be protected by the sport, i.e. given time to catch-up. Indeed, a recent 8-year follow-up study in Serbian youth soccer showed that at the age of 14 years, players with advanced biological age were overrepresented, although eight years later, elite adult soccer competence seems to be achieved more often by the boys who were late maturers (Ostojic *et al.*, 2014).

The identification and evaluation of young soccer players during the pubertal years according to the maturity status is thus recommended (Philippaerts *et al.*, 2006; Vaeyens *et al.*, 2006; Malina *et al.*, 2007; Baldari *et al.*, 2009; Vandendriessche *et al.*, 2012a; Moreira *et al.*, 2013). Various protocols have been used to estimate the maturity status in young soccer players and most include the determination of skeletal age (Malina *et al.*, 2000, 2007; 2010; 2012; Vaeyens *et al.*, 2006; Segers, 2008; Figueiredo *et al.*, 2009a; 2009b; 2010a; 2010b; Hirose, 2012; Valente-dos-Santos, 2012a; 2012b; 2012c; 2012d), the development of pubic hair according to Tanners' stage (Hansen *et al.*, 1999; Malina *et al.*, 2004a; 2005; 2007; 2012; Figueiredo *et al.*, 2009a; 2009b; 2010a; 2010b;), estimated time to or from peak height velocity (Philippaerts *et al.*, 2006; Vandendriessche *et al.*, 2012a; Moreira *et al.*, 2013), levels of testosterone (Hansen *et al.*, 1999; Hansen & Klausen, 2004; Gravina *et al.*, 2008; Baldari *et al.*, 2009; Vanttinen *et al.*, 2010; Moreira *et al.*, 2013) and testicular volume (Hansen *et al.*, 1999; Hansen & Klausen, 2004; Baldari *et al.*, 2009), of which the most commonly used methods will be discussed briefly.

The assessment of skeletal age (SA) is widely used to estimate the maturity status of a child at the time of observation and predict adult or mature height. SA has a meaning relative to chronological age (CA) and may be compared to CA, or expressed as the difference between SA and CA or as a ratio of SA divided by CA (Malina *et al.*, 2004b). Three different methods are commonly used to estimate SA: Greulich-Pyle (GP; Pyle *et al.*, 1971) and Fels (Roche *et al.*, 1988) derived from American children, and Tanner-Whitehouse (TW; Tanner *et al.*, 1983; 2001) derived from British children. All methods use a simple radiograph from the left hand-wrist which is matched to a set of criteria. However, criteria and procedures to derive SA vary with each method (Malina, 2011). The difference between SA and CA is often used to classify maturity status (Malina *et al.*, 2004b): late (or delayed), SA younger than CA by >1 year; on time (or average), SA within a range of ±1 year from CA; early (or advanced), SA older than CA by >1 year.

Pubertal maturation can also be described in terms of sequence, timing and tempo. Puberty consists of a series of predictable events, and the sequence of changes in secondary sexual characteristics (i.e., pubic hair development) has been categorized by Tanner (1962), among others. Such assessments indicate the specific stage of pubic hair development (from *pre-pubertal* (stage I) to *adult genitalia* (stage V) on a five-stage scale) that is evident in the boy at the time of examination, and do not permit an estimate of the onset of, or entry into, each stage. Another alternative, non-invasive method to assess maturation is obtained from chronological age, stature, sitting height, estimated leg length, body mass, and interaction terms which are used to determine maturity offset (Mirwald *et al.*, 2002) that refers to the amount of time before or after peak height velocity and in turn permits the determination of age at peak height velocity (i.e., APHV). For boys, this equation was recommended to produce maturity offset values during circum-pubertal years (Mirwald *et al.*, 2002). Age at peak height velocity obtained from longitudinal data tend to occur about 14 years (Malina *et al.*, 2004b; Philippaerts *et al.*, 2006). Precise estimates of APHV requires serial longitudinal data spanning late childhood through adolescence (Philippaerts *et al.*, 2006; Malina & Koziel, 2014).

A recent study attempted to validate predicted and actual APHV in 193 Polish boys followed longitudinally 8-18 years (Malina & Koziel, 2014). The authors concluded that mean differences between concurrent assessments were reasonably stable among average maturing adolescents between 12 and 15 years. Consistently, the literature suggested that the majority of soccer players aged 11-14 years were classified as on time in maturation based on predicted age at peak height velocity and this was likely due to the reduced standard deviations for predicted ages at peak height velocity compared with that in the samples upon which the offset protocol was developed (Malina *et al.*, 2012). Although classifications between skeletal maturity derived from Fels method and somatic maturity obtained from the APHV were not expected to correspond exactly, the application of the non-invasive protocol to predict the maturity status of players was not recommended. However, the method has been used in large samples of young soccer players (Vandendriessche *et al.*, 2012a; Moreira *et al.*, 2013).

3.2 Relative age effect

Another obstacle in identifying youngsters referring to subtle chronological age differences in players of the same age group and its consequences, is known as the *relative age effect* (i.e., RAE) (Musch & Grondin, 2001). This phenomenon causes an overrepresentation of players born in the first part of the selection year, not only in youth soccer, but also in other youth sports competitions where body size, speed and power are the key characteristics that lead to success (Musch & Grondin, 2001). For example, it is possible that a player born on Jan 1st and another player born on Dec 31st are competing within the same age cohort. Obviously, at younger ages, this chronological age difference provides earlier increases in body size and experience for the relatively older player, which are the major contributing factors to explain the increased success for players born early in the selection year. Several studies investigated the skewed birth date distributions in youth soccer all over Europe and Japan and its impact on talent selection processes (Helsen *et al.*, 1998a; 2005; Carling *et al.*, 2009; Hirose, 2009; Del Campo *et al.*, 2010;). Across Europe, the percentage of players born in the first birth quarter of the selection year ranged from 36.0 % to 50.5 %, which differed significantly from the percentage of players who were born in the last quarter of the selection year (range 3.4 – 17.0 %) (Helsen *et al.*, 2005). Also, Helsen *et al.* (1998a) showed that players born early in the selection year, beginning in the 6–8 year age group, are more likely to be identified as talented and to be exposed to higher levels of coaching. Eventually, these players are more likely to be transferred to top teams, to play for national teams, and to become involved professionally. In comparison, players born late in the selection year tended to dropout as early as 12 years of age. These findings are closely related to the results of Carling *et al.* (2009) and Hirose

(2009) who found that already from the age of 9 years, selection processes tend to create homogenous and superior groups of players in terms of anthropometrical, maturational and physiological characteristics. Also and of interest in the present dissertation, relationships between date of birth and maturity status has been studied and there is a clear trend towards the de-selection of soccer players who are both born late in the selection year as well as late to mature (Figueiredo *et al.*, 2009a; Hirose, 2009). In addition, interacting psychological factors, linked with experience and selection differences according to relative age have also been presented to account for RAE's. Relatively older players may be more likely to develop higher perceptions of competency and self-efficacy. Otherwise, relatively younger players, faced with consistent sport selection disadvantages may be more likely to have negative experiences, develop low competence perceptions, and thus terminate the sport involvement (Musch & Grondin, 2001; Cobley *et al.*, 2009).

Several proposals to reduce or eliminate the relative age effect in youth soccer have been suggested. A rotating cut-off date is seemingly a valid initiative, although it has been suggested that this would only 'shift' the problem (Helsen *et al.*, 1998a; Vaeyens *et al.*, 2005). Other solutions recommended a reduction of the age band width (i.e., < 1 year), a rotating eligibility date for three years so each player will have a relative age advantage during at least 1 of 3 consecutive years, the inclusion of game-related variables such as playing time, number of selections and practice history, and a greater awareness of potential impact of the relative age in youth soccer on talent identification and selection processes (Helsen *et al.*, 2000; Musch & Grondin, 2001; Vaeyens *et al.*, 2005; Carling *et al.*, 2009; Del Campo *et al.*, 2010;). However, despite the considerable increase in published research on this particular topic, accompanied with the various solutions proposed to reduce its impact, the prevalence of the RAE does not seem to have decreased over a period of ten years (2000-2010), on the contrary there is some evidence that it may have increase slightly over time (Helsen *et al.*, 2012). Therefore, it is clear that other, structural solutions are compulsory in order to solve the persistent inequalities that are associated with the RAE in talent identification and selection.

4. OBJECTIVES AND OUTLINE OF THE THESIS

The importance of identifying and evaluating players on a longitudinal basis in a multi-dimensional setting, accounting for relative age and maturation has been stressed previously. However, within the tremendous amount of available scientific literature in youth soccer, the systematic search only provided seven studies (including only two with a longitudinal design, see ***Table 1***) with information in all four potential predictors of soccer talent (***Figure 2***), thereby revealing the difficulties longitudinal, multi-dimensional studies are faced with (Vanderford *et al.*, 2004; Malina *et al.*, 2007; Figueiredo *et al.*, 2009a; Huijgen *et al.*, 2010; Valente-dos-Santos *et al.*, 2012d). With this in mind, the current dissertation emphasized the *physical* and *physiological* predictors of talent in a large sample of young Flemish soccer players. Reasons were out of practical organization of the present test battery, and especially since research in the psychological (i.e., tactical skills) and sociological domain in Flemish children has already been provided (Vaeyens *et al.*, 2007a; 2007b; Vandendriessche *et al.*, 2012b).

Generally, the present dissertation wanted to provide insight in the identification and development of anthropometrical, maturational and physiological characteristics in Flemish youth soccer players. The Ghent Youth Soccer Project was the first mixed-longitudinal study over five years investigating anthropometry, maturity status, functional and sport-specific parameters in elite, sub- and non-elite Flemish youth soccer players, aged 10 to 13 years (Vaeyens *et al.*, 2006). Following this project, in season 2007-2008, a longitudinal engagement was made with two professional soccer clubs from the Belgian first division (i.e., Jupiler Pro League) and lasted till the end of the soccer season 2013-2014. All soccer players from the youth department of both clubs (i.e., U8 to U21) were assessed longitudinally anthropometrical, maturational, motor coordination, and physiological parameters resulting in a total of 20 measurement moments across six soccer seasons with more than 8.000 data points. In addition, players of different levels and nationality were added to address the different research questions (see further).

Several research questions were raised from the data collection with special attention for a soccer-specific field test (i.e., the Yo-Yo Intermittent Recovery test level 1), the use of a formula that estimates the time to or from peak height velocity (i.e., maturity offset) and the use of multilevel modeling analyses to gain insight in the development of anthropometrical and physiological parameters. Therefore, the second part of this thesis ('*Original research*') was structured into four chapters, each outlined in the next section.

4.1 Methodological studies

A relatively recent field test used in young players measuring soccer-specific intermittent running is the Yo-Yo Intermittent Recovery test level 1 (YYIR1) (Krustrup *et al.*, 2003). Several previous studies have shown that the YYIR1 performance has a high level of reproducibility (Krustrup *et al.*, 2003; Thomas *et al.*, 2006) and is a valid measure of prolonged, high intensity intermittent running capacity in adult players (Sirotic & Coutts, 2007). Moreover, strong correlations have been reported between the YYIR1 performance and the amount of high intensity running during a soccer match (Krustrup *et al.*, 2003; 2006; Thomas *et al.*, 2006; Bangsbo *et al.*, 2008; Castagna *et al.*, 2010;). However, little is known about the validity and reliability in young soccer players, which will be discussed in the first two chapters. **Study 1** investigated the test-retest reliability (reproducibility) from the YYIR1 in sub- and non-elite young soccer players (distance and heart rate responses), and the ability of the YYIR1 to differentiate between elite and sub-/non-elite youth soccer players (construct validity), whilst **study 2** focused on the reliability of the YYIR1 in soccer players only from the elite level. Reliability of assessments tools is essential in when evaluating improvements or impairments of young soccer players. According to previous literature in both young as adult players (Krustrup *et al.*, 2003; Thomas *et al.*, 2006; Castagna *et al.*, 2010;), we expected the YYIR1 to be reliable and valid in the evaluation of intermittent running performance.

The third methodological study (i.e., **study 3**) examined the changes in body dimensions and YYIR1 performance in high-level pubertal youth soccer players over two to four years. More precisely, we examined whether the baseline values could influence the magnitude of improvement, and whether this improvement is related to the maturational status. When predicting future success at young age, it is important to know whether anthropometrical and physical performances measures are stable on the long-term. This refers to the consistency of the position or rank of individuals in the group relative to others. Based on previous literature, we expected that the anthropometrical parameters will show high stability, in contrast to the long-term stability of performance measures which we expect to be moderate (Buchheit & Mendez-Villanueva, 2013).

Estimates of maturity status, both invasive as non-invasive methods, has extensively been used in TID programmes to gain insight in the way inter-individual differences in maturation have implications for the selection process. The assessment of skeletal age is considered as golden standard, although has associated expenses, requires trained observers and hand-wrist radiographs requires a low dose of radiation which is still faced a constraint. The estimation of the APHV might be seen as an alternative, however a recent study revealed a limited concordance between maturity classifications (i.e., early, average, late) based on skeletal age and on the maturity offset protocol in young Portuguese soccer players (Malina *et al.*, 2012). Therefore, **study 4** was aimed to examine the agreement between invasive and non-invasive protocols used to estimate mature stature in 58 Flemish youth soccer players, added with 90 elite youth soccer players from Brazil. Invasive formulas including Tanner-Whitehouse (TW) skeletal scores among predictors: version II (Tanner, 1983) and version III (Tanner, 2001) and non-invasive formulas derived from chronological age and anthropometry. In addition, this study examined the interrelationship among maturity groups derived from concurrent protocols. It was hypothesized that although large or very large magnitude of the correlation coefficients between estimates of mature stature could exist, agreement between maturity status classifications is poor.

4.2 Relative age effect and performance

It is already well-known that large RAE's exists in sports where strength, speed and endurance are key factors. The organization of the soccer competition is the main reason for the existence of the RAE. Players born close to the cut-off date are overrepresented, whilst players born late(r) in the selection year are underrepresented simple because they run a couple of months to almost one year behind in growth and maturation. Therefore, the aim of the next two chapters was to explore the existence of a RAE in Flemish youth soccer, and if differences in relative age are associated with differences in YYIR1 performance (**study 5**), anaerobic performance (**study 6**) on the one hand and maturation on the other. Therefore, we used statistical techniques to investigate possible differences between birth quarters when controlled for chronological age and maturation in order to evaluate all players on the same level. We expected the existence of large RAE's among young soccer players, although smaller differences amongst the four birth quarters in performance measures and maturation (Malina *et al.*, 2007; Carling *et al.*, 2009; Hirose, 2009).

4.3 Longitudinal research

Longitudinal models tracking the development of performance measures in the present literature are rather scarce as it is time consuming and missing values might increase on the long term. However, the multilevel model technique allows the number of observations and temporal spacing between measurements to vary among subjects, thus using all available data. It is assumed that the probability of data being missing is independent of any of the random variables in the model. As long as a full information estimation procedure is used, such as maximum likelihood in *MLwiN* for normal data, the actual missing mechanism can be ignored (Rasbash *et al.*, 1999). In the next three chapters, multilevel development models were obtained for the YYIR1 performance (**study 7**) and explosive leg power tests (i.e., countermovement jump and standing broad jump) (**study 8** and **study 9**) based on the contribution of chronological age, anthropometrical characteristics, maturity status, motor coordination and flexibility.

Also, we conducted a longitudinal study which aims were twofold: the first study aimed to expose the anthropometrical, physical performance and motor coordination characteristics that influence drop out from a high-level soccer training program, and in the second study, cross-sectional data of anthropometry, physical performance and motor coordination were retrospectively explored to investigate which characteristics influence future contract status (*contract* vs. *no contract* group) and first-team playing time (**study 10**).

4.4 Positional differences in performance

The final part of the '*Original research*'-section aimed to investigate differences in anthropometrical characteristics and general fitness level through aerobic and anaerobic tests according to the playing position on the field in youth soccer players from a high-level development programme (**study 11**). Based on previous literature, we hypothesized that differences in anthropometry exist between playing positions (Lago-Peñas *et al.*, 2011). On the other hand, we hypothesize that no significant differences in functional performances between playing positions were present (Carling *et al.*, 2009).

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PART 2

Original research

Chapter 1:
Methodological studies

STUDY 1

RELIABILITY AND VALIDITY OF THE YO-YO INTERMITTENT RECOVERY TEST LEVEL 1 IN YOUNG SOCCER PLAYERS

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Abstract

The present study investigated the test-retest reliability from the Yo-Yo IR1 (distance and heart rate responses), and the ability of the Yo-Yo IR1 to differentiate between elite and non-elite youth soccer players. A total of 228 youth soccer players (11 to 17 y) participated: 78 non-elite players to examine the test-retest reliability within 1 week, added with 150 elite players to investigate the construct validity. The main finding was that the distance covered was adequately reproducible in the youngest age groups (U13 and U15) and highly reproducible in the oldest age group (U17). Also, the physiological responses were highly reproducible in all age groups. Moreover, the Yo-Yo IR1 test had a high discriminative ability to distinguish between elite and non-elite young soccer players. Furthermore, age-related standards for the Yo-Yo IR1 established for elite and non-elite groups in this study may be used for comparison of other young soccer players.

Introduction

Soccer requires a soccer-specific endurance capacity, which is an important fitness component in talent identification and selection of young soccer players. Traditionally, many continuous exercise tests have been used to evaluate sport-specific endurance of young soccer players. However, due to the low specificity of these tests, the Yo-Yo intermittent recovery (Yo-Yo IR) tests were developed and these are now commonly used to assess physical capacities of soccer players (Bangsbo, 1994; Castagna, Abt, & D'Ottavia, 2005; Krustrup et al., 2003).

The Yo-Yo IR level 1 (Yo-Yo IR1) has been extensively studied, especially in adult soccer players (Bangsbo, Iaia, & Krustrup, 2008; Castagna, Impellizzeri, Chamari, Carlomagno, & Rampinini, 2006; Krustrup et al., 2003). Only a few studies investigated the efficacy of using the Yo-Yo IR1 in young soccer players (Castagna, Impellizzeri, Cecchini, Rampinini, & Barbero Alvarez, 2009; Deprez, Vaeyens, Coutts, Lenoir, & Philippaerts, 2012; Markovic & Mikulic, 2012). For example, Castagna et al. (2009) reported significant correlations between match-related physical performance and Yo-Yo IR1 performance in 21 young Italian soccer players (i.e. 14 y) as evidence of validity. More recently, Markovic and Mikulic (2012) evaluated the discriminative ability of the Yo-Yo IR1 in young elite soccer players (i.e. 12 to 18 y) and reported differences in YoYo IR1 performance (i.e. distance covered) between several age groups and playing positions. Despite these studies however, there is relatively little information on the normative performances for the YoYo IR1 in young soccer players. Such information is important and can be used in developing and evaluation training processes for their players. To date, only few studies with relatively low samples have reported the age-specific reference values of youth soccer players (Castagna et al., 2009; Deprez et al., 2012; Markovic & Mikulic, 2012).

Population specific information on test reliability is also important for assessing the efficacy of a performance test and this information can be used to interpret the clinical decisiveness of observed changes in test results within individuals and groups. For example, Krustrup et al. (2003) reported the good test-retest reliability (coefficient of variation (CV% 4.9%) of the YoYo IR1 in 13 adult experienced male soccer players. Thomas, Dawson, & Goodman (2006) also reported a test-retest CV of 8.7% in 16 recreational, male adult male soccer players. To date however, no studies have reported the reliability of the Yo-Yo IR1 performance in young soccer players. Therefore, the aim of this study is twofold: 1) to investigate the test-retest reliability (reproducibility) from the Yo-Yo IR1 performance (distance covered) and heart rate responses at fixed points during the test in young Belgian soccer players (U13-U17), and 2) to examine the ability of the Yo-Yo IR1 to differentiate between youth soccer players of different competitive levels (construct validity).

Methods

Study design and participants

A test-retest study design was conducted to investigate test reliability. Youth soccer players (n=228) from four different competition levels (professional (ELITE) level (1st division; n=150), national (SUB-ELITE) level (2nd and 4th division; n=58) and regional (NON-ELITE) level (n=20) with 7.5, 6, 4.5 and 3 training hours per week (+ 1 game), respectively) aged between 11.3 – 17.6 years participated. The total sample was divided into three different age groups according to their birth year (***Table 1***). All players and their parents or legal representatives were fully informed about the experimental procedures of the study, before giving their written informed consent. The Ethics Committee of the University Hospital approved the present study.

Test-retest reliability

Test-retest reliability (part 1) was determined in 78 sub- and non-elite soccer players (age-range: 11.3-17.2 years). Chronological age and anthropometrical characteristics per age group are described in ***Table 2***. Information about years of training is lacking. All participants completed the Yo-Yo IR1 test (according to the protocol as described by Krustrup et al. (2003)) twice in 8 days on the same day of the week and time of day (April 2012). Players were asked to refrain from strenuous training exercise or other high-intensive activities 48 h before the test sessions. Conversely, participants were required to keep their normal training habits in the week before the first test session and during the week between both test sessions. All tests were conducted on the same indoor venue with standardized environmental conditions. Players completed both Yo-Yo IR1 tests with the same running shoes and followed a standardized warm-up. Participants were given feedback on their performances after completing both test sessions.

Heart rate was monitored every second during each test session with a heart rate monitoring system (Polar Team² System, Kempele, Finland). Before the start of each Yo-Yo IR1 test, players were asked to minimize physical activity and interactions with other participants in order to keep the heart rate as low as possible. The start heart rate was the recorded at the starting beep of the test. Dependent on the distance covered by each player, heart rates were recorded at every speed increment during the test (heart rates at level 13.1 (*320 m, 14.0 km.h^{-1}*), level 14.1 (*480 m, 14.5 km.h^{-1}*) and at level 15.1 (*800 m, 15.0 km.h^{-1}*)). Peak heart rate was the highest heart rate recorded during the test, on the condition that players performed the maximum. Players who stopped the test before exhaustion were excluded for analysis. Finally, recovery heart rates were taken at one and two minutes after completing the test. All heart rates, except for the peak heart rate (bpm), were expressed as percentage of peak heart rate.

Construct validity

The total sample of 228 youth soccer players participated in part two of the study. Specifically, the 58 sub-elite players (from the 2nd and 4th division) from part 1 and the150 elite players from 2 professional soccer clubs (1st division) who completed the Yo-Yo IR1 on one occasion in the same season (Feb 2012). Assessing all elite players was part of a larger longitudinal study investigating anthropometric characteristics, motor coordination and physical and physiological parameters, and these players were therefore familiarized with this test. For each player of study 1, the best performance on the Yo-Yo IR1 was selected for further analysis to obtain a more representative score of the examined intermittent endurance and to assure that all players were familiarized with the Yo-Yo IR1 protocol. All players were classified into two different groups according to their level (elite and sub-elite).

Statistical analyses

To determine the reliability of the Yo-Yo IR1 (distance and heart rates), the data of the three age groups were analyzed separately. Relative reliability was expressed using intra-class correlations (ICC). According to the recommendations of Fleiss (1986) we considered an ICC between 0.75 and 1.00 as *excellent*, between 0.41 and 0.74 as *good*, and between 0.00 and 0.40 as *poor.* Further, the typical error (TE) and the coefficient of variation (CV) were calculated to assess absolute reliability (Atkinson & Nevill, 1998). All reliability calculations (ICC, TE and CV) were accompanied with 90% confidence intervals (CI). Additionally, the differences between both Yo-Yo IR1 performances were illustrated using Bland-Altman plots with the limits of agreement (LOA) (Bland & Altman, 1986; Nevill & Atkinson, 1997). The data were tested for normality using the Shapiro-Wilk test. Finally, to examine construct validity, differences between elite and sub-elite youth soccer players were investigated using multivariate analysis of covariates (MANCOVA) with chronological age and maturity offset as covariates. SPSS for windows (version 19.0) was used for all calculations. All variables are presented as *mean* ± *SD*. Minimal statistical significance was set at $p<0.05$.

Results

The grand mean Yo-Yo IR1 distance for each age group were 890 ± 354 m, 1022 ± 444 m and 1556 ± 478 m for the U13, U15 and U17 age groups, respectively. The ICC's for these age groups were considered as *excellent* (ICC's between 0.82 and 0.94). The CV's were 17.3 %, 16.7 % and 7.9 %, for the U13, U15 and U17 age groups, respectively (***Table 3***).

For the U13 age group, the grand mean HR immediately before the start of the Yo-Yo IR1 test was 111 ± 14 bpm (56.7 ± 5.9 %) and increased to 186 ± 10 bpm (92.0 ± 3.8 %), 192 ± 9 bpm (94.6 ± 3.5 %), 198 ± 8 bpm (96.9 ± 2.3 %) and 202 ± 7 bpm after 320 m, 480 m, 800 m and at the end of the test, respectively. The HR decreased to 159 ± 16 bpm (82.1 ± 5.4 %) and 137 ± 14 bpm (70.8 ± 4.8 %), 1 and 2 minutes after completing the test, respectively. Similar detailed analysis for the U15 and U17 age groups are in ***Table 3***. Further, analyses of ICC's in each age group showed *good* to *excellent* correlations between week 1 and week 2 (ICC's between 0.69 and 0.97), and CV's between 1.1 % and 4.1 %.

The 95% ratio LOA were 0.98 x/÷ 1.27, 0.89 x/÷ 1.30 and 0.94 x/÷ 1.15 for the U13, U15 and U17 age group, respectively (***Table 4***). Ratio limits were used since the data showed no normal distribution (Shapiro-Wilk test: $p<0.003$) Bland-Altman plots are presented in ***Figure 1***.

Significant differences ($p<0.001$) were found for the Yo-Yo IR1 performance between elite (U13: 1270 ± 440 m, n=44; U15: 1818 ± 430 m, n=57; U17: 2151 ± 373 m, n=49) and sub-elite (965 ± 378 m, n=31; U15: 1425 ± 366 m, n=31; U17: 1640 ± 475 m, n=11) youth soccer players when controlling for chronological age and maturation. In all age groups, elite players cover more distance than non-elite players (***Table 5***). Expressed as percentages, performance differences (in favour of elite players) between U17, U15 and U13 elite and non-elite players were 30.3 %, 61.2 % and 31.2 %, respectively. No differences in maturity offset, height and weight were found between elite and sub-elite players. Maturity offset was not a significant covariate in the Yo-Yo IR1 performance (***Table 5***).

Table 1 *Number of players per level within each age group*

	Elite	Sub-Elite		Non-Elite	
	1st Div	2nd Div	4th Div	Regional	*Total*
U13	44 #	17 *	14 *	4 Σ	*79*
U15	57 #	7 *	9 *	16 Σ	*89*
U17	49 #	8 *	3 *	0	*60*
Total	*150*	*32*	*26*	*20*	*228*

*Σ players in part 1, # players in part 2, * players in part 1 and 2;*

Table 2 *Age and anthropometrical characteristics per age-group for the sub- and non-elite players (n=78)*

	U13 (*n=35*)	**90% CI**	**U15 (*n=32*)**	**90% CI**	**U17 (*n=11*)**	**90% CI**
Age (y)	12.5 ± 0.6	12.3 - 12.7	14.0 ± 0.5	13.9 - 14.2	16.2 ± 0.6	15.9 - 16.5
MatOffSet (y)	-1.26 ± 0.81	13.6 - 13.8	0.00 ± 0.73	13.8 - 14.2	2.27 ± 0.65	13.7 - 14.3
APHV (y)	13.7 ± 0.4	(-1.49) - (-1.03)	14.0 ± 0.6	(-0.21) - 0.21	14.0 ± 0.6	1.95 - 2.59
Height (cm)	154.5 ± 9.0	152.4 - 157.4	164.3 ± 9.1	161.7 - 167.0	176.5 ± 5.1	174.0 - 179.0
Weight (kg)	42.7 ± 8.0	40.5 - 44.9	49.8 ± 8.4	47.4 - 52.2	66.4 ± 7.5	62.7 - 70.1

MatOffSet = maturity offset

Table 3 *Measures of reliability for performance and heart rate responses to the Yo-Yo IR1 in youth soccer players.*

Variable	**Age Cat**	***N***	**Week 1 (mean ± SD)**	**Week 2 (mean ± SD)**	**Grand Mean (mean ± SD)**	**TE**	**90% CI**	**CV (%)**	**90% CI**	**ICC**	**90% CI**
Yo-Yo IR1 Distance (m)	U13	*35*	885 ± 368	896 ± 339	890 ± 354	154	129 – 193	17.3	14.5 – 21.7	0.82	0.71 – 0.90
	U15	*32*	979 ± 445	1065 ± 443	1022 ± 444	171	142 – 217	16.7	13.9 – 21.2	0.85	0.74 – 0.92
	U17	*11*	1509 ± 474	1604 ± 483	1556 ± 478	123	91 – 196	7.9	5.8 – 12.6	0.94	0.82 – 0.98
HR start (% peak HR)	U13	*28*	56.7 ± 6.4	56.7 ± 5.4	56.7 ± 5.9	2.3	1.9 – 2.9	4.1	3.3 – 5.3	0.87	0.77 – 0.93
	U15	*27*	55.5 ± 6.5	55.5 ± 5.5	55.5 ± 6.0	1.9	1.6 – 2.5	3.8	3.1 – 4.9	0.90	0.81 – 0.95
	U17	*9*	56.4 ± 6.1	55.5 ± 5.0	56.0 ± 5.6	1.3	1.0 – 2.3	2.2	1.6 – 3.7	0.97	0.90 – 0.99
HR level 13.1 (% peak HR)	U13	*27*	91.8 ± 3.6	92.3 ± 4.0	92.0 ± 3.8	2.1	1.7 – 2.7	2.3	1.9 – 3.0	0.71	0.50 – 0.84
	U15	*27*	91.5 ± 4.5	91.5 ± 4.4	91.5 ± 4.5	1.8	1.4 – 2.3	1.9	1.6 – 2.5	0.86	0.75 – 0.93
	U17	*9*	91.8 ± 4.3	91.0 ± 4.7	91.4 ± 4.5	1.8	1.3 – 3.0	2.0	1.5 – 3.5	0.88	0.63 – 0.96
HR level 14.1 (% peak HR)	U13	*26*	94.6 ± 3.4	94.7 ± 3.6	94.6 ± 3.5	2.0	1.6 – 2.6	2.2	1.8 – 2.9	0.69	0.47 – 0.83
	U15	*26*	94.1 ± 3.6	94.0 ± 3.7	94.1 ± 3.6	1.7	1.4 – 2.3	1.8	1.5 – 2.4	0.79	0.63 – 0.89
	U17	*8*	94.2 ± 3.7	93.7 ± 4.5	93.9 ± 4.1	1.4	1.0 – 2.4	1.5	1.0 – 2.7	0.92	0.74 – 0.98
HR level 15.1 (% peak HR)	U13	*19*	97.0 ± 2.1	96.9 ± 2.5	96.9 ± 2.3	1.3	1.0 – 1.8	1.3	1.0 – 1.8	0.72	0.46 – 0.86
	U15	*18*	96.7 ± 2.6	96.6 ± 2.6	96.6 ± 2.6	1.1	0.8 – 1.5	1.1	0.9 – 1.5	0.86	0.71 – 0.94
	U17	*4*	94.5 ± 1.7	94.6 ± 2.4	94.5 ± 2.1	0.5	0.3 – 1.4	1.0	0.6 – 3.1	0.88	0.73 – 0.99

Peak HR ($b.min^{-1}$)	U13	*29*	202 ± 7	201 ± 8	202 ± 7	3.0	2.5 – 3.8	1.4	1.1 – 1.8	0.87	0.77 – 0.93
	U15	*29*	200 ± 7	200 ± 6	200 ± 7	3.1	2.5 – 3.9	1.5	1.3 – 2.0	0.80	0.65 – 0.89
	U17	*9*	203 ± 10	203 ± 10	203 ± 10	2.6	1.9 – 4.5	1.3	0.9 – 2.3	0.95	0.83 – 0.98
HR recovery 1’ (% peak HR)	U13	*29*	82.5 ± 5.1	81.7 ± 5.8	82.1 ± 5.4	2.9	2.4 – 3.7	3.7	3.1 – 4.9	0.72	0.53 – 0.84
	U15	*28*	84.0 ± 4.3	83.0 ± 5.4	83.5 ± 4.9	2.5	2.1 – 3.3	3.2	2.6 – 4.1	0.74	0.56 – 0.85
	U17	*8*	79.2 ± 5.8	79.0 ± 6.0	79.1 ± 5.9	2.0	1.4 – 3.6	2.7	1.9 – 4.8	0.92	0.73 – 0.98
HR recovery 2’ (% peak HR)	U13	*29*	71.1 ± 4.8	70.5 ± 4.9	70.8 ± 4.8	2.7	2.2 – 3.5	4.1	3.3 – 5.2	0.69	0.49 – 0.82
	U15	*28*	70.7 ± 5.0	71.1 ± 5.5	70.9 ± 5.2	2.6	2.2 – 3.4	3.8	3.1 – 4.9	0.77	0.60 – 0.87
	U17	*8*	68.4 ± 4.1	69.1 ± 6.4	68.7 ± 5.2	2.5	1.8 – 4.5	3.6	2.5 – 6.5	0.85	0.54 – 0.96

TE*=Typical Error,* ***CI****=Confidence Interval,* ***CV****=Coefficient of Variation,* ***ICC****=Intra-Class Correlation*

Table 4 *Sample size, measurements means and differences (log transformed) and the ratio limits of agreement with the limit range.*

	Log transformed Yo-Yo IR1 measurements					
	n	*Mean 1*	*Mean 2*	*Difference (SD)*	*Ratio limits*	*Range*
Overall	78	6.813	6.878	-0.065 (0.241)	0.94 x/÷ 1.27	0.74 to 1.19
U13	35	6.708	6.728	-0.020 (0.238)	0.98 x/÷ 1.27	0.77 to 1.24
U15	32	6.770	6.885	-0.115 (0.265)	0.89 x/÷ 1.30	0.68 to 1.16
U17	11	7.269	7.331	-0.062 (0.140)	0.94 x/÷ 1.15	0.82 to 1.08

SD = standard deviation

Table 5 *Anthropometrical characteristics and Yo-Yo IR1 performance (m) (mean ± SD) per level*

						Covariates					
	Age Cat	***N***	**Elite**	***N***	**Sub-Elite**	***F(Age)***	***P(Age)***	***F(Mat)***	***P(Mat)***	**F(Level)**	**P(Level)**
Age (y)	U13	*44*	12.8 ± 0.6	*31*	12.4 ± 0.6	-	-	-	-	6.141	0.016
	U15	*57*	14.8 ± 0.6	*16*	14.1 ± 0.4	-	-	-	-	23.126	<0.001
	U17	*49*	16.6 ± 0.6	*11*	16.2 ± 0.6	-	-	-	-	4.717	0.034
MatOffSet (y)	U13	*44*	-1.04 ± 0.81	*31*	-1.36 ± 0.77	*112.105*	*<0.001*	-	-	0.113	0.737
	U15	*57*	0.95 ± 0.84	*16*	-0.06 ± 0.76	*65.879*	*<0.001*	-	-	1.382	0.244
	U17	*49*	2.52 ± 0.65	*11*	2.27 ± 0.65	*44.815*	*<0.001*	-	-	0.106	0.746
Height (cm)	U13	*44*	156.3 ± 8.8	*31*	153.7 ± 8.7	*15.018*	*<0.001*	*333.749*	*<0.001*	0.026	0.873
	U15	*57*	169.9 ± 7.6	*16*	162.1 ± 9.9	*28.779*	*<0.001*	*255.982*	*<0.001*	0.439	0.510
	U17	*49*	176.3 ± 5.2	*11*	176.5 ± 5.1	*13.550*	*0.001*	*85.055*	*<0.001*	0.423	0.518
Weight (kg)	U13	*44*	44.2 ± 7.6	*31*	42.1 ± 8.1	*30.942*	*<0.001*	*220.019*	*<0.001*	0.173	0.678
	U15	*57*	58.3 ± 9.4	*16*	47.7 ± 8.0	*13.455*	*<0.001*	*179.826*	*<0.001*	2.931	0.091
	U17	*49*	66.5 ± 7.0	*11*	66.4 ± 7.5	*6.486*	*0.014*	*47.388*	*<0.001*	0.158	0.692
Yo-Yo IR1 (m)	U13	*44*	1270 ± 440	*31*	965 ± 378	*5.360*	*0.024*	*0.0147*	*0.829*	4.750	0.033
	U15	*57*	1818 ± 430	*16*	1425 ± 366	*12.062*	*0.001*	*0.001*	*0.972*	7.570	0.038
	U17	*49*	2151 ± 373	*11*	1640 ± 475	*11.036*	*0.002*	*3.797*	*0.056*	10.304	0.002

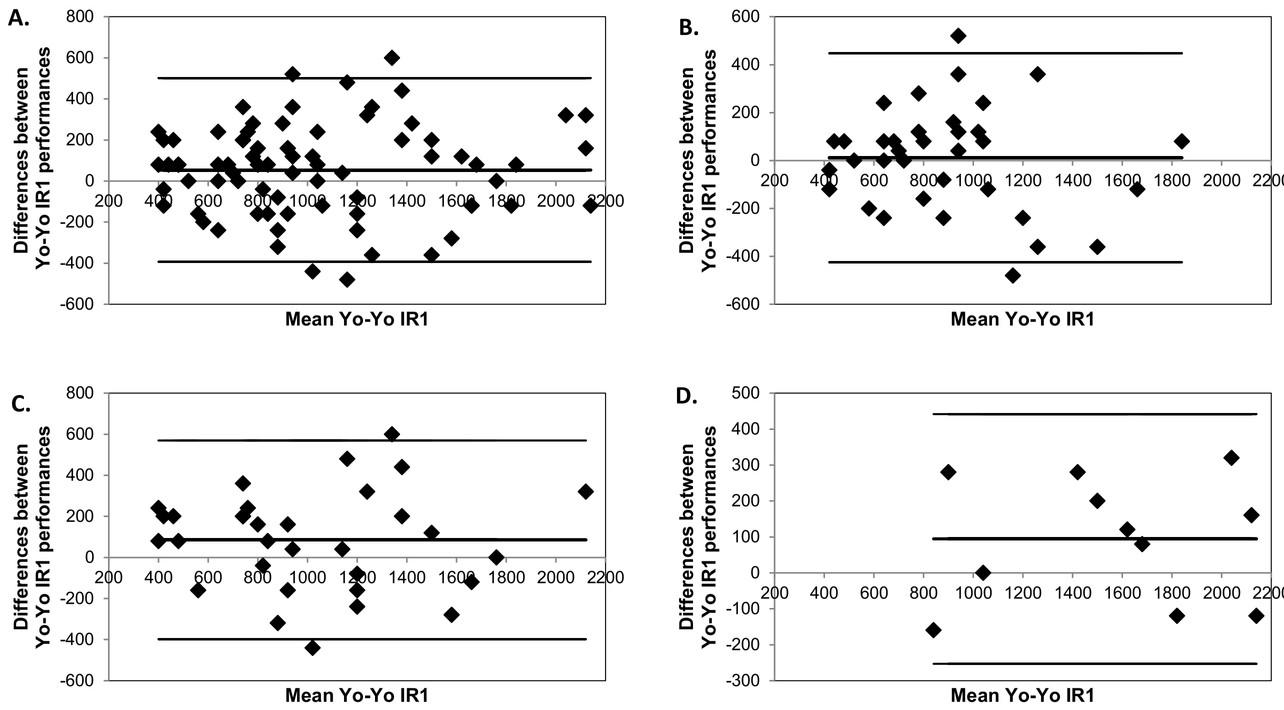

Figure 1 *Bland-Altman plot with 95% limits of agreement between Yo-Yo IR1 performances for (**A.**) the total sample (n=78), (**B.**) U13 players (n=35), (**C.**) U15 players (n=32) and (**D.**) U17 players (n=11).*

Discussion

The aims of the present study investigated the test-retest reliability and the construct validity of the Yo-Yo IR1 in young soccer players. The main finding was that, in the younger age groups (U13 and U15), the test-retest reliability of the distance covered was adequate, however highly reproducible in the oldest age group (U17). Besides, the physiological responses were highly reproducible in all age groups. Moreover, the Yo-Yo IR1 test had a high discriminative ability to distinguish between young elite and non-elite soccer players. Whilst many studies have reported on the Yo-Yo IR1 test in the last decade (Castagna et al., 2009; Castagna, Manzi, Impellizzeri, Weston, & Barbero Alvarez, 2010; Krustrup et al., 2003), relatively few studies have investigated the Yo-Yo IR1 performance in young soccer players. The present study revealed distances in young, sub-elite soccer players similar to the distances reported in elite Croatian soccer players who ran 933 ± 241 m, 1184 ± 345 m and 1581 ± 390 m in the U13 (n=17), U15 (n=21) and U17 (n=20) age category, respectively (Markovic & Mikulic, 2011). Also, Castagna et al. (2009; 2010) conducted two studies with elite 14 year old soccer players from San Marino and revealed Yo-Yo IR1 distances of 842 ± 252 m and 760 ± 283 m, respectively, which are much lower than the distance covered by the present elite and sub-elite soccer players. These comparisons show the high level of intermittent-endurance of the tested Belgian young soccer players. Similar to the present study, Deprez et al. (2012) also reported significant higher standards for young elite Belgian soccer players of 1135 ± 341 m, 1526 ± 339 m and 1912 ± 408 m in the U13 (n=271), U15 (n=272) and U17 (n=269) group, respectively.

Although similar Yo-Yo IR1 performances were found between the test and re-test, the re-test performance was higher in each age category (+ 11 m, + 86 m and + 95 m, for the U13, U15 and U17 age group, respectively). This systematic bias could be attributed to a test effect since the players never ran the Yo-Yo IR1 test before the present study. To our knowledge, this is the first study reporting reliability data about the Yo-Yo IR1 in young soccer players between 11 and 17 years, as previous studies have investigated older athletes in a wider age-range. Therefore, conclusions for usefulness in young children are difficult to make, since the variance in performance is to be expected higher for this age-group. The current results also revealed CV's between 16.7 and 17.3 % for the U13 and U15 age group, respectively, which is higher than previous reports from 17 untrained adults (CV = 4.9 %) and 16 recreationally active adults (CV = 8.7 %) (Krustrup et al., 2003; Thomas et al., 2006). However, the CV in the present U17 age group (CV = 7.9 %) is similar with those reported in the latter two studies. Though, the present results in the U13 and U15 age group are lower than the test-retest CV of the modified Yo-Yo IR1 test (2 x 16 m) in 35 young school children aged 6 to 9 years (CV = 19 %), which was found highly reproducible (Ahler, Bendiksen, Krustrup, & Wedderkopp, 2012). This is in part due to the fact that the absolute running distances are shorter in the youngest age groups (U13 and U15) compared with the oldest (U17) (***Table 3***). These larger CV's in the youngest age groups are also reflected by larger LOA. The ratio LOA revealed that any two Yo-Yo IR1 performances will differ due to measurement error by no more than 27 %, 30 % and 15 % in the U13, U15 and the U17 age group, respectively. Additionally, one could expect higher CV's when using a larger evaluation time (> 1 week) due to several factors (e.g. possible training effects fatigue and match schedules), otherwise practical problems are rising when using a smaller evaluation time (< 1 week). Noticeably, the CV of the oldest age group is approximately half the CV of the two youngest age-groups, reflecting smaller variances in performances and therefore, approaching the variances reported by others in older age-groups (Krustrup et al., 2003; Thomas et al., 2006). The reason for the decrement in CV in the older age group is not clear. The fact that the U17 age group mostly consists of 2nd division players (n=8) could explain the smaller variation. This might also be due to large inter-individual differences in the maturational status, especially in the U15 age group, which overlaps the pubertal phase reflected by a wide range of Yo-Yo IR1 performance. In contrast however, the present results showed (***Table 5***) that the maturational status was likely to have a relatively small influence on the Yo-Yo IR1 results, since the maturity offset was not a confounding factor in their analyses, which is in agreement with a study from Deprez et al. (2012).

Heart rates increase progressively during the Yo-Yo IR1 test, reflecting an increasing oxygen uptake (Bangsbo et al., 2008). Immediately before the start of the Yo-Yo IR1 test, mean heart rates were between 55.5 and 56.7 % of mean peak heart rates. These values are higher than the value reported by Krustrup et al. (2003) immediately before the start of the test (44.4 %). At the end of the test, players reached peak heart rates between 200 and 203 bpm, suggesting these values correspond with (theoretical) maximal heart rates. This was not investigated in the present study, although Krustrup et al. (2003) reported Yo-Yo IR1 peak heart rates corresponding to 99 ± 1 % of maximal heart rate determined by a standardized treadmill test in adults. Moreover, in agreement with Krustrup et al. (2003), additional analyses revealed an inverse correlation between the heart rate at level 15.1 (after 6.7 minutes) and the Yo-Yo IR1 performance (U17: r=-0.79; U15: r=-0.50; U13: r=-0.57). Although, the small number of players in the U17 age group (n=4) should be considered in the interpretation of the present results. Together with the observed decreases in submaximal heart rate (after 6 minutes) during the season, it seems that this relatively low intensity test may also provide useful information about soccer fitness. Whilst further validation of peak heart rates achieved in Yo-Yo IR1 in young soccer players is required, it seems reasonable to suggest that maximal heart rates can be achieved during the YoYo IR1 when young players are motivated to perform maximally. Accordingly, we suggest that, coaches should emphasize the importance of a maximal effort during the test and also provide strong and consistent encouragement throughout.

Players' recovery heart rates were recorded at 1- and 2-min following the Yo-Yo IR1 test, respectively. Notably, the U17-age group showed slightly faster heart rate recovery than the younger age-groups, at both the 1- and 2-min after the test. This improved recovery could be attributed to higher and more soccer-specific training loads, leading to a better soccer-specific intermittent-endurance in older compared to younger age-groups, resulting in the higher capacity to recover after intensive exercises (Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004). Also, due to maturational development processes during adolescence, players' anaerobic capacities are improving into late adolescence, suggesting that players can cope better with intermittent activities (Malina et al., 2004; Philippaerts et al., 2006).

The Yo-Yo IR1 test seems to be reproducible and can be of practical use in the present sample of sub- and non-elite youth soccer players. Although, the typical error, which corresponds with 3.9, 4.3 and 3.1 running bouts and the large range of absolute limits of agreement in the U13, U15 and U17 age groups, respectively, is a possible concern for the coach on the field. Moreover, a longitudinal study in youth soccer players (Roescher et al., 2010) investigating the intermittent endurance capacity (via the Interval Shuttle Run Test; ISRT) showed that that young soccer players who became professional showed a faster improvement than their non-professional counterparts between 14 and 18 years. Therefore, different growth, maturation and development pathways should be considered when evaluating performance improvements or impairments in young individuals.

Many studies already reported the ability of the Yo-Yo IR1 test to discriminate between different levels of competitions in various sports (Bangsbo et al., 2008). The present differences found between players of different competitive levels further support the construct validity of this test for measuring the ability to repeat high intensive intermittent exercise in young soccer players. We do however acknowledge that the small number of sub-elite players in the present study is a limitation.

Conclusion

In summary, the Yo-Yo IR1 test has proven to be adequately reliable in the youngest age groups (U13 and U15) and highly reliable in the oldest players (U17). Additionally, the Yo-Yo IR1 can discriminate between levels in young soccer players, aged 11 to 17 years. No such data were reported in previous studies. Also, the present Yo-Yo IR1 performances established for elite and non-elite players may be used for comparison of other young soccer players in the search for prospective young soccer players.

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STUDY 2

THE YO-YO INTERMITTENT RECOVERY TEST LEVEL 1 IS RELIABLE IN YOUNG, HIGH-LEVEL SOCCER PLAYERS

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Abstract

The aim of the study was to investigate test reliability of the Yo-Yo intermittent recovery test level 1 (YYIR1) in 36 high-level youth soccer players, aged between 13 and 18 years. Players were divided into three age groups (U15, U17 and U19) and completed three YYIR1 in three consecutive weeks. Pairwise comparisons were used to investigate test reliability (for distances and heart rate responses) using technical error (TE), coefficient of variation (CV), intra-class correlation (ICC) and limits of agreement (LOA) with Bland-Altman plots. The mean YYIR1 distances for the U15, U17 and U19 groups were 2024 ± 470 m, 2404 ± 347 m and 2547 ± 337 m, respectively. The results revealed that the TEs varied between 74 and 172 m, CVs between 3.0 and 7.5%, and ICCs between 0.87 and 0.95 across all age groups for the YYIR1 distance. For heart rate responses, the TEs varied between 1 and 6 bpm, CVs between 0.7 and 4.8%, and ICCs between 0.73 and 0.97. The small ratio LOA revealed that any two YYIR1 performances in one week will not differ by more than 9 to 28% due to measurement error. In summary, the YYIR1 performance and the physiological responses have proven to be highly reliable in a sample of Belgian high-level youth soccer players, aged between 13 and 18 years. The demonstrated high level of intermittent endurance capacity in all age groups may be used for comparison of other prospective young soccer players.

Introduction

The Yo-Yo intermittent recovery test level 1 (YYIR1) has been extensively studied in different populations and age groups [1]. Also, the YYIR1 has been described as a valid tool in adult professional [2] and non-elite youth soccer players [3], in soccer referees [4] and in youth handball players [5]. In intermittent sports, such as soccer, where high-intensity activities are interspersed with periods of (active) recovery, the YYIR1 may assist as a valuable tool to measure an athlete's intermittent endurance capacity. Moreover, in recent literature, the YYIR1 has often been used in talent identification and development programmes in youth soccer populations [6,7,8].

Measures of reliability are extremely important in sports sciences [9]. A coach needs to know whether an improvement (in intermittent endurance) is real or due to a large amount of measurement error. For example, Krustrup et al. [2] reported the good test-retest reliability of the YYIR1 (coefficient of variation (CV) of 4.9%) in 13 adult professional soccer players, whilst Thomas et al. [10] found a CV of 8.7% in 18 recreationally active adults. Also, Castagna et. al [11] reported a CV of 3.8% for the YYIR1 in 18 elite youth soccer players (14.4 years) of San Marino. However, the latter study aimed to investigate the direct validity between endurance field tests and match performance, rather than the reliability of the YYIR1.

Recently, a test-retest reliability study by Deprez et al. [3] reported CVs of 17.3, 16.7 and 7.9% in U13 (n = 35), U15 (n = 32) and U17 (n = 11) non-elite youth soccer players, respectively, showing adequate to high reproducibility of the YYIR1. This study was the first to investigate the reliability of the YYIR1 in a large sample of youth soccer players, aged between 12 and 16 years. However, the authors mentioned possible concerns in interpreting the results regarding the protocol used (2 test sessions), the level of the players (sub- and non-elite), and the relatively high coefficients of variation, typical errors and limits of agreement compared with those reported in adults. Therefore, as a consequence of previous findings and similar to the previous study, we conducted a reliability study with three test sessions in high-level youth soccer players, aged between 13 and 18 years. Also, since structured talent identification (and development) programmes are now fundamental at the highest (youth) level for the preparation of future (professional) athletes, information about the reliability of evaluation tools is essential. Consequently, the aim of the study was to investigate test reliability of the YYIR1 performance and physiological responses in high-level youth soccer players.

Materials and Methods

Participants and design

Participants were 76 youth soccer players from one professional Belgian soccer club, aged between 13.1 and 18.5 years, who underwent a high-level soccer training programme (6 training hours and 1 game (on Saturday) per week). All players were assessed for anthropometrical characteristics and three YYIR1 in November 2013. Players were divided into three age groups according to their birth year (U15, U17 and U19) For example, players born in 1999 and 2000 were assigned to the U15 age group. All participants and their parents or legal representatives were fully informed about the aims of the study and written informed consent was obtained. The study was approved by the Ethics Committee of the University Hospital (approval number: EC 2009/572), and was performed in accordance with the ethical standards of the Helsinki Declaration.

Only all youth players who completed three YYIR1 in three consecutive weeks were retained in the analyses (n=36), against which a total of 40 players were excluded (drop-out rate of 53%). As a consequence, 22 players, 10 players and 4 players were retained in age groups U15 (13.9 ± 0.5 years; 162.3 ± 10.3 cm; 47.7 ± 10.1 kg), U17 (16.2 ± 0.6 years; 173.9 ± 4.9 cm; 61.8 ± 8.4 kg) and U19 (18.1 ± 0.4 years; 176.4 ± 7.1 cm; 67.4 ± 5.5 kg), respectively.

The YYIR1 was conducted according to the guidelines described by Krustrup and colleagues [2], each time on Tuesday (November 2013), and started around 6 pm (successively U15 > U17 > U19). All players were familiarized with the YYIR1 (players were part of the Ghent Youth Soccer Project follow-up study [12] and ran at least two YYIR1 before the start of the present study) and were asked to refrain from strenuous training exercise 48 h before each test session. All tests were conducted on the same outdoor location (artificial turf) in dry, windless weather conditions (temperature about 10°C in each test assessment), wearing soccer boots. Participants were given feedback on their performances after completing all three test sessions.

Heart rate (HR) was recorded every second during each test session with a heart rate monitoring system (Polar Team^2 System, Kempele, Finland). The start HR (HR at first beep), the submaximal HR (after level 14.8, circa 90% of maximal HR), the peak HR (highest heart rate recorded), and the recovery HRs after 30 seconds, and 1 and 2 minutes after completing the test were used for analyses. It was found that the heart rates at fixed points during the YYIR1 test (i.e., after 6 and 9 min) were inversely correlated with the YYIR1 performance [2]. However, this relationship was not established after 3 min, suggesting that the test should be longer than 3 minutes. Therefore, the submaximal heart rate after completing level 14 (i.e., after 14.8) was included in the present analyses. This submaximal version corresponds to a total time of exactly 6 minutes and 22 seconds. All heart rates, except for the peak HR (bpm), were expressed as percentage of peak HR.

Statistics

All analyses were performed separately for the three age groups. First, the differences between test sessions were checked for outliers and 3 players were excluded from the analyses (differences were larger than 2 SDs). Test reliability was carried out using pairwise comparisons between the 3 test sessions. Absolute reliability was measured using the typical error (TE = $SD_{diff} / \sqrt{2}$) and coefficient of variation (CV = (TE / grand mean) * 100), and relative reliability was investigated using intra-class correlations (ICC), and considered as *excellent* between 0.75 and 1.00, *good* between 0.41 and 0.74, and *poor* between 0.00 and 0.40 [13]. All reliability calculations (TE, CV and ICC) were accompanied with 90% confidence intervals (CI). In addition, the ratio limits of agreement (LOA) (log transformed data) with Bland and Altman plots were examined to illustrate the differences in YYIR1 performances between test sessions for all age groups together [9,14]. SPSS for Windows (version 20.0) was used for all calculations. All data are presented as mean (*SD*) values.

Results

The grand mean YYIR1 performances for the U15, U17 and U19 age groups were 2024 ± 470 m, 2404 ± 347 m, and 2475 ± 347 m, respectively (***Table 1***). The ICCs for these age groups were considered *excellent* and varied between 0.87 and 0.95. The TEs (and accompanying CVs) for the YYIR1 differences between test sessions 1 and 2 were 137 m (6.8%), 101 m (4.3%) and 107 m (4.1%); between test sessions 2 and 3 were 149 m (7.1%), 77 m (3.1%) and 74 m (3.0%); and between test sessions 1 and 3 were 147 m (7.5%), 126 m (5.4%) and 172 m (6.9%), for age groups U15, U17 and U19, respectively. The ICCs amongst test sessions for all HRs were considered *excellent* and varied between 0.76 and 0.97, except for the recovery HR after 1 minute, which was considered as *good* (ICC = 0.73). ***Table 1*** gives a detailed overview of mean (SD) values for each test session and pairwise comparisons with TEs and CVs.

The 95% ratio LOA between test sessions 1 and 2 were 1.17 */÷ 1.24, 1.09 */÷ 1.13 and 1.02 */÷ 1.11, for age groups U15, U17 and U19, respectively (***Table 2***). Similar analyses between test session 2 and 3 revealed 95% LOA of 0.96 */÷ 1.23, 0.97 */÷ 1.09 and 0.88 */÷ 1.12, for age groups U15, U17 and U19, respectively. Finally, the 95% LOA between test sessions 1 and 3 were 1.13 */÷ 1.28, 1.06 */÷ 1.15, and 0.90 */÷ 1.22 for age groups U15, U17 and U19, respectively. ***Figure 1*** illustrates Bland and Altman plots for the differences between test sessions 1 and 2, test sessions 2 and 3, and test sessions 1 and 3 for all players.

Table 1 *Means (SD) for YYIR1 distance and heart rates for each test moment with pairwise typical errors (TE (90% confidence interval)) and coefficients of variation (CV (90% confidence interval), and grand mean intra-class correlation (ICC (90% confidence interval)) between the three test moments.*

Variable	Age cat.	n	Week 1 mean (SD)	Week 2 mean (SD)	Week 3 mean (SD)	Grand Mean mean (SD)	TE (abs) 1-2 (90% CI)	CV (%) 1-2 (90% CI)	TE (abs) 2-3 (90% CI)	CV (%) 2-3 (90% CI)	TE (abs) 1-3 (90% CI)	CV (%) 1-3 (90% CI)	ICC (90% CI)
YYIR1 (m)	U15	22	1849 (471)	2162 (523)	2062 (409)	2024 (470)	137 (110-184)	6.8 (5.5-9.2)	149 (119-200)	7.1 (5.6-9.5)	147 (118-198)	7.5 (6.0-10.1)	0.92 (0.85-0.96)
	U17	10	2288 (357)	2496 (322)	2428 (360)	2404 (347)	101 (74-167)	4.3 (3.1-7.0)	77 (56-126)	3.1 (2.3-4.8)	126 (92-207)	5.4 (3.9-8.8)	0.95 (0.87-0.98)
	U19	4	2610 (266)	2660 (314)	2370 (415)	2547 (337)	107 (66-312)	4.1 (2.5-11.8)	74 (46-217)	3.0 (1.8-8.6)	172 (106-500)	6.9 (4.3-20.1)	0.87 (0.41-0.99)
HR start (%)	U15	22	53.5 (4.4)	53.8 (4.4)	53.7 (4.1)	53.7 (4.2)	2.2 (1.8-3.0)	2.1 (1.7-2.9)	2.1 (1.7-2.8)	2.0 (1.6-2.7)	1.6 (1.3-2.1)	3.0 (2.4-3.9)	0.95 (0.90-0.97)
	U17	10	49.3 (4.5)	47.9 (4.7)	48.4 (4.9)	48.5 (4.6)	2.2 (1.6-3.6)	2.2 (1.6-3.6)	1.8 (1.3-3.0)	2.2 (1.6-3.6)	0.8 (0.6-1.4)	1.6 (1.2-2.9)	0.97 (0.91-0.99)
	U19	4	45.4 (9.5)	47.0 (10.6)	45.7 (11.0)	46.0 (10.3)	3.2 (2.0-9.3)	3.2 (2.0-9.6)	2.6 (21.6-7.6)	2.9 (1.8-8.7)	2.2 (1.4-6.4)	4.8 (3.1-14.1)	0.97 (0.82-1.00)
HR submax (%)	U15	22	95.4 (2.4)	95.3 (2.1)	95.1 (1.7)	95.3 (1.8)	2.5 (2.0-3.3)	1.3 (1.0-1.8)	2.1 (1.7-2.9)	1.2 (1.0-1.6)	1.1 (0.9-1.5)	1.1 (0.9-1.6)	0.92 (0.86-0.96)
	U17	10	92.8 (3.0)	91.8 (1.5)	92.1 (1.9)	92.3 (1.9)	2.7 (2.0-4.5)	1.5 (1.1-2.5)	1.4 (1.0-2.3)	1.5 (1.1-2.5)	1.7 (1.2-2.8)	1.8 (1.3-3.0)	0.95 (0.87-0.98)
	U19	4	88.1 (2.7)	89.5 (4.3)	90.0 (4.3)	89.2 (3.7)	2.0 (1.2-5.8)	1.1 (0.7-3.3)	2.9 (1.8-8.3)	1.5 (1.0-4.6)	1.2 (0.7-3.4)	1.3 (0.8-3.8)	0.95 (0.72-1.00)
Peak HR ($b.min^{-1}$)	U15	22	202 (6)	200 (6)	201 (6)	201 (6)	2.2 (1.7-2.9)	1.1 (0.9-1.5)	1.7 (1.3-2.2)	0.8 (0.7-1.1)	2.5 (2.0-3.3)	1.2 (1.0-1.6)	0.90 (0.82-0.95)
	U17	10	199 (6)	198 (6)	198 (7)	198 (6)	1.7 (1.2-2.8)	0.8 (0.6-1.4)	1.7 (1.2-2.8)	0.8 (0.6-1.4)	2.3 (1.7-3.8)	1.5 (0.9-1.9)	0.94 (0.86-0.98)
	U19	4	202 (11)	198 (9)	198 (8)	199 (9)	2.9 (1.8-8.3)	1.4 (0.9-4.1)	1.5 (0.9-4.3)	0.7 (0.5-2.2)	3.2 (2.0-9.3)	1.6 (1.0-4.7)	0.93 (0.62-1.00)
HR rec 30" (%)	U15	22	93.0 (2.9)	93.1 (2.3)	93.1 (2.3)	93.1 (2.2)	3.4 (2.7-4.5)	1.8 (1.5-2.5)	2.4 (1.9-3.2)	1.3 (1.0-1.7)	1.6 (1.3-2.2)	1.7 (1.4-2.4)	0.76 (0.60-0.87)
	U17	10	94.1 (2.3)	93.6 (1.7)	94.4 (1.2)	94.0 (1.4)	4.0 (2.9-6.6)	2.1 (1.6-3.5)	2.8 (2.1-4.6)	2.1 (1.6-3.5)	1.3 (0.9-2.1)	1.4 (1.0-2.2)	0.80 (0.56-0.93)
	U19	4	94.2 (1.2)	94.3 (1.5)	93.7 (1.4)	94.1 (1.1)	3.2 (2.0-9.4)	1.8 (1.1-5.3)	3.0 (1.8-8.7)	1.7 (1.0-5.0)	1.0 (0.6-2.9)	1.1 (0.6-3.1)	0.92 (0.58-0.99)
HR rec 1' (%)	U15	22	81.6 (5.2)	81.8 (4.7)	82.6 (4.3)	82.0 (4.2)	5.2 (4.4-7.3)	3.6 (2.9-4.9)	5.3 (4.2-7.1)	3.4 (2.7-4.6)	3.1 (2.5-4.2)	3.8 (3.0-5.1)	0.73 (0.56-0.85)
	U17	10	81.9 (6.6)	80.5 (4.9)	81.4 (5.1)	81.2 (5.3)	4.7 (3.4-7.7)	2.7 (2.0-4.5)	4.9 (3.6-8.1)	2.7 (2.0-4.5)	2.4 (1.8-3.9)	2.9 (2.2-4.8)	0.91 (0.79-0.97)
	U19	4	84.0 (1.7)	83.8 (2.2)	80.7 (1.4)	82.8 (0.5)	5.3 (3.3-15.4)	3.3 (2.0-10.0)	3.4 (2.4-11.3)	2.3 (1.4-6.9)	1.9 (1.2-5.7)	2.3 (1.5-6.9)	0.81 (0.26-0.99)
HR rec 2' (%)	U15	22	69.4 (5.6)	69.1 (5.9)	70.6 (4.8)	69.7 (5.1)	3.0 (2.4-4.0)	2.3 (1.9-3.1)	4.8 (3.9-6.5)	3.6 (2.9-4.9)	2.9 (2.4-4.0)	4.1 (3.4-5.7)	0.89 (0.80-0.94)
	U17	10	67.5 (7.0)	66.0 (7.4)	66.6 (7.0)	66.7 (6.9)	3.8 (2.7-6.2)	2.9 (2.1-4.8)	5.8 (4.3-10.0)	2.9 (2.1-4.8)	2.5 (1.8-4.0)	3.7 (2.7-5.8)	0.93 (0.83-0.98)
	U19	4	70.5 (6.0)	71.2 (5.8)	68.1 (3.3)	69.9 (4.9)	3.3 (2.1-9.7)	2.5 (1.6-7.6)	4.9 (3.0-14.2)	3.1 (1.9-9.2)	2.2 (1.4-6.4)	3.2 (2.0-9.2)	0.91 (0.55-0.99)

Table 2 *Sample size, measurement means and differences (log transformed), the ratio limits of agreement with the limit range, and correlations between the absolute differences and the mean.*

	Log transformed YYIR1 measurements						
	n	*Week 1*	*Week 2*	*Difference (SD)*	*Ratio limits*	*Range*	*Correlation (Abs (diff) v mean)*
U15	22	7.489	7.647	0.157 (0.111)	1.17 */÷ 1.24	0.94 to 1.45	0.98
U17	10	7.724	7.815	0.091 (0.063)	1.09 */÷ 1.13	0.96 to 1.23	0.98
U19	4	7.863	7.881	0.017 (0.053)	1.02 */÷ 1.11	0.92 to 1.13	0.97
	n	*Week 2*	*Week 3*	*Difference (SD)*	*Ratio limits*	*Range*	*Correlation (Abs (diff) v mean)*
U15	22	7.647	7.611	-0.036 (0.104)	0.96 */÷ 1.23	0.78 to 1.18	0.31
U17	10	7.815	7.784	-0.030 (0.045)	0.97 */÷ 1.09	0.89 to 1.06	-0.29
U19	4	7.881	7.759	-0.122 (0.056)	0.88 */÷ 1.12	0.79 to 0.99	-0.96
	n	*Week 1*	*Week 3*	*Difference (SD)*	*Ratio limits*	*Range*	*Correlation (Abs (diff) v mean)*
U15	22	7.489	7.611	0.121 (0.125)	1.13 */÷ 1.28	0.88 to 1.45	-0.22
U17	10	7.724	7.784	0.070 (0.072)	1.06 */÷ 1.15	0.92 to 1.22	0.03
U19	4	7.863	7.759	-0.104 (0.103)	0.90 */÷ 1.22	0.74 to 1.10	-0.64

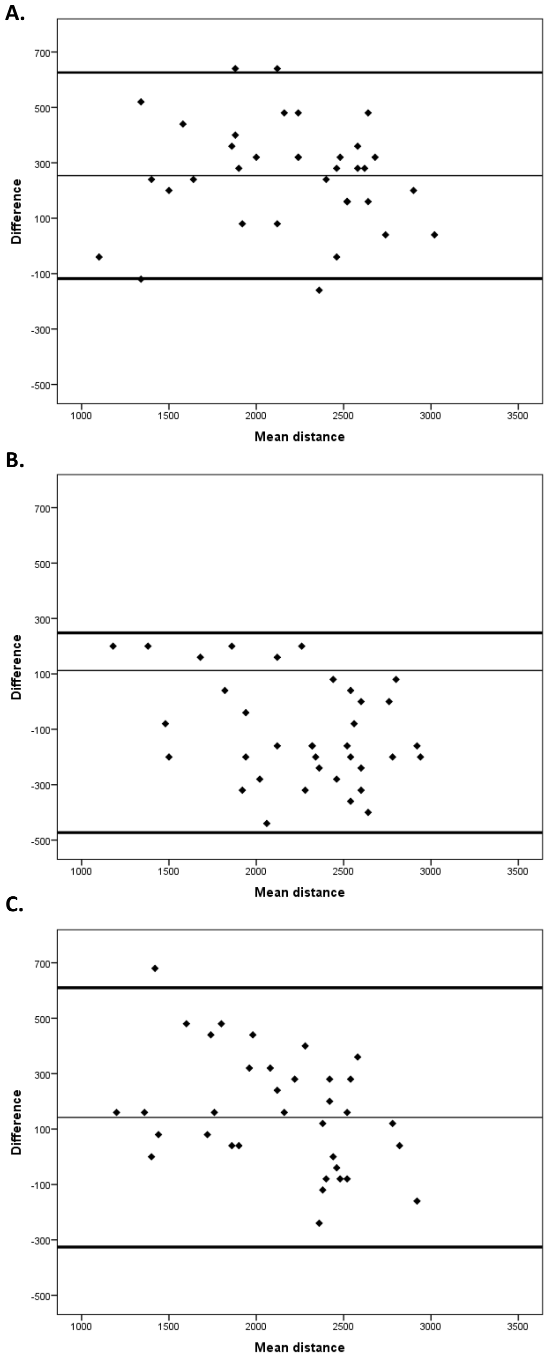

Figure 1 *Bland and Altman plots with 95% LOA for the total sample (n=36) between (**A**) test sessions 1 and 2, (**B**) test sessions 2 and 3, and (**C**) test sessions 1 and 3.*

Discussion

The present study investigated the test reliability of the YYIR1 performance in 36 Belgian high-level youth soccer players, aged between 13 and 18 years. Therefore, three test sessions in three consecutive weeks were conducted. Overall, it emerged from the results that the YYIR1 is highly reproducible with CVs between 3.0 and 7.5% over all age groups. Also, excellent relative reliability was found within each age group for YYIR1 performance (ICCs between 0.87 and 0.95). Additionally, the physiological responses have also been found to be highly reliable. The present results encourage the use of the YYIR1 to assess and evaluate the intermittent endurance capacity in high-level youth soccer players. Also, age-specific reference values of the present soccer sample may be useful to trainers and coaches in the development and evaluation processes.

The YYIR1 performances of the present high-level youth soccer population demonstrated the high level of intermittent endurance capacity when compared with elite youth soccer players of San Marino, Croatia and Belgium, who performed between 400 and 2219 m from U15 to U19 age groups [6], [7], [8]. Therefore, it could be hypothesized that the present youth soccer sample is subjected to training stimuli which greatly focus on the development of the intermittent endurance capacity, therefore explaining the high level of YYIR1 performances. Consequently, the present data could serve as reference values or standards for a youth soccer sample in a high-level soccer development programme. However, we do acknowledge that the small number of U19 players is a limitation of the present study. Sample size calculations for a minimal detectable change of 94 m (0.2 times the between-subject standard deviation) with similar typical errors between 74 and 172 m revealed a minimum of 10 and 37 players, respectively [15]. Additionally, data concerning biological maturation (predicted years from peak height velocity via Mirwald et al. [16]) were deliberately excluded, although available, for the reasons that (1) the YYIR1 performance is relatively little influenced by the maturational status of the player [8], and (2) the YYIR1 performances according to the players' biological maturation were not the focus of the present study. Moreover, the use of the maturity offset protocol is only justifiable in the U15 and U17 age groups and not in the U19 age group, as the age range within which the equation can be used confidently is 9.8 to 16.8 years [16].

The present results demonstrated the high degree of reproducibility of the YYIR1 distance (ICCs between 0.87 and 0.95; CVs between 3.0 and 7.5%) in youth soccer players, aged between 13 and 18 years. Studies investigating the YYIR1 test-retest reliability revealed CVs of 4.9% and 8.7% in 13 adult professional soccer players and 18 recreationally active adults, respectively [2], [10]. However, as today the YYIR1 is well established in talent identification and development programmes [6], [7], [8], little information about the YYIR1 reliability is known in young high-level soccer players. However, Deprez et al. [3] reported in non-elite youth soccer players CVs of 17.3%, 16.7% and 7.9% in age groups U13, U15 and U17, respectively, which suggests that the YYIR1 test is more reliable in a high-level youth soccer population.

The small ratio LOA revealed that any two YYIR1 performances in one week will not differ by more than 9 to 28% due to measurement error across all age groups. The highest agreement was found between test 2 and 3 for the U17 age group (small bias: 0.97, and excellent agreement ratio: 1.09). The worst agreements were found between test sessions 1 and 2, and between test sessions 1 and 3 for the U15 age group (biases: 1.17 and 1.13, and agreement ratios: 1.24 and 1.28) which could indicate that the youngest players had the least experience with the YYIR1 or benefit/improve the most from the physical overload in the first test session during the last two sessions. Moreover, the bias between test moment 2 and 3 for the U15 age group was significantly lower (0.96) but with a similar agreement ratio (1.23), accounting for the larger variation in YYIR1 performance (reflected by larger standard deviations) and shorter distances run in comparison with the older age groups. Also, the typical errors in the U15 age group (137 to 149 m, which corresponds with approximately 3.5 running bouts) were remarkably higher than those in the U17 (77 to 126 m) and U19 age group (74 to 107 m, except for the TE between test sessions 1 and 3: 172 m) which corresponds to approximately 2 to 2.5 running bouts. It seems possible that the grand mean YYIR1 performance of 2024 m (± level 18.8) for a typical U15 player could decrease to 1884 m (± level 18.4) or improve to 2164 m (± level 19.3) within one week. This largest performance range in the present study is likely to be of great practical application for coaches on the field and seems acceptable by sport scientists involved in exercise or performance testing.

The HRs during the YYIR1 progressively increased and reached mean peak HRs of 201, 198 and 198 bpm for the U15, U17 and U19 age groups, respectively, which corresponds to the athlete's maximal HR on the condition that players were motivated to perform maximally [2]. Also, the submaximal HRs, expressed as percentage of peak HR, varied between 89.2 and 95.3%, and were inversely correlated with the mean YYIR1 distance ($r = -0.64$, -0.63 and -0.53 for the U15, U17 and U19 age groups, respectively). Together with the observations of Krustrup et al. [2] that the submaximal HRs during the season were lower than those measured during the preseason, it seems that the YYIR1 is appropriate to measure changes in physical fitness without using the test to maximal exhaustion. Further, players' recovery HRs were very similar between all age groups and were approximately 94, 81 and 69% of peak HR, 30 seconds, 1 and 2 minutes after the end of the test, respectively. The present recovery HRs are slightly higher than those reported by Krustrup and colleagues [2], who found recovery HRs after 1 and 2 minutes of 79.1 and 64.7%, respectively. This improved recovery in professional adult soccer players could be attributed to higher and more soccer-specific training loads, leading to a better soccer-specific intermittent endurance capacity, resulting in a higher capacity to recover after intensive efforts [17].

Additionally, small absolute TEs (between 1.4 and 5.8 bpm) and CVs (between 0.7 and 4.8%) with high ICCs (between 0.73 and 0.97) for all physiological responses were observed between test moments, resulting in the high reproducibility of HR measurements during the YYIR1 test. This finding might encourage coaches to survey the players' HRs with the aim of monitoring improvements or decrements in physical fitness during a competitive soccer season.

Conclusions

In summary, the typical error, coefficients of variation, intra-class correlations and ratio limits of agreement were used to investigate test reliability of the YYIR1 test. The YYIR1 performance and all physiological responses have proven to be highly reliable in a sample of Belgian elite youth soccer players, aged between 13 and 18 years. The demonstrated high level of intermittent endurance capacity in all age groups may be used as reference values in well-trained adolescent soccer players.

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STUDY 3

A LONGITUDINAL STUDY INVESTIGATING THE STABILITY OF ANTHROPOMETRY AND SOCCER-SPECIFIC ENDURANCE IN PUBERTAL HIGH-LEVEL YOUTH SOCCER PLAYERS

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Abstract

Objectives: We investigated the evolution and stability of anthropometrical characteristics and soccer-specific endurance of 42 high-level, pubertal soccer players with *high*, *average* and *low* yo-yo intermittent recovery test level 1 (YYIR1) baseline performances over two and four years. *Methods*: The rates of improvement were calculated for each performance group, and intra-class correlations were used to verify short- and long-term stability. *Results*: The main finding was that after two and four years, the magnitudes of the differences at baseline were reduced, although players with high YYIR1 baseline performance still covered the highest distance (e.g., *low* from 703 m to 2126 m; *high* from 1503 m to 2434 m over four years). Furthermore, the YYIR1 showed a high stability over two years (ICC = 0.76) and a moderate stability over four years (ICC = 0.59), due to large intra-individual differences in YYIR1 performances over time. Anthropometry showed very high stability (ICCs between 0.94 to 0.97) over a two-year period, in comparison with a moderate stability (ICCs between 0.57 and 0.75) over four years. *Conclusions*: These results confirm the moderate-to-high stability of high-intensity running performance in young soccer players, and suggest that the longer the follow-up, the lower the ability to predict player's future potential in running performance. They also show that with growth and maturation, poor performers might only partially catch up their fitter counterparts between 12 and 16 years.

Introduction

Over the past two decades, research in the domain of talent identification and development in youth soccer has grown exponentially. Anthropometry, motor coordination and physical performance measures (i.e., explosivity, speed and endurance) have shown to be discriminative between successful and less successful youth soccer players (Vaeyens et al., 2006; Figueiredo et al., 2009), and are thought to be predictive for future adult soccer success (Le Gall et al., 2010; Gonaus and Müller, 2012). Biological maturation confounds these identification and selection processes as late maturing players are systematically excluded as age and sports specialization increase (Malina et al., 2000).

Longitudinal designs are necessary in defining pathways to excellence and maturational status should be considered when evaluating young athletes (Malina et al., 2000; 2004; Vaeyens et al., 2008). For example, Philippaerts et al. (2006) showed that the average age at peak height velocity (13.8 ± 0.8 years) in 33 male youth soccer players was slightly earlier compared to the general population (between 13.8 and 14.2 years). Also, corresponding data for peak oxygen uptake indicated that maximal gains occur at the time of peak height velocity, with continued improvements during the late adolescence (Mirwald and Bailey, 1986). It seems that around the age of 14 years, maturational status has a critical impact on the development of physiological characteristics in pubertal athletes, and has therefore strong implications for talent identification and development programs (Baxter-Jones et al., 1993). A field test, measuring the ability to (quickly) recover between repeated intensive efforts (e.g., sprinting, tackling, jumping) is the Yo-Yo Intermittent Recovery Test Level 1 (YYIR1) that maximizes the aerobic energy system through intermittent exertion (Krustrup et al., 2003). Previous studies both in youth and adult soccer have shown that the Yo-Yo IR1 performance has an adequate to high level of reproducibility (Krustrup et al., 2003; Deprez et al., 2014) and is a valid measure of prolonged, high intensity intermittent running capacity (Sirotic and Coutts, 2007).

When predicting future success at young age, it is important to know whether anthropometrical and physical performances measures are stable on the long-term. This refers to the consistency of the position or rank of individuals in the group relative to others. A review by Beunen and Malina (1988) showed, that in the general population, the stability of physical fitness was moderate (Maia et al., 2003) to good (Maia et al., 2001) throughout adolescence. They also reported that individuals who performed well for their maturity level during adolescence had a good chance of still performing above average at the age of 30 (Lefevre et al., 1990). In contrast however, within a general sporting population, the best performing players at young age might not remain the best over one year, accounting for poor long-term stability (Abbott and Collins, 2002). Recently, a longitudinal study in 80 pubertal soccer players showed high stability (ICC's: 0.91 to 0.96) for anthropometry, moderate stability (ICC's: 0.66-0.71) for sprint, speed and explosive leg power and high stability for maximal aerobic speed (ICC: 0.83) (Buchheit and Mendez-Villanueva, 2013).

However, to date, no such data are available in youth soccer for the intermittent-endurance performance. Therefore, the aim of the present study is to examine the changes in body dimensions and YYIR1 performance in high-level pubertal youth soccer players over two-to-four years. More precisely, we examined whether the baseline values could influence the magnitude of improvement, and whether this improvement is related to the maturational status.

Methods

Subjects and study design

A longitudinal study design was conducted over a two- and four-year-period. Subjects were 42 young high-level pubertal soccer players from two Belgian professional soccer clubs, aged between 11 and 16 years. All players participated in a high-level training program with minimal 7.5 training hours and 1 game (on Saturday) per week. The two-year follow-up subsample included 21 soccer players, aged 13.2 ± 0.3 y at the baseline, who were assessed annually, each time at the end of August (a total of three test moments). In addition, the four-year follow-up subsample included 21 players, aged 12.2 ± 0.3 y at baseline, who were assessed every second year, each time at the end of August (a total of three test moments). All subjects and their parents or legal representatives were fully informed about the aim and the procedures of the study before giving their written informed consent. The study was carried out in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the University Hospital.

Anthropometric measures

Stature (0.1 cm, Harpenden Portable Stadiometer, Holtain, UK), sitting height (0.1 cm, Harpenden sitting height table, Holtain, UK) and body mass (0.1 kg, total body composition analyzer, TANITA BC-420SMA, Japan) were assessed according to manufacturer guidelines. Leg length was calculated by subtracting sitting height from stature. All anthropometric measures were taken by the same investigator to ensure test accuracy and reliability. For height, the intra-class correlation coefficient for test-retest reliability and technical error of measurement (test-retest period of one hour) in 40 adolescents were 1.00 ($p < 0.001$) and 0.49 cm, respectively.

Maturity status

An estimation of maturity status was calculated using equation 3 from Mirwald et al. (2002) for boys. This non-invasive method predicts years from peak height velocity as the maturity offset, based on anthropometric variables (height, sitting height, weight, leg length). Subsequently, the age at peak height velocity (APHV) is determined as the difference between the chronological age and the maturity offset. According to Mirwald et al. (2002), this equation accurately estimates the APHV within an error of ±1.14 years in 95% of the cases in boys, derived from three longitudinal studies on children who were four years from and three years after peak height velocity (i.e., 13.8 years). Accordingly, the age range from which the equation confidently can be used is between 9.8 and 16.8 years, which matches with the present age range (11.7-16.7 y).

High intensity intermittent running performance

High intensity intermittent running performance was investigated using the YYIR1. This test was conducted according to the methods of Krustrup et al. (2003). Participants were instructed to refrain from strenuous exercise for at least 48 hours before the test sessions and to consume their normal pre-training diet before the test session. All tests were conducted on the same indoor venue with standardized environmental conditions. Players completed the YYIR1 test with running shoes and followed a standardized warm-up. To investigate the effect of baseline high intensity intermittent running performance on its changes over the years, players in each subsample were divided into three performance groups according to their YYIR1 performance at baseline: players which YYIR1 performance was below percentile 33 (P33) were classified as '*low*', between P33 and P66, as '*average*' and above P66, as '*high*'.

The YYIR1 test showed good test-retest reliability in 13 adult male experienced soccer players (CV of 4.9 %) and in 16 recreational adults (CV of 8.7 %), respectively (Krustrup et al., 2002; Thomas et al., 2006). Recently, in a non-elite youth soccer population, Deprez and colleagues (2014) reported a CV of 17.3%, 16.7 % and 7.9 % for the YYIR1 test in under-13 (n=35), under-15 (n=32) and under-17 (n=11) age groups, respectively, showing adequate to good reliability. However, of importance in interpreting differences between measures, it is not the CV of a measure that matters, but the magnitude of this 'noise' compared with (1) the usually observed changes (signal) and (2) the changes that may have a practical effect (smallest worthwhile difference) (Hopkins, 2004). A measure showing a large CV, but which responds largely to training can actually be more sensitive and useful than a measure with a low CV but poorly responsive to training. The greater the signal-to-noise ratio, the likely greater the sensitivity of the measure.

Statistical analysis

All statistical analyses were completed using SPSS for windows (version 20.0). First, for each of the two subsamples (two- and four-year follow-up, respectively) differences between the three performance groups (*low*, *average* and *high*) were investigated using multivariate analysis of variance (MANOVA) with performance group as independent and age, maturity offset, stature, body mass and YYIR1 as dependent variables. After running normality tests (Shapiro-Wilk) for all dependent variables in each performance group (in both two- and four-year subsamples), the data passed the assumption of normality (p-values between 0.058 and 0.855) (except for MatOffSet ($p=0.019$) in the low performance, four-year subsample group). Since MANOVA revealed a significant main effect (Wilks' Lambda) in both the two- ($F=15.517$; $p<0.001$) and four-year subsample ($F=9.639$; $p<0.001$), test of between-subject effects were further analyzed for its significance ($p<0.05$) and Bonferroni *post hoc* tests were performed where appropriate. Also, Cohen's *d* effect sizes were calculated to estimate the magnitude of the differences between each performance group. Thresholds were 0.2, 0.6, 1.2, 2.0 and 4.0 for trivial, small, moderate, large, very large and extremely large, respectively (Hopkins et al., 2008).

Next, for the two- and four-year follow-up subsamples, the changes in stature, body mass and YYIR1 between each test moment for each performance group were expressed as percentages. Also, for each subsample, the rates of improvement (ROI) were calculated for each performance group. A players' rate of improvement (=*attained* ROI) is compared to the rate of improvement of a typical peer (=*benchmark* ROI, based on the mean performance) and is one of the factors considered in determining whether a player (either belonging to the *low*, *average* or *high* group) has made adequate progress. The *target* ROI is defined as the rate of improvement a player should realize to end up as a typical player. For example, the *low* players' rate of improvement must be greater than the rate of improvement of a typical player (=*target* ROI) in order to "close the gap" and shift to an *average* level of performance (Shapiro, 2008). The ROI was expressed as the number of meters per year (m/y) that players improved from baseline to the end of the present study.

Finally, intra-class correlations (ICC) for maturity offset, stature, body mass and YYIR1 performance were calculated to investigate the two- and four-year stability, respectively. The use of the ICC is the only sensible approach to compute an average correlation between more than two trials, and is calculated as ((SD^2 - typical $error^2$) / SD^2) where SD is the between-subject standard deviation and the typical error is the within-subject standard deviation (Hopkins, 2000). According to the thresholds of Hopkins et al. (2008) we considered an ICC larger than 0.99 as *extremely high*, between 0.90 and 0.99 as *very high*, between 0.75 and 0.90 as *high*, between 0.50 and 0.75 as *moderate*, between 0.20 and 0.50 as *low* and lower than 0.20 as *very low*. All results are presented as means (SD) and 95% confidence intervals (CI), and minimal statistical significance was set at $p<0.05$.

Results

Within the two-year follow-up subsample, there was no significant performance group difference, at each test moment, for chronological age (MANOVA: F=1.113; p=0.336) and maturity offset (after post hoc tests, MANOVA: F=7.824; p=0.001), reflected by *trivial* to *small* effect sizes (0.00 to 0.24). For stature (MANOVA: F=15.762; p<0.001) and body mass (MANOVA: F=13.302; p<0.001), at each test moment, *high* players was were significant smaller (*large* ES between 1.28 and 1.82) and leaner (*moderate* to *large* ES between 1.19 and 1.81) compared with *low* and *average* players. Also, the YYIR1 performance (MANOVA: F=42.235; p<0.001) was significantly different between all performance groups at each test moment (*moderate* to *extremely large* effect sizes) with the following order: *high* > *average* > *low* (***Table 1***).

Table 1 *Descriptives and differences between low-, average- and high-YYIR1 performance groups and effect by 2- and 4-year follow-up subsamples.*

		Grand mean (n=21)		*low* (n=7)		*average* (n=7)		*high* (n=7)		ANOVA*		Cohen's *d*		
2-year follow-up	**Test**	**Mean (SD)**	**95% CI**	**Mean (SD)**	**95% CI**	**Mean (SD)**	**95% CI**	**Mean (SD)**	**95% CI**	**F-value**	***P-Value***	**Low-Average**	**Average-High**	**Low-High**
Age (y)	1	13.2 (0.3)	± 0.1	13.2 (0.2)	± 0.1	13.1 (0.4)	± 0.2	13.2 (0.2)	± 0.1	-	-	0.00	0.00	0.11
	2	14.2 (0.3)	± 0.1	14.2 (0.2)	± 0.1	14.1 (0.4)	± 0.2	14.2 (0.2)	± 0.1	-	-	0.24	0.24	0.12
	3	15.2 (0.3)	± 0.1	15.2 (0.2)	± 0.1	15.2 (0.3)	± 0.1	15.2 (0.2)	± 0.1	-	-	0.24	0.24	0.24
Maturity OffSet (y)	1	-0.85 (0.51)	± 0.12	-0.76 (0.46)	± 0.18	-0.60 (0.49)	± 0.20	-1.20 (0.43)	± 0.17	3.287	*0.061*	0.16	0.09	0.11
	2	0.14 (0.72)	± 0.16	0.27 (0.58)	± 0.23	0.44 (0.76)	± 0.30	-0.29 (0.69)	± 0.28	2.181	*0.142*	0.08	0.06	0.08
	3	1.17 (0.70)	± 0.16	1.36 (0.49)	± 0.20	1.45 (0.85)	± 0.34	0.70 (0.52)	± 0.21	2.849	*0.084*	0.07	0.03	0.03
Stature (cm)	1	157.8 (6.5)	± 1.5	158.4 (3.6)	± 1.4	162.2 (6.5)	± 2.6	152.8 (5.6)	± 2.2	5.432	*0.014*$^{\Sigma}$	0.78	1.67	1.28
	2	164.8 (7.5)	± 1.7	165.7 (3.8)	± 1.5	169.8 (7.8)	± 3.1	159.0 (6.4)	± 2.6	5.294	*0.016*$^{\Sigma}$	0.72	1.64	1.38
	3	171.1 (6.5)	± 1.5	172.8 (2.9)	± 1.2	174.6 (7.3)	± 2.9	165.7 (5.2)	± 2.1	5.272	*0.016*$^{\Sigma}$	0.35	1.52	1.82
Body mass (kg)	1	46.0 (6.8)	± 1.6	48.2 (6.6)	± 2.6	49.3 (5.5)	± 2.2	40.5 (5.0)	± 2.0	4.863	*0.020*$^{\Sigma}$	0.20	1.81	1.42
	2	52.7 (8.7)	± 2.0	54.6 (7.6)	± 3.0	57.0 (8.0)	± 3.2	46.2 (7.6)	± 3.0	3.592	*0.049*$^{\Sigma}$	0.33	1.50	1.19
	3	59.3 (8.8)	± 2.0	62.5 (7.7)	± 3.1	63.5 (7.9)	± 3.2	52.0 (6.3)	± 2.5	5.312	*0.015*$^{\Sigma}$	0.14	1.74	1.61
YYIR1 (m)	1	1319 (366)	± 83	886 (114)	± 46	1357 (100)	± 40	1714 (145)	± 58	82.471	*<0.001*$^{\#}$	4.74	3.10	6.86
	2	1705 (371)	± 85	1366 (360)	± 144	1823 (231)	± 92	1926 (265)	± 106	7.386	*0.005*$^{\#}$	1.63	0.45	1.91
	3	1823 (427)	±97	1411 (252)	± 101	1920 (414)	± 166	2137 (220)	± 88	10.296	*0.001*$^{\#}$	1.60	0.71	3.32

		Grand mean (n=21)		*low* (=7)		*average* (n=7)		*high* (n=7)		ANOVA*		Cohen's *d*		
4-year follow-up	**Test**	**Mean (SD)**	**95% CI**	**Mean (SD)**	**95% CI**	**Mean (SD)**	**95% CI**	**Mean (SD)**	**95% CI**	**F-value**	***P-value***	**Low-Average**	**Average-High**	**Low-High**
Age (y)	1	12.2 (0.3)	± 0.1	12.3 (0.3)	± 0.2	12.2 (0.4)	± 0.3	12.2 (0.2)	± 0.2	-	-	0.31	0.00	0.42
	2	14.2 (0.3)	± 0.1	14.3 (0.3)	± 0.2	14.2 (0.4)	± 0.3	14.2 (0.2)	± 0.2	-	-	0.31	0.00	0.42
	3	16.2 (0.3)	± 0.1	16.3 (0.3)	± 0.2	16.3 (0.4)	± 0.3	16.1 (0.3)	± 0.2	-	-	0.00	0.61	0.72
Maturity OffSet (y)	1	-1.72 (0.34)	± 0.15	-1.54 (0.33)	± 0.24	-1.83 (0.38)	± 0.28	-1.80 (0.28)	± 0.21	-	-	0.88	0.10	0.92
	2	0.28 (0.61)	± 0.26	0.57 (0.50)	± 0.37	0.04 (0.83)	± 0.61	0.23 (0.36)	± 0.27	-	-	0.84	0.32	0.84
	3	2.14 (0.47)	± 0.20	2.28 (0.23)	± 0.17	2.11 (0.63)	± 0.47	2.04 (0.52)	± 0.39	-	-	0.39	0.13	0.64
Stature (cm)	1	150.7 (3.6)	± 1.5	152.5 (1.8)	± 1.3	149.9 (3.4)	± 2.5	149.7 (4.8)	± 3.6	-	-	1.03	0.05	0.83
	2	165.2 (5.2)	± 2.2	167.8 (4.6)	± 3.4	163.3 (5.6)	± 4.2	164.5 (4.9)	± 3.6	-	-	0.95	0.25	0.75
	3	174.6 (3.9)	± 1.7	175.8 (4.1)	± 3.0	174.3 (2.8)	± 2.1	173.8 (4.8)	± 3.6	-	-	0.46	0.14	0.48
Body mass (kg)	1	39.5 (4.4)	± 1.9	42.3 (5.0)	± 3.7	37.9 (4.2)	± 3.7	38.4 (2.8)	± 2.1	2.375	*0.121*	1.03	0.15	1.04
	2	52.3 (7.2)	± 3.1	57.5 (8.7)	± 6.4	48.5 (5.7)	± 6.4	50.7 (3.6)	± 2.7	3.781	*0.043*$^{\infty}$	1.32	1.10	0.15
	3	62.9 (5.1)	± 2.2	66.7 (6.5)	± 4.8	60.7 (3.0)	± 4.8	61.2 (3.1)	± 2.3	3.732	*0.044*$^{\infty}$	1.28	0.18	1.17
YYIR1 (m)	1	1090 (367)	± 157	703 (224)	± 166	1063 (128)	± 95	1503 (83)	± 61	45.947	*<0.001*$^{\#}$	2.13	4.41	5.12
	2	1749 (406)	± 174	1686 (194)	± 144	1384 (311)	± 230	2177 (202)	± 150	19.281	*<0.001*$^{\Sigma}$	1.26	3.27	2.68
	3	2175 (338)	± 145	2126 (373)	± 276	1966 (218)	± 161	2434 (248)	± 184	4.801	*0.021*$^{\Sigma}$	0.57	2.17	1.05

SD=standard deviation; CI=confidence interval *one-way analysis of variance (ANOVA) with Bonferroni post-hoc test was performed if multivariate analysis of variance (MANOVA) for each variable revealed significant differences between performance groups. MANOVA revealed non-significant main effects for age in the 2-year subsample ($F=1.113$; $p=0.336$), for age ($F=0.726$; $p=0.489$), maturity offset ($F=2.736$; $p=0.074$) and stature ($F=3.031$;$p=0.057$) in the 4-year subsample.*

[#] significant differences between all performance groups; [∞] Low is different from Average; [Σ] high is different from low and average

Regarding the four-year follow-up subsample, no significant differences were found at each test moment for chronological age (MANOVA: F=0.726; p=0.489), maturity offset (MANOVA: F=2.736; p=0.074)and stature (MANOVA: F=3.031; p=0.057) (*trivial* to *moderate* ES between 0.00 and 1.03). For body mass, *low* players had a higher body mass compared with *average* players at the second (57.5 ± 8.7 kg vs. 48.5 ± 5.7 kg; *large* ES = 1.32) and third test moment (66.7 ± 6.5 kg vs. 60.7 ± 3.0 kg; *large* ES = 1.28). At each test moment, *high* players showed the best YYIR1 performance compared with *low* and *average* players, reflected by *moderate* to *extremely large* ES (between 1.05 and 5.12) (***Table 1***). Two-year follow-up analyses revealed similar increases in both stature and body mass in all performance groups (for stature about 7.8 %, for body mass about 27.0 %). The increase in YYIR1 performance in *low* players after the first two-year period was the highest compared with *average* and *high* players (i.e., 97.1 %, 39.1 % and 25.3 %, respectively) (***Table 2***). Over the overall four-year period, the increase for stature was about 16.0 %, whilst the increase for body mass was about 60.0 % across all performance groups. Also, the increase in YYIR1 performance in *low* players was the highest compared with *average* and *high* players (i.e., 235.7 %, 86.8 % and 62.2 %, respectively) (***Table 2***).

Table 2 *Percent change and correlations between the three test moments for stature, body mass andYYIR1 within all performance groups by 2- and 4-year follow-up subsamples.*

		low **(n=7)**			***average*** **(n=7)**			***high*** **(n=7)**		
2-year follow-up	**Test**	**Mean**	**SD**	**95% CI**	**Mean**	**SD**	**95% CI**	**Mean**	**SD**	**95% CI**
Stature (%)	1-2	4.3	1.4	± 0.6	4.2	1.2	± 0.5	4.2	1.5	± 0.6
	2-3	3.4	1.5	± 0.6	3.4	1.8	± 0.7	3.4	1.8	± 0.7
	1-3	7.9	2.6	± 1.0	7.8	2.5	± 1.0	7.8	3.0	± 1.2
Body mass (%)	1-2	14.1	6.3	± 2.5	14.1	5.2	± 2.0	13.3	5.4	± 2.2
	2-3	12.0	5.2	± 2.1	12.2	5.3	± 2.0	11.7	7.2	± 2.9
	1-3	27.8	8.9	± 3.6	28.0	9.2	± 3.5	26.7	11.1	± 4.4
YYIR1 (%)	1-2	70.6	75.4	± 30.2	17.2	21.3	± 8.2	11.7	19.2	± 7.7
	2-3	18.5	30.0	± 12.0	22.2	25.9	± 10.0	15.2	23.0	± 9.2
	1-3	97.1	91.7	± 36.7	39.1	23.8	± 9.2	25.3	14.0	± 5.6
		low **(n=7)**			***average*** **(n=7)**			***high*** **(n=7)**		
4-year follow-up	**Test**	**Mean**	**SD**	**95% CI**	**Mean**	**SD**	**95% CI**	**Mean**	**SD**	**95% CI**
Stature (%)	1-2	10.0	2.1	± 1.6	9.0	2.3	± 1.7	9.9	2.7	± 2.0
	2-3	4.8	3.3	± 2.4	6.8	2.9	± 2.2	5.7	2.2	± 1.6
	1-3	15.3	3.2	± 2.4	16.4	2.7	± 2.0	16.2	2.7	± 2.0
Body mass (%)	1-2	35.7	9.6	± 7.1	28.3	7.7	± 5.7	32.2	8.4	± 6.2
	2-3	17.3	12.5	± 9.3	26.0	9.6	± 7.1	21.2	8.6	± 6.4
	1-3	58.8	16.4	± 12.2	61.2	10.2	± 7.6	59.9	12.2	± 9.0
YYIR1 (%)	1-2	170.7	118.1	± 87.5	30.3	27.5	± 20.4	45.2	15.3	± 11.3
	2-3	25.7	13.3	± 9.9	47.2	30.6	± 22.7	11.9	6.2	± 4.6
	1-3	235.7	132.7	± 98.3	86.8	28.4	± 21.0	62.2	15.7	± 11.6

SD=standard deviation; CI=confidence interval; # significant at p<0.05

Within the two-year follow-up subsample, the benchmark ROI was 252 m/y. Only for *low* players, the attained ROI (263 m/y) was lower compared with the target ROI (469 m/y). For *average* and *high* players, the attained ROI's (252 and 212 m/y, respectively) were larger compared with the target ROI's (233 and 55 m/y, respectively) (***Table 3***, ***Figure 1***). For the four-year follow-up subsample, the benchmark ROI was 271 m/y. The attained ROI's for *low* (356 m/y) and *average* (226 m/y) players were just below the target ROI's (368 and 278 m/y, respectively). For *high* players, the attained ROI (233 m/y) was larger compared with the target ROI (168 m/y) (***Table 3***, ***Figure 1***).

Table 3 *Rates of improvements (ROI) for YYIR1 of the different performance groups over a 2- and 4-year period.*

2-year follow-up	***PG***	**Formula**	**ROI**	**Linear Regression**
Benchmark ROI	*Mean*	(1823m – 1319m) / 2	252 m/y	y = 252 x + 1112
Target ROI	*Low*	(1823m – 886m) /2	469 m/y	
	Average	(1823m – 1357m) / 2	233 m/y	
	High	(1823m – 1714m) / 2	55 m/y	
Attained ROI	*Low*	(1411m – 886m) /2	212 m/y	y = 263 x + 696
	Average	(1920m – 1357m) / 2	252 m/y	y = 252 x + 1112
	High	(2137m – 1714m) /2	263 m/y	y = 212 x + 1503
4-year follow-up	***PG***	**Formula**	**ROI**	**Linear Regression**
Benchmark ROI	*Mean*	(2175m – 1090m) / 4	271 m/y	y = 543 x + 586
Target ROI	*Low*	(2175m – 703m) / 4	368 m/y	
	Average	(2175m – 1063m) / 4	278 m/y	
	High	(2175m – 1503m) / 4	168 m/y	
Attained ROI	*Low*	(2126m – 703m) / 4	356 m/y	y = 712 x + 82
	Average	(1966m – 1063m) / 4	226 m/y	y = 452 x + 568
	High	(2434m – 1503m) / 4	233 m/y	y = 466 x + 1107

PG = Performance group; ROI = Rate of improvement; m/y = meter per year

Two-year stability analyses revealed *very high* ICC's for stature, body mass and maturity offset, and *low*-to-*moderate* ICC's for the YYIR1 performance in each performance group (***Table 4***). Overall, when analyzing the total subsample, *high*-to-*very high* ICCs for all variables were found. Within the four-year subsample, stability analyses for maturity offset, stature and body mass revealed *low* to *moderate* ICC's in all performance groups, except for body mass in *average* players. For YYIR1 performance, *low* ICC's were reported for all performance groups. Generally, *moderate* ICC's for all variables after a four-year period were reported (***Table 4***).

Table 4 *Intra-class correlations for maturity offset, stature, body mass and YYIR1 by 2- and 4-year intervals.*

	Overall (n=21)		***low* (n=7)**		***average* (n=7)**		***high* (n=7)**	
2y stability	**ICC**	**95% CI**	**ICC**	**95% CI**	**ICC**	**95% CI**	**ICC**	**95% CI**
Maturity OffSet	0.97	0.95 - 0.98	0.97	0.94 - 0.98	0.97	0.93 - 0.98	0.97	0.54 - 0.86
Stature	0.94	0.91 - 0.96	0.92	0.86 - 0.96	0.95	0.91 - 0.98	0.93	0.86 - 0.97
Body mass	0.94	0.92 - 0.96	0.95	0.90 - 0.98	0.93	0.88 - 0.97	0.94	0.88 - 0.97
YYIR1	0.76	0.68 - 0.84	0.43	0.18 - 0.67	0.68	0.48 - 0.82	0.73	0.54 - 0.86
	Overall (n=21)		***low* (n=7)**		***average* (n=7)**		***high* (n=7)**	
4y stability	**ICC**	**95% CI**	**ICC**	**95% CI**	**ICC**	**95% CI**	**ICC**	**95% CI**
Maturity OffSet	0.66	0.44 - 0.83	0.59	0.12 - 0.90	0.74	0.34 - 0.94	0.48	0.00 - 0.86
Stature	0.57	0.32 - 0.78	0.27	-0.17 - 0.71	0.54	0.07 - 0.89	0.70	0.28 - 0.93
Body mass	0.75	0.57 - 0.88	0.73	0.32 - 0.94	0.81	0.47 - 0.96	- 0.38	0.09 - 0.82
YYIR1	0.59	0.34 - 0.79	0.38	-0.09 - 0.83	0.36	-0.11 - 0.82	- 0.44	0.04 - 0.87

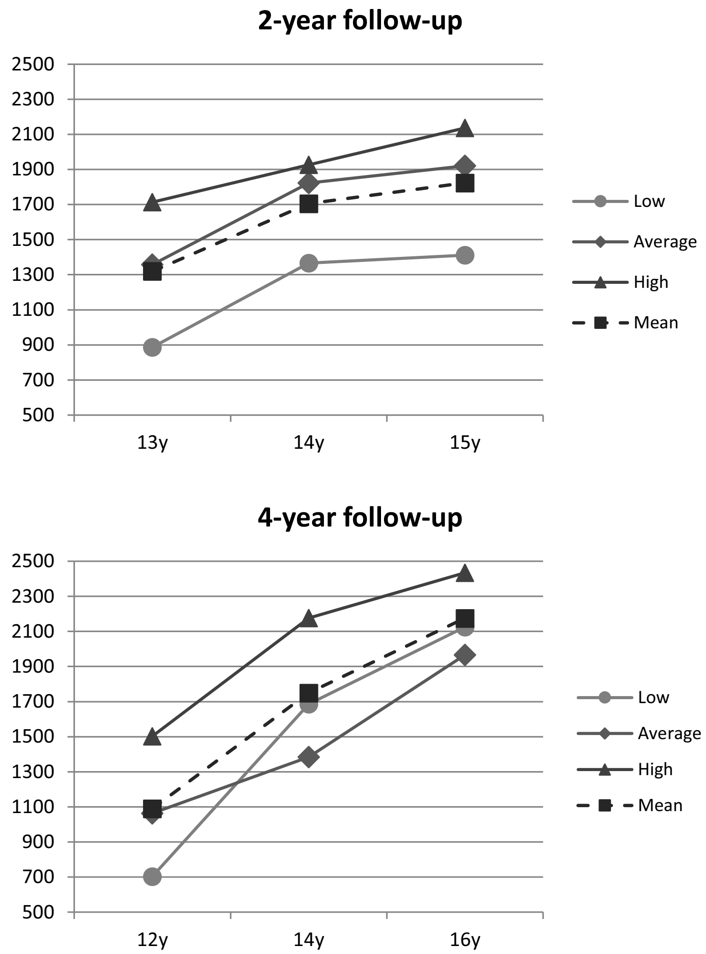

Figure 1 *Attained and target (=mean) rate of improvements for the three performance groups (i.e., High, Average and Low) for the 2-year and 4-year follow-up subsample.*

Discussion

We investigated the evolution and stability of anthropometry and YYIR1-performance of 42 high-level, pubertal soccer players with *high*, *average* and *low* YYIR1 baseline performances over two and four years. Also, two- and four-year stability of anthropometrical characteristics and YYIR1 performance was examined. The main finding was that after two and four years, the magnitudes of the differences at baseline were reduced, although players with high YYIR1 baseline performance still covered the highest distance up till 16 years. Furthermore, the YYIR1 showed a high stability over two years (ICC = 0.76) and a moderate stability over four years (ICC = 0.59). Anthropometry showed very high stability (ICCs between 0.94 to 0.97) over a two-year period, in contrast to a moderate stability (ICCs between 0.57 and 0.75) over four years. This indicates that the YYIR1 performance together with the anthropometrical characteristics, should be evaluated over time, with emphasis on individual development (and comparison with benchmarks).

The present YYIR1 results showed the high level of intermittent-endurance capacity when compared with 16 elite youth soccer players, aged 17 years (2150 ± 327 m; Rampinini et al., 2008), Croatian elite youth soccer players (U13: 933 ± 241 m, U17: 1581 ± 390 m; Markovic and Mikulic, 2011), and 21 youth soccer players from San Marino, aged 14 years (842 ± 352 m; Castagna et al., 2009). Therefore, it could be hypothesized that the present youth soccer sample is subjected to training stimuli which are greatly focusing on the development of the intermittent-endurance capacity, and therefore explaining the high level of YYIR1 performances. Consequently, the present data could serve as reference values or standards for a youth soccer sample in a high-level soccer development program.

Considering the differences in YYIR1 between the three performance groups at baseline, these large discrepancies for YYIR1 performance decreased over time, especially between the *low* and *high* performance groups. For example, the difference at baseline between *low* and *high* was 800 m (ES = 5.12) corresponding with 20 YYIR1 running bouts, whilst four years later, the difference decreased to 308 m (ES = 1.05), which corresponds with approximately 8 running bouts. A similar trend was noticeable over a two-year period, however less distinct: the difference in YYIR1 performance between *low* and *high* at baseline was 828 m (ES = 6.86) and diminished to 726 m (ES = 3.32), corresponding with approximately 21 and 18 running bouts, respectively. Also, the higher performance groups continued to perform better than the lower performance groups within each subsample. Indeed, within the two-year follow-up period, the highest baseline performance group continued to improve their YYIR1 performance with a higher rate compared with the lowest baseline performance group (263 m/y vs. 212 m/y, respectively). In contrast, in the four-year follow-up period, the lowest baseline performance group progressed with a higher rate compared with the highest baseline performance group (356 m/y vs. 233 m/y, respectively).

These results indicate that during the pubertal years (i.e., 11 to 16 y), high-level soccer players with a relatively low intermittent-endurance capacity have the potential to improve their YYIR1 performance up to the average level of their peers. The higher improvement of players from the lowest baseline performance group (up to 235.7 % over a four-year period) compared with average (up to 86.8 %) and high (up to 62.2 %) performance groups, might reveal their potential to eventually catch-up or close the gap with the better performers on the long term, although no longitudinal data were available after the age of 16 years. Moreover, Hill-Haas and colleagues (2009) investigated the effect of implementing small-sided game versus mixed generic training on several physiological parameters during seven weeks in pre-season in 19 elite youth soccer players, aged 14 years. Both training groups improved their YYIR1 performance after seven weeks: the small-sided training group ran 254 m further (from 1488 m to 1742 m; + 16.9 %), whilst the mixed generic training group improved their performance with 387 m (from 1764 m to 2151 m; + 21.7 %). The latter results showed that both training groups were capable to quickly improve their aerobic fitness level, although baseline and outcome differences between both training groups were still apparent.

The highest improvement in both subsamples occurred around the timing of peak height velocity (when players moved from pre- to post-peak height velocity) (***Table 3***). This is in accordance with the results of a longitudinal study by Philippaerts et al. (2006), where the highest increase in cardiorespiratory endurance coincident with the timing of peak height velocity. A study by Malina & Bailey (1986) already indicated that maximal gains in peak oxygen occurred around peak height velocity timing, and that a continued improvement was observed during the late adolescence. Future research should extend this longitudinal approach into young adulthood (after 16 years) to examine if low performers eventually catch-up with their initially higher performing counterparts.

The differences in YYIR1 performances at baseline between low and high performance groups seem not to be influenced by body size and maturational status since in both subsamples, the highest performers were the smallest, leanest and most away from peak height velocity (i.e., in the two-year period: 152.8 cm, 40.5 kg and -1.20 y, respectively) compared with the lowest performers (i.e., 158.4 cm, 48.2 kg and -0.76 y, respectively). Also, a study in 143 Portuguese young soccer players (11-14 years) showed that body mass was disadvantageous for the YYIR1 performance (Figueiredo et al., 2011). Therefore, anthropometrical characteristics and maturational status cannot explain these baseline differences, although several studies have shown that soccer players with increased body size dimensions and biological maturity perform better in speed, power and strength, especially during the pubertal years (Malina et al., 2004; Vaeyens et al., 2006; Carling et al., 2009; Figueiredo et al., 2009).

Moreover, another study investigating anthropometrical characteristics, skeletal age and physiological parameters among 159 Portuguese elite youth soccer players, aged 11-14 years, showed that late maturing soccer players had a higher intermittent endurance compared with early maturing peers (Figueiredo et al., 2009). Also, a study by Deprez et al. (2012) reported that the maturational status had a relatively small influence on the YYIR1, since selection procedures focus on the formation of homogenous groups in terms of anthropometry and biological maturation. Additionally, a study by Segers et al. (2008) stated that running style plays an important role in the running economy of late maturing soccer players, and therefore the latter players succeed in keeping up with early maturing soccer players. Other possible factors like training volume, experience, quality of training and field positions might influence the large range of YYIR1 performance in each subsample, and the lack of this information is a limitation of the present study. Nevertheless, all players in the present study underwent the same training program. Also, in Belgium, the transition from the U11 to U12 age group is accompanied with increases in the number of players during games (from 8 vs. 8 to 11 vs. 11 players) and pitch dimensions, which some players might experience badly.

The present results revealed high stability (ICC's: 0.90-0.94) of anthropometrical characteristics and maturational status over a two-year period. However in contrast, a poorer, although high (ICC = 0.76) stability in YYIR1 was apparent in the latter subsample despite similar changes in anthropometrical characteristics and maturational status. In contrast with the very high stability of anthropometrical characteristics and maturational status over a two-year period, moderate stability of both anthropometry and maturational status was found on the long-term (four-year period). This possibly indicates the large inter-individual differences in growth and maturation of pubertal children (Malina et al., 1994), despite the homogeneity in terms of anthropometry and maturational status in elite youth soccer players around peak height velocity (Deprez et al., 2012). Indeed, additional analyses revealed that 47.6 % and 28.2 % of the players were moving to a higher or lower percentile group on the long-term for stature and maturational status, respectively. Additionally, 47.6 % of the players were moving to a higher or lower YYIR1 performance group, also resulting in moderate stability over a four-year period (ICC = 0.59). For example, 12-year-old players with the highest high-intensity intermittent-performance might not remain the best when they reach the age of 16 years, in agreement with poor long-term stability observed in a general sporting population over a year (Abbott and Collins, 2002). Indeed, a review by Vaeyens et al. (2008) discussed the unstable non-linear development of performance determinants, making one-shot long-term predictions unreliable. The fact that some players were able to extremely improve their YYIR1 performance (e.g., one player went from 1280 m to 2360 m over two years), lends support to individual interventions to develop high-intensity intermittent running performance.

The present study has its limitations. First, we found a large variation in rank scores of the players regarding anthropometrical characteristics and YYIR1 performance over a four-year period. However, within such a limited group of players (n = 7), small changes in ranking are responsible for large changes in ICCs. Therefore, we expected the overall ICCs to be larger than within each performance group, which reflects more the reality of a young soccer team, with players from different performance levels at the same time. Further, longitudinal studies on a larger sample size and after 16 years of age, accounting for individual training contents are warranted to draw definite conclusions. Also, caution is warranted when using maturity offset as an estimation of biological maturation. According to Mirwald et al. (2002), the equation is appropriate for children between 9.8 and 16.8 years, although it appears that the estimation is more accurate in the middle of this range. Since players in the present study matched the latter age-range and players were only compared within the same age group, these limitations of the predictive equation were restrained and the use of maturity offset justified (Deprez et al., 2012). Also, recent studies showed poor to moderate agreement between invasive and non-invasive methods to predict maturational status (Malina et al., 2012; 2013). The equation to estimate maturity offset emerged from longitudinal studies from Canada and Belgium and many users tend to ignore the magnitude of standard error of estimation and the potential variation of agreements between estimated and real values at ages long before PHV and long after PHV. This limitation should be considered when considering future research in this area. Moreover, further research is necessary to validate the maturity offset method in a young soccer population.

Conclusion

In the present follow-up study, we tried to identify developmental pathways for maturational status, anthropometrical characteristics and high-intensity intermittent-running performance in homogenous groups of players according to their performance at baseline. Although the magnitudes of the differences at baseline were reduced after two and four years, players with high initial YYIR1 performance still covered the highest distance. Furthermore, the YYIR1 showed a high stability over two years and a moderate stability over four years, suggesting that the longer the follow-up, the lower the ability to predict player's future potential in running performance (Vaeyens et al., 2008). Our results also show that with growth and maturation, poor performers might only partially catch up their fitter counterparts between 12 and 16 years.

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Keypoints

- Young, high-level soccer players with a relatively low intermittent-endurance capacity are capable to catch up with their better performing peers after four years.
- Individual development and improvements of anthropometrical and physical characteristics should be considered when evaluating young soccer players.

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STUDY 4

PREDICTION OF MATURE STATURE IN ADOLESCENT SOCCER PLAYERS AGED 11-16 YEARS: AGREEMENT BETWEEN INVASIVE AND NON-INVASIVE PROTOCOLS

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Abstract

This study aimed to examine the agreement between invasive (TW2 and TW3 skeletal age) and non-invasive (estimated maturity offset) protocols to estimate mature stature, and the interrelationship among maturity groups derived from concurrent protocols in a mixed-sample of 160 Belgian and Brazilian elite youth soccer players, aged 10 to 16 years. The results showed that the correlations between the invasive and non-invasive protocols to predict mature stature were very large to nearly perfect (ranged 0.70 to 0.95). The bias (mean difference between measurements) was +3.98 cm (±4.17 cm) for the non-invasive method against the TW2 equation. Correspondent values were +2.98 cm (±4.63 cm) against TW3 equation. For the total sample, percentages of agreement between maturity categories derived from the protocol that estimates 'age at peak height velocity' and based on the difference between skeletal and chronological age ranged between 45.9% and 56.1%, for TW2 and TW3, respectively. Corresponding values for the method estimating mature stature were 64.4% and 78.9%, for TW2 and TW3, respectively. In conclusion, caution is needed in the transformation of non-invasive protocols into somatic maturity categories. The current results confirmed that this approach tend to over-estimate the percentage of players who are on time, although the literature consistently suggest adolescent soccer players as more likely to be advanced according to the discrepancy between skeletal age and chronological age.

Introduction

Physical growth refers to changes in body size and has implications on proportions, shape, composition and functional capacities (Malina et al., 2004a). Biological maturation corresponds to progresses from birth to the mature stature. The term maturity ordinarily refers to the extent to which the individual has progressed to the mature state and is translated into a categories: delayed, on time, advanced and mature (Malina et al., 2004a). In the context of youth soccer, the average statures and weights of young soccer players tended to fluctuate above and below reference medians for non-athletic youth from childhood to mid-adolescence (Center for Disease Control and Prevention, 2000). However, during late adolescent years mean stature heights are at or below reference medians, while average weights fall above and below the 75th percentile (Malina et al., 2000). The literature also suggests that adolescent players who were advanced in skeletal maturation tended to attain better performances compared to other players contrasting in skeletal maturity (Figueiredo et al., 2009). Youth soccer players classified as local and elite (Coelho-e-Silva et al., 2011) differed in body size and maturity status. Additionally, adolescent soccer players aged 13–15 years classified by skill level did not differ in age, experience, body size, speed and muscle power, but stage of puberty and aerobic resistance (positive coefficients) and height (negative coefficient) were significant predictors of soccer skill (29% of the total explained variance), highlighting the inter-relationship of growth, maturity and functional characteristics of youth soccer players (Malina et al. 2007).

The assessment of skeletal age is probably the best alternative to assess biological maturation and is widely used to produce the difference between SA and chronological age which allows the classification into skeletal maturity groups (Malina et al. 2010). In the context of youth soccer, the ratio of skeletal divided by chronological age was also used to predict functional capacities and sport-specific skills (Figueiredo, Coelho-e-Silva, & Malina, 2011). Two different protocols are commonly adopted to estimate skeletal age in youth sports: Fels (Roche, Chumlea, & Thissen, 1988), and Tanner-Whitehouse (Tanner, 1983, 2001). Criteria and procedures to derive SA vary with each protocol (Malina et al., 2004a; Malina, 2011). Another method is often called the atlas or Greulich-Pyle methods (Greulich & Pyle, 1959) and corresponds to standardized films for boys and girls, respectively 31 and 29 plates, from birth to maturity, and demands for assessment of individual bones, but is often applied clinically by comparing the radiograph as a whole to the pictorial standards (Malina, 2011). Independent from the protocol, differences between skeletal and chronological ages are used to classify skeletal maturity status within a range of ±1 year band (Malina et al., 2004a). However, Skeletal age is considered an invasive method and has associated expenses. Hand-wrist radiographs require trained observers and although the method implies a low dose of radiation exposure, this aspect is still a methodological constraint. Equations for predicting mature stature originally required skeletal age (Roche et al., 1975; Tanner, 1983), which is a substantial limitation to their applicability.

Given the perceived invasiveness of secondary sex characteristic examination, radiation exposure related to assessment of skeletal age, there is interest in anthropometric estimates that permit a non-invasive assessment of biological maturation. Current stature may be expressed as percentage of predicted mature stature (PMS) and is considered an estimate of biological maturation (Malina et al., 2005a; Malina et al., 2005b). Percentage of PMS attained at a given age is positively related to skeletal age during adolescence (Beunen, et al., 1997). Two individuals of the same sex and age could have the same stature, but one is closer to mature stature than the other (Malina et al., 2004a). Another non-invasive method to assess somatic maturation is obtained from chronological age, stature, sitting height, estimated leg length, body mass, and interaction terms (Mirwald et al., 2002) and refers to the amount of time before or after peak height velocity and in turn permits the determination of age at peak height velocity (APHV). Based on measurements obtained from 224 boys classified as early, average, or late maturers, depending on their APHV, cumulative height velocity curves were developed for each maturity groups, and distance in cm left to grow in stature were calculated to predict mature values within ±5.35 cm (Sherar et al., 2005). This protocol has the merit to permit the determination of estimated mature stature from estimated APHV. Although classifications between maturity groups derived from skeletal age and non-invasive indicators were not expected to correspond, the application of the anthropometry-based protocols is being used in large samples of young athletes (Deprez et al., 2012; Matthys et al., 2012; Vandendriessche et al., 2011). Maturity status classifications of soccer players with skeletal and non-invasive methods (derived from APHV and % PMS attained at a given age) showed moderate concordance, but most players were classified as average by the latter (Malina et al. 2012). This probably reflected the narrow range of variation in predicted ages. In parallel, the maturity-offset portocol to estimate APHV was suggested as a categorical variable, pre- or post-PHV (Mirwald et al. 2002). This appears most useful near the time of actual PHV in average maturing boys within a narrow CA range, 13.00 to 14.99 years (Malina & Koziel, 2014) which limits its utility with adolescent male soccer players who tend to be early maturing especially after middle puberty (Malina et al. 2000; Figueiredo et al. 2009; Coelho e Silva et al. 2010). Ethnic variation in sitting height and leg length may be a potential confounder in predictions (Malina et al. 2004a).

The current study evaluates the agreement between invasive and non-invasive predictions of mature stature. Invasive estimates include formulas include skeletal maturation based on two Tanner-Whitehouse (TW) methods (Tanner et al., 1983; Tanner et al., 2001). Non-invasive estimates are based on predicted age at PHV and mature height based on predicted age at PHV. The study also examined the interrelationship among maturity status classifications based on the invasive and non-invasive protocols. It was hypothesized that agreement between maturity status classifications would be poor, although the mature height predictions would be moderately-to-strongly correlated.

Methods

Sample and procedures

The sample included 160 male soccer players 10-16 years of age, 60 of Flemish ancestry and 100 of Brazilian ancestry. The project was approved by the Ethics Committees of Ghent University (B67020097274; study 2009/572) and the Federal University of Santa Catarina (protocol 2004/2011). Parents or legal guardians were informed about the aim of the study and informed consent obtained from each participant. Chronological age was determined as the difference between date of birth and the date a posterior-anterior radiograph of the left wrist was taken. The sample retained for analysis was 148. Seven players were skeletally mature according to RUS scores and five attained 100% of predicted mature stature (three adolescents using TW2 equation and two additional cases using TW3 equation).

Anthropometry

The measurement of stature (model 98.603, Holtain Ltd, Crosswell, UK) and sitting height (Holtain sitting table, Crosswell, UK) were performed to the nearest 0.1 cm. Leg length was calculated as stature minus sitting height. Body mass was measured to the nearest 0.1 kg. All assessments were taken by an unique experienced observer (one in Belgium and another in Brazil) at the same day of the radiograph. The project management and time available to contact with participants did not permit the assessment of data quality for anthropometry.

Predicted age at peak height velocity (APHV)

The algorithm derived from two longitudinal studies of Canadian youth and one of Belgian twins was used to predict the time before or after PHV in years, labeled maturity offset (Mirwald et al., 2002) as presented in equation 1 and predicted age at PHV was estimated in years as CA minus maturity offset.

$$
\begin{aligned}
\text{Maturity offset} = \quad & -9.236 \\
& + (0.0002708 * (\text{Leg Length} * \text{Sitting Height})) \\
& + (-0.001663 * (\text{Age} * \text{Leg Length})) \\
& + (0.007216 * (\text{Age} * \text{Sitting Height})) \\
& + (0.02292 * (\text{Weight}/\text{Height} * 100)), \\
& [R = 0.94,\ R^2 = 0.89, \text{ and SEE} = 0.59]
\end{aligned}
$$

Players were classified as late, average or early relative to the mean APHV for the three samples upon which the prediction equation was based: 13.8±0.9 years (Malina et al. 2012). Average (on time) was defined as an APHV within one standard deviation of the group mean (12.9 to 14.7 years); players with an APHV >14.7 years were classified late and those with an APHV <12.9 years were classified as early.

Predicted mature stature from estimated APHV

Mature stature was also predicted from the maturity status based on estimated APHV using sex-specific tables indicating remaining stature growth (cm) until mature stature (Sherar et al., 2005). This method was developed from serial stature measurements on 224 boys obtained from three studies (the Saskatchewan Growth and Development Study: 1964 to 1973; 1998 and 1999; the Saskatchewan Pediatric Bone Mineral Accrual Study: 1991 to 1998; 2002 to 2004, the Leuven Longitudinal Twin Study: 1985 to 1999). The authors (Sherar et al., 2005) used sex-specific regression equations (Formula 1 of the current study) to determine APHV in the Flemish sample and then the some individuals were categorized as early-, average-, and late- maturing, depending on estimated APHV (early maturers were defined as preceding the mean APHV by 1 year; average maturers were ±1 year from APHV; and late maturers were >1 year after APHV that was 14.0 in boys). Afterwards, predicted years from APHV for the Flemish participants were used to estimate height left to grow using the maturity specific cumulative velocity curves obtained from longitudinal data of the two Saskatchewan studies. Finally, the validity of procedure was examined against actual mature height using the Flemish data.

Skeletal age (SA)

Skeletal age was estimated with the Tanner-Whitehouse RUS protocol which is based on the radius, ulna, and metacarpals and phalanges of the first, third and fifth digits. A maturity score was assigned to each bone and the summed (range of variation is 0-1000). The score was transformed into and SA using TW2 (Tanner et al., 1983) and TW3 (Tanner et al., 2001) tables. Seven players were skeletally mature (RUS score = 1000) and were excluded. An SA is not assigned and the prediction of adult height is not applicable to skeletally mature youth.

Predicted mature stature using SA

Mature stature for each player was also predicted using the Tanner-Whitehouse algorithms for boys which include chronological age, current stature and RUS score; TW2 RUS (Tanner et al., 1983) and TW3 RUS (Tanner et al., 2001) were used.

Analysis

Percentages of predicted mature stature based on the TW2 and TW3 equations were transformed into z-scores using age-specific means and standard deviations attained at half-yearly intervals by boys in the Berkeley Guidance Study (Bayer & Bayley, 1959; Bayley & Pinneau, 1952). Corresponding data are not available for Brazilian. Z-scores were classified into maturity groups as follows: *on time* (z-score between -1.0 and +1.0); *delayed* (<-1.0); *advanced* (>+1.0). This approach was already used in studies dealing with adolescent soccer players (Malina et al., 2012) and American football players (Malina et al. 2007b).

Descriptive statistics were calculated for the total sample and for each age group. Bivariate correlations between estimates of predicted mature stature based on the estimates were calculated. Pearson correlation coefficients were interpreted as follows (Hopkins, 2000): *trivial* (r < 0.1), *small* (0.1 < r < 0.3), *moderate* (0.3 < r < 0.5), *large* (0.5 < r < 0.7), *very large* (0.7 < r < 0.9) and *nearly perfect* (r > 0.9). Regressions and Bland-Altman plots of predicted mature height based on the two TW estimates based on SA and the estimated based on predicted APHV were done. Cross-classifications of maturity status based on the invasive (Skeletal age) versus the two non-invasive protocols (predicted APHV, percentage mature height based on predicted APHV) were also calculated, including percentage of agreement, rank-order correlations and kappa coefficients.

Results

Seven individuals from the original sample attained 1000 RUS score (chronological age: 13.59-15.31 years; stature: 170-0-182.6 cm; body mass: 60.2-76.6 kg) and predicted mature stature were not calculated for these cases. In addition, five soccer players who were not fully mature according to RUS scores already attained 100% of predicted mature stature derived from TW2 formula (n=3; RUS: 925 to 968) and TW3 formula (n=2; RUS: 9415 to 984) and were excluded from subsequent analyses. ***Table 1*** summarizes descriptive statistics for the final sample (n=148) and subsamples. Chronological age, anthropometric dimensions, maturity offset, predicted age at PHV and SA did not differ between subsamples; however, predicted mature height based on both TW protocols differed substantially. ***Figure 1*** presents the regression lines between concurrent estimates of mature stature (panel a.1: values obtained from the anthropometry-based equation and the estimates from RUS scores using TW2 version; panel b.1: the same non-invasive estimate and TW3 version). Standard errors related to each of the regression lines were 3.21cm and 3.38 cm. The differences between non-invasive and invasive estimates were plotted separately and a positive BIAS (over-estimation) were noted. On average, about +3.98 cm when using the anthropometry-based equation in relation to values obtained from RUS-TW2 and +2.98 cm when using RUS-TW3. The 95% limits of agreement in Bland-Altman plots were larger for TW3 (-6.10 cm to +12.10 cm as presented in panel b.2) compared to TW2 (-4.20 to +12.20 cm as presented in panel a.2). Negative correlation coefficients between differences and means were noted: -0.378 (TW2) and -0.422 (TW3) suggesting a more pronounced lack of agreement between protocols to estimate mature stature among individuals who tend to attain shorter mature height values.

Correlations (coefficients and respective 95% confidence interval) between invasive and non-invasive estimates of mature stature are summarized in ***Table 2***. For the total sample, correlations between estimates based on RUS scores (TW2 and TW3) with that based on maturity offset scores (Sherar et al. 2005) were 0.753 and 0.721, respectively. The interpretation of the association between methods seemed to be affected by age. The magnitude of correlation coefficients between predicted mature stature (PMS) obtained from the anthropometry-based formula and the invasive methods were higher for the group aged 15-16 years (0.948 and 0.946) and the lowest coefficients were found among the age group 13-14 years (0.696 and 0.742). Respective coefficients for the younger groups were 0.848 and 0.849. The correlation between estimates based on TW2 and TW3 was *nearly perfect* (0.968 for the total sample and ranged from 0.970 to 0.992 across age groups).

Agreement between maturity classifications based on invasive and non-invasive protocols is summarized in ***Table 3***. For the total sample, agreement ranged between 49.5% (r_S = 0.334, κ = 0.011) and 56.1% (r_S=0.276, κ = 0.005), for TW2 and TW3, respectively. Agreement rates between maturity groups (late, on time, early) derived by protocols including RUS scores with that obtained from estimated APH fluctuated between 47.3%-36.5% for players aged 10-12 and 13-14 years which were substantially lower than 78.9% found for 15-16 years, when using TW2 version. The contrast between younger ages and late adolescent years was not so evident when using the TW3 version with age-specific agreement rates being 61.8% for 10-12 years, 48.6% for 13-14 years and 68.4% for 15-16 years. The trend

The analyses were repeated between the categories obtained from predicted mature stature using the non-invasive equation (Sherar et al., 2005) and maturity groups derived from the difference between SA and CA (***Table 3***). For the total sample, the percentage of agreements was lower when SA was determined using TW2 protocol (68.4%, r_S = 0.378, κ = 0.136). In contrast, the higher percentage of agreement was noted when SA was determined using TW3 (78.9%, r_S = 0.531, κ = 0.406). When the sample was splitted into three age groups, the agreement rates between maturity status obtained by attained predicted mature stature and skeletally maturity status using TW2 were always lower compared to above mentioned value for the total sample: 34.5%, 58.1% and 54.1% respectively for 10-12, 13-14 and 15-16 years. This suggest an evident lack of agreement between protocols among the younger group of soccer players. In contrast, the gradient was for higher rates of agreement when skeletal age was obtained using TW3 version: 70.9% among 10-to 12-year-old players, 43.2%-58.1% for the two other older groups.

For the total sample and also for the three age groups, the non-invasive protocols produced lower frequencies of adolescent soccer players classified at the extremes (late and early) when compared to respective frequencies obtained by protocols using skeletal age.

Table 1 *Descriptive statistics for the each subsample and the total sample.**

Variables		Total sample (n=148)				Age groups (Gi)			Comparison between samples (Xi)			
(Y_i)	Unit	Mean			Sd	G1:	G2:	G3:	Descriptive		t	p
		Value	SE	(95% CI of the mean)		10-12 years (n=55)	13-14 years (n=74)	15-16 years (n=19)	X1: Brazilian (n=90)	X2: Belgium (n=58)		
Chronological age	years	13.43	0.11	(13.21 to 13.64)	1.33	12.06±0.66	14.87±0.48	15.69±0.55				
Body mass	kg	48.5	1.0	(46.6 to 50.3)	11.6	±	±	±	48.2±11.0	48.9±12.6	-0.403	0.688
Stature	cm	159.9	1.0	(157.9 to 161.9)	12.1	149.7±7.8	163.7±9.4	174.7±6.3	158.9±11.7	161.4±12.6	-1.240	0.217
Sitting height (SitH)	cm	82.6	0.5	(81.5 to 83.7)	6.6	77.3±3.9	84.1±5.2	92.1±3.7	82.1±6.2	83.4±7.2	-1.214	0.227
Ratio SitH-to-stature	%	51.7	0.1	(51.5 to 51.9)	1.3	51.7±1.0	51.4±1.3	52.7±1.0	51.7±1.2	51.7±1.4	-0.062	0.951
Estimated leg length (LL)	cm	77.3	0.5	(76.3 to 78.3)	6.1	72.4±4.5	79.6±5.2	82.6±3.4	76.8±6.1	78.0±6.2	-1.130	0.260
Ratio LL to SitH	%	93.7	0.4	(92.9 to 94.5)	4.7	93.7±3.9	94.7±5.1	89.8±3.4	93.7±4.4	93.7±5.2	0.020	0.984
Maturity_offset	years	-0.49	0.12	(-0.73 to -0.26)	1.44	-1.83±0.69	-0.12±0.84	1.94±0.53	-0.67±1.24	-0.22±1.67	-1.757	0.082
Age at peak height velocity	years	13.92	0.05	(13.83 to 14.02)	0.57	13.90±0.43	13.99±0.63	13.75±0.66	13.88±0.56	13.99±0.58	-1.207	0.229
Skeletal maturation scores												
RUS		572	14	(545 to 600)	168	437.8±82.9	618.0±147.1	784.9±105.7	581±167	558±170	0.849	0.397
TW2-SA	years	14.59	0.13	(14.32 to 14.81)	1.55	13.24±1.21	15.08±1.18	16.26±0.57	14.62±1.63	14.45±1.44	0.635	0.527
TW3-SA	years	13.50	0.13	(13.20 to 13.72)	1.61	12.08±1.06	13.94±1.31	15.67±0.73	13.54±1.63	13.24±1.57	1.101	0.273
Predicted mature stature:												
TW2	cm	175.7	0.5	(174.6 to 176.7)	6.3	174.2±5.3	176.0±7.0	178.7±5.2	174.9±6.6	176.9±5.8	-1.924	0.056
TW3	cm	176.7	0.5	(175.6 to 177.8)	6.7	175.2±4.9	176.8±7.3	180.3±7.3	175.5±6.6	178.6±6.4	-2.830	0.005
Sherar	cm	179.7	0.4	(178.9 to 180.5)	4.9	178.7±4.8	180.7±4.7	178.2±5.1	179.8±5.1	179.5±4.5	0.274	0.785

SitH (sitting height); LL (estimated leg length); APHV (estimated age at peak height velocity); RUS (radius ulna and short bones), TW2 (Tanner-Whitehouse: version 2); TW3 (Tanner-Whitehouse: version 3); SE (standard error); 95% CI (95% confidence interval)

**Note, 7 boys were skeletally mature and 5 boys attained mature height and were excluded from the analysis.*

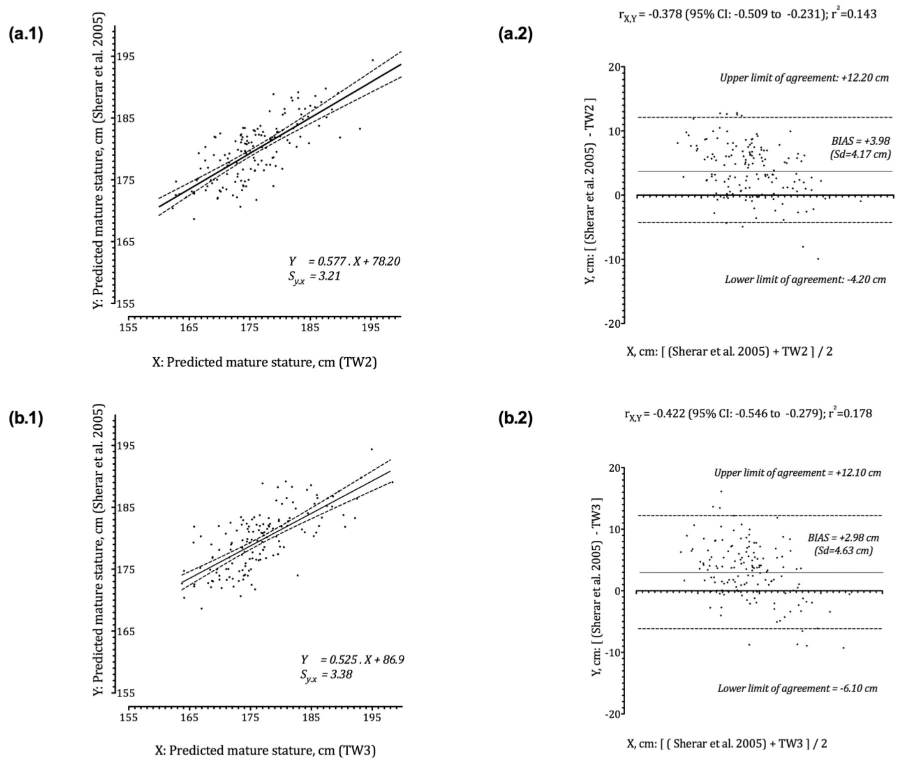

Figure 1 *Interrelationships between estimates of mature stature obtained from the protocols using maturity offset and the ones determined using the TW2 (a.1, a.2) and TW3 (b.1, b.2) equations, respectively.*

Table 2 *Bivariate correlations between estimates of mature stature of youth soccer players using different predictions equations for the total sample and by age group.*

Age group		Invasive estimates		Non-invasive estimate	
		TW2 (Tanner et al. 1983)		(Sherar et al., 2005)	
		r	(95%CI)	r	(95%CI)
10-12 years (n=55)	TW2 /Tanner et al. 1983)			0.849	(0.753 to 0.909)
	TW3 (Tanner et al. 2001)	0.974	(0.956 to 0.985)	0.848	(0.752 to 0.909)
13-14 years (n=74)	TW2 /Tanner et al. 1983)			0.742	(0.618 to 0.830)
	TW3 (Tanner et al. 2001)	0.970	(0.953 to 0.981)	0.696	(0.556 to 0.798)
15-16 years (n=19)	TW2 /Tanner et al. 1983)			0.948	(0.867 to 0.980)
	TW3 (Tanner et al. 2001)	0.992	(0.979 to 0.997)	0.946	(0.862 to 0.979)
Total	TW2 /Tanner et al. 1983)			0.753	(0.673 to 0.815)
	TW3 (Tanner et al. 2001)	0.968	(0.956 to 0.977)	0.721	(0.633 to 0.790)

TW2 (Tanner-Whitehouse: version II); TW3 (Tanner-Whitehouse: version III); r (correlation coefficient), 95%CI (95% confidence interval)

Table 3 *Cross-classifications of maturity categories based on skeletal age, predicted age at PHV and predicted mature stature using RUS scores (invasive)*

Age group	Skeletal Age	f	Y_1: Predicted APHV (Mirwald et al. 2002) Frequencies late	average	early	Statistics % agreement	Spearman correlation	Kappa	Y_s: % PMS (Sherar al. 2005) Frequencies late	average	early	Statistics % agreement	Spearman correlation	Kappa
10-12 years (n=55)	TW2	late	0	0	0	47.3%	0.124	0.030	0	1	0	34.5%	0.098	0.018
		average	0	25	0				0	18	0			
		early	0	29	1				0	35	1			
	TW3	late	0	0	0	61.8%	0.167	0.054	0	9	0	70.9%	0.247	0.008
		average	0	33	0				0	38	0			
		early	0	21	1				0	7	1			
13-14 years (n=74)	TW2	late	0	1	0	36.5%	0.434	0.062	0	11	0	58.1%	0.000	-0.027
		average	10	24	0				0	32	1			
		early	0	36	3				0	11	0			
	TW3	late	0	0	0	48.6%	0.396	0.019	1	2	0	32.4%	0.407	-0.025
		average	10	33	0				8	20	0			
		early	0	28	3				1	39	3			
≥15 years (n=19)	TW2	late	0	0	0	78.9%	0.415	0.255	6	12	0	54.1%	0.422	0.188
		average	2	14	0				4	31	0			
		early	0	2	1				0	18	3			
	TW3	late	0	0	0	68.4%	0.062	0.118	2	4	0	43.2%	0.291	0.005
		average	2	13	1				7	28	1			
		early	0	3	0				1	29	2			
Total (n=148)	TW2	late	0	1	0	45.9%	0.334	0.011	0	0	0	68.4%	0.378	0.136
		average	12	63	0				2	12	0			
		early	0	67	5				0	4	1			
	TW3	late	0	0	0	56.1%	0.276	0.005	2	2	0	78.9%	0.531	0.406
		average	12	79	1				0	13	1			
		early	0	52	4				0	1	0			

TW2 (Tanner-Whitehouse: version II); TW3 (Tanner-Whitehouse: version III); APHV (Age at P[a]eak Height Velocity); PMS (Predicted Mature Stature)

Discussion

During adolescence, control for individual differences in biological maturation is of particular importance for both in context of youth sport classification and research investigations (Mirwald et al., 2002). Popular methods to date have used multiple variables within a regression equation to predict biological maturity (Sherar et al., 2005). The most commonly used methods used to estimate adult stature are those of Bayley and Pinneau (1952), Roche et al. (1975), and Tanner et al. (1983; 2001). Recently, however, predictive equations have been developed that do not require a measure of SA (e.g., Beunen et al., 1997; Sherar et al., 2005). The purpose of the current study was to investigate the agreement between invasive (Tanner, 1983; 2001) and non-invasive (Sherar, et al., 2005) protocols often used to estimate mature stature. In addition, the interrelationships between maturity status classifications derived from the method proposed by Sherar and colleagues (Sherar, et al., 2005) against other concurrent protocols (Tanner, 1983; 2001) was also examined. The method of predicting adult stature presented by Sherar et al. (2005), unlike other nonintrusive methods, takes into account the child's biological maturity status (rate of somatic growth). On the other hand, in contrast to earlier versions limited to British samples, reference values for TW3 are based on youth from Europe (Belgium, Italy, Spain, UK), South America (Argentina), a sample from the USA (Houston, Texas, area), and Japan. Revision of the TW2 to TW3 method modified the SAs for a given maturity score. Hence, for the same RUS maturity score, a younger (lower) SA is assigned with TW3. Moreover, the age at skeletal maturity was reduced from 18.2 years with TW2 to 16.5 years with TW3 (Tanner et al., 2001). Radiographs were obtained from a sample of Flemish and Brazilian, elite young soccer players aged 11-16 years. The hypothesis that despite large correlation coefficients between estimates of mature stature could exist, agreement between maturity status classifications would rather be trivial to modest was generally supported which should be noted in interpretation of the results. Overall, the results showed very large to nearly perfect correlations between the different estimates of mature stature. It seems that the maturity offset protocol that uses the number of centimeters left to grow is an alternative to estimate the mature stature within elite adolescent soccer players. Meantime, caution is warranted in the evaluation of players as procedures to classify maturity status tended to over-estimate players in contrast to the literature that consistently classify elite players as advanced especially after 14 years of age.

Soccer players of the current study had mean statures and mean body between the 50th and 75th US age-specific percentiles (Kuczmarski et al., 2002) and were about 2.5 cm shorter than boys in the Leuven Longitudinal Twin Study at PHV (Beunen et al., 2000). Secular changes in stature have occurred in European populations since the 1960s (Bodzsar & Susanne, 1998), but have slowed or stopped in many countries. Corresponding trends for APHV in longitudinal studies limited to relatively small samples, on the other hand, are inconsistent over the past two generations (Malina et al., 2004). The predicted mature stature of the total sample using the non-invasive protocol (Sherar et al., 2005), 179.7±4.9 cm, was similar to that for a sample participating in youth football programs in central Michigan, 180.0±6.7 cm (Malina et al., 2007), to that for a larger sample of youth football players in an earlier study, 179.6±6.0 cm (Malina et al., 2005), and just below the 75th US reference percentile (181.2 cm) for 18-year-old males (Kuczmarski et al., 2002). Methods of predicting adult stature that use SA are the gold standard. Previous studies that used SA reported being able to predict adult stature anywhere between 5 cm and 8 cm 95% of the time in boys (Tanner et al., 1975; 1983; Wainer et al., 1978). The error associated with the non-invasive prediction method (±5.35 cm in 95% of the time in boys; Sherar et al., 2005) falls within this range. However, to obtain this degree of accuracy, correct protocols of measuring sitting height, stature, and body mass need to be adopted. If accurate measurements are not ensured, maturity offset values are probably larger (error of estimation) and, in addition, there is a chance that an individual could be placed into the wrong maturity category which is central to obtain mature stature.

The adolescent growth spurt in stature starts, on average, at about 10-11 years of age in boys and reaches peak velocity (APHV) at about 14 years (Malina et al., 2004). Mean estimated APHV in the total sample of youth soccer players was 13.92 ± 0.57 years. The mean was consistent with estimates for two longitudinal samples that used different models for the fitting of individual height records [14.2+0.9 years (Welsh, *n* = 32; Bell, 1993), and 13.8+0.8 years (Belgian, *n* = 33, Philippaerts et al., 2006)]; for a cross-sectional study in youth soccer players using Mirwald's et al. (2002) multiple regression equation [14.0+0.5 years (Portuguese, *n* = 181; Malina et al., 2012)]; and, for the three longitudinal samples upon which the protocol was developed [13.9+0.9 years (Canadian and Belgian, *n* = 200; Mirwald et al., 2002)]. However, the standard deviation in the present soccer sample was about two-thirds of that of the three longitudinal samples upon which the maturity offset protocol was developed. An estimate of APHV for the general population of Brazilian or Flemish boys was not available. Application of the equation to estimate maturity-offset and calculate APHV was originally recommended for boys four years from and three years after average APHV (i.e., 13.8 years), or between approximately 10 and 18 years (Mirwald et al., 2002; Sherar et al., 2005). The equation to predict APHV has not been extensively validated in independent longitudinal samples. An exception was a study that examined differences between predicted and actual age at PHV in 193 Polish boys (Malina & Koziel, 2014a). Predicted years from PHV and APHV derived from the longitudinal sample followed from 8 to 18 years were dependent on CA at prediction and actual APHV; predicted APHV also had a reduced range of variation compared to actual APHV (Malina and Kozieł, 2014a). Identical results have been reported for an independent longitudinal sample of girls, highlighting the limitations of the prediction protocol (Malina and Kozieł, 2014b). Nevertheless, predicted APHV appears to have validity for boys who are on time (average) in the timing of actual APHV and during the age interval that spans the growth spurt, approximately 12.0 to 14.99 years (Malina and Kozieł, 2014a). Allowing for the limitations of the prediction, estimated years before or after APHV provided a continuous indicator of maturational timing. In the current study, although the mentioned limitations about the applications of the maturity-offset equation, bivariate correlations between predicted mature stature derived from the application of APHV and other methods (TW2 and TW3) were very large (r = 0.753 and 0.721, respectively). Mature stature can thus be reasonably obtained by using reference values obtained from age and sex- specific cumulative height velocity curves (Sherar et al., 2005).

The ability to predict maturity status and timing of the adolescent growth spurt are often mentioned as relevant aspects to the long-term athlete development and was part of a selection strategy for U16 and U17 players of the Royal Belgian Football Association (Vandendriessche et al., 2012). Recently, Malina et al. (2012) addressed the issue of concordance between classifications of youth soccer players into contrasting maturity categories (late, on time, early) on the basis of percentage of predicted adult stature and predicted APHV with classifications based on established maturity indicators. Kappa coefficients indicated relatively poor agreement between maturity classifications based on specific pairs of indicators. For example, among soccer players aged 13.3-15.3 by using predicted APHV ±1.0 year to classify maturity status resulted in 14% late and only 3% early maturing boys (Malina, et al., 2012). This contrasted with classifications based on SA minus CA, which indicated 4% late and 36% early maturing, and classifications based on percentage of predicted adult stature, which indicated no late- and 28% early maturing players (Malina, et al., 2012). This may reflect in part the methods of classifying players into maturity categories; classifications based on SA-CA and predicted APHV were based on a standard deviation of approximately one year, while those based on percentages of predicted mature stature were based on age-specific z-scores for the Berkeley sample (Bayer & Bayley, 1959). In the present study the limited concordance between maturity classification based on predicted APHV and the indicators derived from SA was likely due to the reduced standard deviations for predicted APHV compared with that in the samples upon which the offset protocol was developed and other longitudinal studies of boys. Also, it may reflect error in the prediction equation, which has a 95% confidence interval of 1.18 years (Mirwald et al., 2002). The equation includes interaction terms for leg length and sitting height, age and leg length, and age and sitting height. However, leg length/sitting height ratios was, on average, similar to Polish boys from the Wroclaw Growth Study (WGS) (Malina et al., 2014) and Canadian boys from the Pediatric Bone Mineral Accrual Study (PBMAS) (Mirwald et al., 2002). Sampling per se and/or population variation in the proportions of the extremities (leg length) and trunk (sitting height) may be additional factors (Malina & Koziel, 2014a).

Although classifications were not expected to correspond exactly, the observation that the non-invasive protocol classified the overwhelming majority of players as on time in maturation has implications for the application of the protocol to predict the maturity timing of players in developmental programs. The limitation of the maturity offset protocol to differentiate players at the extremes of the maturity continuum requires further evaluation. The maturity indicators used in the present study measured different but related aspects of biological maturation during male adolescence. Skeletal age reflects the maturation of the skeletal system, specifically ossification of cartilaginous endochondral bones of the hand–wrist (Malina et al., 2004). In contrast, percentage of predicted mature stature and predicted APHV are indicators of somatic maturation, specifically progress in stature towards the mature value and the timing of maximal rate of growth in stature during the growth spurt, respectively (Malina et al., 2012). Maturity timing is given SA-CA or predicted APHV. Although the four maturity indicators were related, interrelationships varied somewhat with age (Table 3). It is thus possible that differences in maturation among the specific systems may have influenced the limited congruence between specific pairs of indicators.

Conclusions

In summary, percentage of predicted mature stature attained at a given CA has been used in studies of physical activity (Cumming et al., 2012) and of youth athletes (Malina et al., 2005a; Malina et al, 2005b; Malina et al., 2012). Given the worldwide popularity of soccer and interest in youth players, predicted mature stature may be relevant to estimate the adult stature or maturity status during pre-participation examinations. The present study suggested a reasonable agreement between concurrent equations to predict the mature stature in adolescent soccer players and the correlation between the protocol derived from APHV and others were very large. It seems that the maturity offset protocol that uses the number of centimeters left to grow is an alternative to be considered in the estimation of the mature stature at least among elite youth Flemish and Brazilian soccer players. Meantime and despite the moderate agreement with the TW3-method to classify players into maturity status categories, caution is in the evaluation of players as the maturity offset protocol over-estimates players as on time, although the literature consistently suggest adolescent soccer players as more likely to be advanced according to the discrepancy between skeletal age and chronological age (Coelho-e-Silva et al., 2011; Figueiredo et al., 2009; Malina, 2011; Malina et al., 2000). There is a need for further refinement of methods for assessment of maturity status, comparisons among methods, and validation relative to established indicators of biological maturity in youth.

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Chapter 2:

Relative age effect and performance

STUDY 5

RELATIVE AGE EFFECT AND YO-YO IR1 IN YOUTH SOCCER

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Abstract

The aims of the study were to investigate the presence of a relative age effect and the influence of birth quarter on anthropometric characteristics, an estimation of biological maturity and performance on the yo-yo intermittent recovery test level 1 in 606 elite, Flemish youth soccer players. The sample was divided into five chronological age groups (U10-U19), each subdivided into four birth quarters. Players had their APHV estimated and were assessed height, weight and yo-yo IR1 performance. Differences between quarters were investigated using uni- and multivariate analyses. Overall, significantly ($P<0.001$) more players were born in the first quarter (37.6%) compared to the last (13.2%). Further, no significant differences in anthropometric variables and yo-yo IR1 performance were found between the four birth quarters. However, there was a trend for players born in the first quarter being taller and heavier than players born in the fourth quarter. Players born in the last quarter tended to experience their peak in growth earlier, this may have enabled them to compete physically with their relatively older peers. Our results indicated selection procedures who are focused on the formation of strong physical and physiological homogeneous groups. Relative age and individual biological maturation should be considered when selecting adolescent soccer players.

Introduction

Competition categories in most youth sports are organized into annual age groups with discrete cut-off dates. Whilst the intent of this approach is to provide equal competition, fair play and age-appropriate training for young athletes, these age-derived categories are responsible for creating subtle chronological age advantages [11]. This difference in chronological age is referred to as *relative age*, and its consequences are known as the *relative age effect* (RAE) [3, 33]. Being chronologically older within a(n annual) sporting cohort provides significant attainment advantages when compared with those who are chronologically younger [3, 4]. In support, several authors have revealed skewed birth date distributions with overrepresentations of youth and professional level athletes born in the first part of the selection year in various sports [4, 11, 33]. Specifically, in soccer, players born in the first part of the selection year are likely to be more present at elite level [40]. It is generally considered that differences in growth and maturation and the advantages of a greater physique are the major contributing factors to explain the increased success for players born earlier in the selection year [28, 33].

Since youth athletes with advanced biological maturation tend to have increased physical capacities compared to age-matched but less mature counterparts, coaches and talent scouts tend to favour the physically advanced players [26]. Several studies have shown that soccer players with increased biological maturity perform better in strength, power, speed and endurance, especially during the pubertal years (11 to 15 years) [6, 7, 14, 15, 25, 27, 41]. Moreover, it has been shown that athletes born earlier in the selection year are taller and heavier than athletes born later in the selection year [6, 21]. Indeed, Sherar et al. [37] concluded that team selectors appear to preferentially select taller, heavier and early maturing male ice hockey players (aged 14 to 15 years) who have birth dates early in the selection year. In contrast, Hirose [21] reported no differences in height, body mass and skeletal age between the four birth quarters in 9-15 year old elite young Japanese soccer players selected into representative teams. Notably however, the small number of players born later in the selection year also possessed advanced biological and physical maturation, which likely explain why these players were successful selected into the elite representative teams. A similar trend was reported by Carling et al. [6], who suggested that the relative older age of soccer players (aged 14 years) may not always be linked to a significant advantage in physical and physiological components.

Research from a variety of team sports, such as soccer, basketball and handball, have shown that the ability to perform intermittent high intensity activity seems to be an important discriminating factor between elite and sub-elite players [2]. Indeed, it is widely reported that soccer players from higher levels of competition (i.e., higher level professional leagues) travel greater distances during games at higher speeds than lower level counterparts [31]. Moreover, it has been suggested that increased aerobic fitness is an important physiological quality that allows players to recover faster between high intensity efforts and exercise at higher intensities during prolonged high intensity intermittent exercise [2, 20].

The Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) is a soccer specific field test that maximizes the aerobic energy system through intermittent exertion [1, 8, 23]. Several previous studies have shown that the Yo- Yo IR1 performance has a high level of reproducibility [23, 39] and is a valid measure of prolonged, high intensity intermittent running capacity [38]. Moreover, strong correlations have been reported between the Yo-Yo IR1 performance and the amount of high intensity running during a soccer match [2, 8, 23, 24, 39]. Whilst, there is relatively little information available on Yo-Yo IR1 performance in elite youth soccer players, Rampinini et al. [34] and Castagna et al. [9, 10] reported distances of 2150 ± 327m (n=16), 842 ± 352m (n=21) and 760 ± 283m (n=18) for elite soccer players, aged 17.6 ± 0.5 years, 14.1 ± 0.2 years and 14.4 ± 0.1 years, respectively. An experimental study by Hill-Haas et al. [20] reported Yo-Yo IR1 distances between 1488 ± 345 m and 2115 ± 261 m before and after the implementation of a soccer-specific preseason training program, respectively. Recently, a study by Markovic et al. [29] reported Yo-Yo IR1 performances of 106 elite, Croatian youth soccer players in 7 age-groups during adolescence varying from U13 to U19. The Yo-Yo IR1 distances ranged from 933 ± 241 m within U13-players (n=17) to 2128 ± 326 m within U19-players (n=15). However, at present there is little information on the changes in Yo-Yo IR1 performance in youth soccer players during adolescence. Such information may be useful for the process of monitoring development of physical capacity in gifted players.
To our knowledge, there is little information on age related variance in performance in Yo-Yo IR1 in youth soccer players. Additionally, there have only been a few studies that have investigated the association between performance characteristics, biological maturity and the relative age effect in youth soccer players [6, 21, 37]. Therefore, the aims of this study were: (1) to describe the distribution of birth dates in elite Flemish youth soccer players (U10-U19) and (2) to examine the influence of relative age and an estimation of biological maturity on anthropometric characteristics and performance on Yo-Yo IR1 across the four birth quarters of the selection year in these elite youth soccer players.

Materials and methods

Subjects and Design

Elite youth male soccer players from two professional soccer clubs from the Belgian first division participated in this mixed-longitudinal study. The age range of the players was 9.1 – 18.8 years. All players and their parents or legal representatives were fully informed of experimental procedures before giving their written informed consent to participate. The study was approved by the Ethics Committee of the Ghent University Hospital and the study was performed in accordance with the ethical standards of the International Journal of Sports Medicine [16].

The original data set contained 2901 observations, however, to account for effect of familiarization on physical performance, the first Yo-Yo IR1 of each player was not included in the final data set. Additionally, age categories younger than 9 (<U10) and older than 18 years (>U19) were also excluded because of low frequencies to assure sufficient statistical power. The final data set consisted of 1253 data points of the Yo-Yo IR1 from 606 players who were classified into five age categories (U10-U11: *n=241*; U12-U13: n*=271*; U14-U15: *n=272*; U16-U17: *n=269*; U18-U19: *n=200*). All players were born between 1988 and 2001 (e.g. players born in 1996 who were assessed in 2009 belong to the U14 age category).

The data included in the present analysis was collected from 12 test occasions, between August 2007 and August 2010. Within each test year, two (in 2007 and 2010) to four (in 2008 and 2009) test periods were scheduled. Accordingly, a small number of players had several measures taken within each age category. To ensure that only one measure was taken for each player within each age category, the best performance on the Yo-Yo IR1 was taken. This approach ensured that each player only had one data point included within each age category and a maximum of four measures across different age categories (n players at one test result = 221; n players at two test results = 209; n players at three test results = 90; n players at four test results = 86).

Birth date distribution

To examine birth date distribution, players were divided into four birth quarters (BQ) and two semesters (S) according to their birth month (*BQ1*: January – March; *BQ2*: April – June; *BQ3*: July – September; *BQ4*: October – December and *S1*: January – June; *S2*: July – December). With a cut-off date of January 1, the selection year for youth soccer in Belgium runs from January 1 to December 31.

Anthropometric measures

Anthropometric measures of height (0.1 cm, Harpenden Portable Stadiometer, Holtain, UK), sitting height (0.1 cm, Harpenden Sitting Height Table, Holtain, UK) and body mass (0.1 kg, total body composition analyzer, TANITA BC-420SMA, Japan) were assessed according to previously described procedures (Lohman, 1988) and to manufacturer guidelines. Leg length was calculated by subtracting sitting height from stature. All anthropometric measures were taken by the same investigator to ensure test accuracy and reliability. The intra-class correlation coefficient for test-retest reliability and technical error of measurement (test-retest period of one hour) in 40 adolescents were 1.00 ($p < 0.001$) and 0.49 cm for height and 0.99 ($p < 0.001$) and 0.47 cm for sitting height, respectively.

Yo-Yo IR1

The Yo-Yo IR1 was conducted according to the methods of Krustrup et al. [23]. Participants were instructed to refrain from strenuous exercise for at least 48 h before the test sessions and to consume their normal pre-training diet before the test session. A standardized warming-up preceded each Yo-Yo IR1. All tests were completed on an indoor tartan running track with a temperature between 15−20°C. The total duration of the test was 2−25 min and the individual scores were expressed as covered distance (m). All subjects ran the Yo-Yo IR1 test at least twice. In order to account for test familiarization, the first result was not taken into account. All players ran the test with running shoes.

Maturity Status

An estimation of the biological maturity status from each player was calculated using equation three from Mirwald et al. [30]:

Maturity offset = -9.236 + 0.0002708 · (leg length x sitting height) – 0.001663 · (decimal age x leg length) + 0.007216 · (decimal age x sitting height) + 0.02292 (weight/height ratio)

This non-invasive method, based on anthropometric variables, predicts years from peak height velocity as a measure of maturity offset. Consequently, age at peak height velocity (APHV) was calculated as the difference between chronological age (CA) and the predicted time (years) from peak height velocity (i.e., maturity offset). CA was calculated as the difference between the player's birth date and the test date according to the table of Weiner and Lourie (1969). According to Mirwald et al. [30], equation three accurately estimates the maturity offset within an error of ± 1.14 years in 95% of the cases in boys. This predictive equation was developed using data from three longitudinal studies (SGDS: Bailey, 1968; BMAS: Bailey, 1997; LLTS: Maes et al., 1996) on children who were 4 years from and 3 years after PHV (i.e., 13.8 years). Accordingly the age range from which the equation can be confidently applied is from 9.8−16.8 years. Therefore, in the present study the equation was only applied to players in the U10 to U17 age categories. This equation was not applied to the U18 and U19 categories which included players aged 17.1−18.8 years.

Statistical analyses

All statistical analyses were completed using SPSS for windows (version 19.0). All results are presented as mean ± SD. First, differences between the observed and the expected birth date distributions were tested with chi-square statistics. Expected birth date distributions were calculated in accordance with the birth rate in Flanders between 1989 and 2001 (National Institute of Statistics) using weighted means. Second, within each age category, differences for chronological age (CA) and APHV were investigated between birth quarters (independent variable) using one-way analysis of variance (ANOVA).

Multivariate analysis of covariance (MANCOVA) with CA and APHV as covariates and height, weight and Yo-Yo IR1 performance as dependent variables was used to examine differences between birth quarters (independent variable). Chronological age and APHV were controlled for as these are potential confounding factors in the analysis especially since significant differences in these variables were observed across birth quarters within each age category (*U10-U11*, Age: F = 14.393, P<0.001, APHV: F = 3.781, P<0.05; *U12-U13*, Age: F = 18.398, P<0.001, APHV: F = 4.015, P<0.01; *U14-U15*, Age: F = 10.195, P<0.001; *U16-U17*, Age: F = 13.116, P<0.001; *U18-U19*, Age: F = 14.778, P<0.001). Within the U18-U19 age category, data were only adjusted for CA because the Mirwald equation had not previously been validated in these age groups. To interpret the results more distinct, partial eta squared (η^2) values were calculated. Threshold values for effect size statistics were 0.01, 0.06 and 0.14 for small, medium and large effect sizes, respectively [12]. Minimal statistical significance was set at P<0.05. Follow-up univariate analyses using Bonferroni *post hoc* test were used where appropriate.

Results

Table 1 shows the birth date distribution by quarter and semester for the total sample (U10-U19) and for the five age categories separately. Overall, 37.6% of the players were born in the first quarter, while only 13.2% of the players were born in the fourth (i.e., last) quarter. More detailed analysis within the age categories revealed that the percentage of players born in the first quarter of the selection year varied between 33.0 and 43.3%, and 12.2 – 13.9% for the last quarter. The birth date distribution of the soccer players differed significantly from the Flemish population (*U10-U19*, χ^2_3 = 122.1, P<0.001; *U10-U11*, χ^2_3 = 17.8, P<0.001; *U12-U13*, χ^2_3 = 38.9, P<0.001; *U14-U15*, χ^2_3 = 38.7, P<0.001; *U16-U17*, χ^2_3 = 18.5, P<0.001; *U18-U19*, χ^2_3 = 20.1, P<0.001).

The distribution of players between semesters also demonstrated that a greater proportion of players were born in the first semester of the selection year (67.2% for the total sample and 64.0 - 70.5% amongst the age categories). Similar to the quarterly distribution, there were significant differences from the Flemish population and the observed birth date distribution by semester (*U10-U19*, χ^2_1 = 103.3, P<0.001; *U10-U11*, χ^2_1 = 12.7, P<0.001; *U12-U13*, χ^2_1 = 32.9, P<0.001; *U14-U15*, χ^2_1 = 24.0, P<0.001; *U16-U17*, χ^2_1 = 16.7, P<0.001; *U18-U19*, χ^2_1 = 19.2, P<0.001).

Anthropometric variables and Yo-Yo IR1 performance across the four birth quarters for each age category are shown in ***Table 2***. The MANCOVA analysis demonstrated no significant main effect for birth quarter within all age categories: U10-U11 (F(9, 399) = 0.55, Wilks' λ = 0.97), U12-U13 (F(9, 467) = 1.07, Wilks' λ = 0.95), U14-U15 (F(9, 453) = 0.86, Wilks' λ = 0.96), U16-U17 (F(9, 467) = 1.08, Wilks' λ = 0.95) and U18-U19 (F(9, 355) = 1.13, Wilks' λ = 0.93). Between-subjects effects for the covariates of age and APHV revealed a significant influence on height and weight in age categories

U10-U17. Further, there was a significant effect of chronological age on the Yo-Yo IR1 performance in all age categories, except for age categories U10-U11 and U18-U19. Also, with the exception of the U10-U11 category, APHV did not influence the Yo-Yo IR1 performance in all age categories. In addition, the one way-ANOVA for APHV between the four birth quarters revealed significant differences within age categories U10-U11 (F=3.781; $P<0.05$) and U12-U13 (F=4.015; $P<0.01$). These results illustrate an earlier APHV for players born in the fourth birth quarter compared with players born in the first birth quarter.

Table 1 *Birth date distribution per quarter (BQ) and semester (S) by age group (n (%))*

Age Category	*n*	BQ and S				χ^2_3 *(BQ)*	χ^2_1 *(S)*
		BQ 1	BQ 2	BQ 3	BQ 4		
		S1		S2			
U10-U19	*920*	346 *(37.6%)*	272 *(29.6%)*	181 *(19.7%)*	121 *(13.2%)*	122.1***	
		618 *(67.2%)*		302 *(32.8%)*			103.3***
Flanders		*81,921 (25.0%)*	*83,539 (25.4%)*	*84,741 (25.8%)*	*78,124 (23.8%)*		
U10-U11	*172*	60 (*34.9%*)	50 (*29.1%*)	41 (*23.8%*)	21 (*12.2%*)	17.8***	
		110 *(64.0%)*		62 *(36.0%)*			12.7***
Flanders		*15,582 (24.9%)*	*15,926 (25.4%)*	*16,162 (25.8%)*	*14,937 (23.9%)*		
U12-U13	*200*	82 (*41.0%*)	59 (*29.5%*)	33 (*16.5%*)	26 (*13.0%*)	38.9***	
		141 *(70.5%)*		59 *(29.5%)*			32.9***
Flanders		*15,827 (24.9%)*	*16,135 (25.3%)*	*16,525 (26.0%)*	*15,178 (23.8%)*		
U14-U15	*194*	84 (*43.3%*)	48 (*24.7%*)	35 (*18.0%*)	27 (*13.9%*)	38.7***	
		132 *(68.0%)*		62 *(32.0%)*			24.0***
Flanders		*16,292 (24.9%)*	*16,687 (25.5%)*	*16,816 (25.7%)*	*15,610 (23.9%)*		
U16-U17	*200*	66 (*33.0%*)	64 (*32.0%*)	43 (*21.5%*)	27 (*13.5%*)	18.5***	
		130 *(65.0%)*		70 *(35.0%)*			16.7***
Flanders		*16,999 (25.1%)*	*17,214 (25.4%)*	*17,502 (25.8%)*	*15,997 (23.6%)*		
U18-U19	*154*	54 (*35.1%*)	51 (*33.1%*)	29 (*18.8%*)	20 (*13.0%*)	20.1***	
		105 *(68.2%)*		49 *(31.8%)*			19.2***
Flanders		*17,221 (25.0%)*	*17,577 (25.5%)*	*17,736 (25.7%)*	*16,402 (23.8%)*		

***** *P<0.001*

Table 2 *Anthropometric variables, estimation of biological maturity and Yo-Yo IR1 performance of elite youth soccer players (U10-U19) across four birth quarters (BQ1-BQ4)*

Age Category	Variable	BQ1	BQ2	BQ3	BQ4	Covariates F(Age)	P	F(APHV)	P	F(BQ)	P
U10-U11		*N = 60*	*N = 50*	*N = 41*	*N = 21*						
	Age (years)	$9.7 \pm 0.6_a$	$9.6 \pm 0.6_a$	$9.1 \pm 0.5_b$	$9.0 \pm 0.6_b$	-	-	-	-	*14.393* [#]	***
	APHV (years)	13.0 ± 0.4	13.0 ± 0.4	12.8 ± 0.4	12.8 ± 0.3	-	-	-	-	*3.781* [#]	*
	Height (cm)	138.9 ± 5.2	138.0 ± 5.7	135.4 ± 4.9	134.3 ± 4.6	*547.204*	***	*498.247*	***	*0.954*	*n.s.*
	Weight (kg)	32.2 ± 4.4	30.9 ± 4.2	29.6 ± 3.8	29.5 ± 3.3	*287.767*	***	*345.655*	***	*0.296*	*n.s.*
	Yo-Yo IR1 (m)	739 ± 270	797 ± 267	748 ± 275	705 ± 242	*0.004*	*n.s.*	*5.255*	*	*0.492*	*n.s.*
U12-U13		*N = 82*	*N = 59*	*N = 33*	*N = 26*						
	Age (years)	$12.0 \pm 0.6_a$	$11.5 \pm 0.6_b$	$11.4 \pm 0.5_b$	$11.3 \pm 0.6_b$	-	-	-	-	*18.398* [#]	***
	APHV (years)	$13.8 \pm 0.4_a$	$13.6 \pm 0.4_b$	$13.7 \pm 0.3_{a,b}$	$13.6 \pm 0.3_{a,b}$	-	-	-	-	*4.015* [#]	**
	Height (cm)	150.2 ± 6.5	148.8 ± 7.2	147.0 ± 5.5	145.7 ± 6.2	*448.446*	***	*367.365*	***	*0.483*	*n.s.*
	Weight (kg)	38.4 ± 5.0	38.1 ± 5.9	36.5 ± 4.9	36.2 ± 4.8	*241.065*	***	*273.099*	***	*0.627*	*n.s.*
	Yo-Yo IR1 (m)	1186 ± 402	1126 ± 351	1008 ± 248	1218 ± 363	*9.347*	**	*0.408*	*n.s.*	*1.940*	*n.s.*
U14-U15		*N = 84*	*N = 48*	*N = 35*	*N = 27*						
	Age (years)	$13.8 \pm 0.6_a$	$13.7 \pm 0.5_{a,b}$	$13.4 \pm 0.5_{b,c}$	$13.3 \pm 0.6_c$	-	-	-	-	*10.195* [#]	***
	APHV (years)	14.0 ±0.6	14.0 ± 0.5	14.0 ± 0.6	13.8 ± 0.5	-	-	-	-	*0.674* [#]	*n.s.*
	Height (cm)	162.6 ± 9.2	161.5 ± 7.6	160.5 ± 8.3	160.8 ± 8.2	*232.291*	***	*833.955*	***	*0.079*	*n.s.*
	Weight (kg)	49.0 ± 10.0	49.2 ± 8.4	47.5 ± 8.6	47.7 ± 8.2	*212.375*	***	*697.117*	***	*1.135*	*n.s.*
	Yo-Yo IR1 (m)	1565 ± 393	1616 ± 422	1410 ± 355	1512 ± 184	*17.607*	***	*0.647*	*n.s.*	*1.263*	*n.s.*
U16-U17		*N = 66*	*N = 64*	*N = 43*	*N = 27*						
	Age (years)	$15.8 \pm 0.6_a$	$15.7 \pm 0.6_{a,b}$	$15.5 \pm 0.6_b$	$15.0 \pm 0.6_c$	-	-	-	-	*13.116* [#]	***
	APHV (years)	14.1 ± 0.7	14.0 ± 0.6	14.0 ± 0.7	13.8 ± 0.6	-	-	-	-	*1.246* [#]	*n.s.*
	Height (cm)	174.5 ± 6.5	174.0 ± 7.6	172.4 ± 7.6	173.6 ± 6.8	*113.074*	***	*432.137*	***	*0.947*	*n.s.*
	Weight (kg)	61.9 ± 8.1	63.0 ± 8.8	60.7 ± 9.2	59.8 ± 6.1	*89.093*	***	*347.692*	***	*1.124*	*n.s.*
	Yo-Yo IR1 (m)	2012 ± 427	1961 ± 416	1900 ± 374	1770 ± 416	*5.398*	*	*0.012*	*n.s.*	*0.738*	*n.s.*
U18-U19		*N = 54*	*N = 51*	*N = 29*	*N = 20*						
	Age (years)	$17.7 \pm 0.5_a$	$17.4 \pm 0.5_b$	$17.3 \pm 0.6_{b,c}$	$16.9 \pm 0.6_c$	-	-	-	-	*14.778* [#]	***
	Height (cm)	177.6 ± 6.6	178.4 ± 6.9	175.6 ± 5.9	175.9 ± 7.0	*0.403*	*n.s.*	-	-	*1.191*	*n.s.*
	Weight (kg)	68.7 ± 6.7	70.0 ± 8.2	66.8 ± 7.8	68.4 ± 8.3	*6.672*	*	-	-	*1.309*	*n.s.*
	Yo-Yo IR1 (m)	2139 ± 462	2187 ± 465	2219 ± 402	2210 ± 453	*0.641*	*n.s.*	-	-	*0.435*	*n.s.*

Means having a different subscript are significantly different at p<0.05. Between-subjects effects for covariates and BQ are significant at: * *p<0.05;* ** *p<0.01;* *** *p<0.001; n.s. not significant.* [#] *F- and P-values for one way analysis of varianc*

Discussion

The aims of this study were to investigate the presence of a relative age effect and the influence of birth quarter on anthropometric variables, estimated biological maturation and Yo-Yo IR1 performance in 606 Flemish, elite youth soccer players. The results demonstrated an asymmetry in birth month distribution with ~40% of players born in the first quarter of the selection year, which corresponds to ~1.5 times the expected frequency in the general Flemish population. Distribution of players in the first quarter within age categories U12-U13 and U14-U15 were more distinct (~42%) than in age categories U10-U11, U16-U17 and U18-U19 (~34%), while percentages of players born in the fourth quarter remained constant over the five age categories (~13%).

Further, there were no significant differences in anthropometric variables and Yo-Yo IR1 performance between the four birth quarters. However, there was a trend for players born in the first birth quarter being taller and heavier than players born in the fourth quarter. APHV did not influence the Yo-Yo IR1 performance. This finding supports the results of previous studies [6, 21, 28]. Notably, the values for APHV within the U10-U11 (9 to 10 years old) group in this study are lower than within the rest of the age-groups. This could be explained by the age of the verification samples (i.e., children between 11 and 16 years old) used for the development of Mirwald's predictive equation [30]. Although Mirwald et al. [30] have reported that the formula is appropriate for athletes aged 10 − 16 years, it appears that the estimation is more accurate when for athletes in the middle of this range. However, since the players in the present study were only compared within the same age-group these limitations of the predictive equation are not so important.

The present Yo-Yo IR1 results are similar to Rampinini et al. [34] who reported a distance of 2150 ± 327 m in 17-year-old elite soccer players. Moreover, Hill-Haas et al. [20] also showed similar performance levels in talented 14-year-old Australian soccer players at the start of an experimental study (i.e. 1488 ± 345 m for the experimental and 1764 ± 256 m for the control group). These comparisons ishow the high level of intermittent-endurance performance of the tested Belgian young elite players. Indeed, Bangsbo et al. [2] also reported lower Yo-Yo IR1 performance levels in an elite population of American and New Zealand youth soccer players aged 12 to 18 years (personal communication, unpublished observation). In addition, the present population had a considerably greater performance than that of 106 age-matched Croatian soccer players (e.g., Croatian U17 players: 1581 ± 390 m vs. current U17 players: 1911 ± 408 m) [29].

The first aim of this study was to examine the presence of a RAE in elite Flemish youth soccer players. The findings revealed a skewed distribution of birth dates over the five age categories towards an earlier birth date which was in contrast to the evenly distributed general Flemish population. In agreement with many previous studies [4, 11], we observed that more youth soccer players were born in the first quarter of the selection year (from 33.0 to 43.3%) compared with the fourth quarter (12.2 to 13.9%). Indeed, several previous studies have shown that athletes who are relatively older within their age group are more likely to be selected to compete at the elite level in ice hockey, rugby, volleyball and basketball [4, 11]. Moreover, the relative proportion of players born in the first and last quarter of each selection year is similar to those previously reported in elite Spanish, Basque and Belgian youth soccer players (i.e. first quarter: 32.2 - 47.8%, fourth quarter: 6.8 - 18.0%) [13, 17, 19, 22, 32].

Similar to soccer, most sports that use annual age groupings to classify competition levels demonstrate subtle chronological age differences. Whilst the age-groups are intended to provide young athletes with better opportunities for developmentally appropriate instruction, equal competition and fair play, it seems that these groupings create a positive selection bias for relatively older athletes. Indeed, in accordance with observations of others [18, 28, 40] the present results indicate that relatively older soccer players also receive early recognition from coaches and talent scouts. This has been suggested to be due to their larger anthropometric dimensions and increased physiological capacity, rather than advantages in technical or tactical skills, especially during puberty and adolescence [28]. Accordingly, it seems logical to assume that in sports such as soccer where an advanced physical development is advantageous, the relatively younger players are at considerable disadvantage. However, in contrast, the present results showed no differences in anthropometric and physiological characteristics between players across all birth quarters in each category. Nonetheless, there was a trend with players born in the first quarter being taller and heavier than players born in the fourth quarter. This tendency was especially apparent in the younger age categories (further analysis revealed small to medium effect sizes for height (0.001-0.017) and weight (0.005-0.050) in all age categories). Whilst these tendencies in anthropometry are likely to be practically important (i.e., relatively older and thus taller players are likely to be more selected), they are most likely explained by increased chronological age. These observations agree with previous studies that also reported no differences across the four birth quarters in anthropometric and functional capacities in 160 French elite U14 soccer players [6] and 69 Portuguese 13-15 years old youth soccer players [28].

A possible explanation for the lack of differences between the birth quarters is that the talent identification and selection programs from which these players were selected, may have created homogenous groups of players possessing similar anthropometric characteristics and intermittent endurance capacity, whatever their birth month within an age group [6]. This may also explain the trends for differences in age at peak height velocity between the first and the last birth quarter. Indeed, whilst the players born in the fourth quarter are relatively younger, these players have compensated for this disadvantage through demonstrating an earlier age for onset of puberty (i.e., a younger age at peak height velocity). Hirose [21] reported similar findings in a study with 332 Japanese elite youth soccer players, aged 9−15 years, where the few players born late(r) in the selection year that were selected into the elite teams also showed advanced biological and physical characteristics. Collectively, these findings indicate an influence for a greater physique in the process of talent selection in soccer. In this study, it seems that players born later in the selection year have greater biological maturity or enter puberty earlier than players born earlier of the same age cohort to cope with the potential physical and physiological advantages of their relatively older peers. Therefore, coaches should be aware that physical and biological maturation are important components in the selection process. This could explain the homogeneity in anthropometric characteristics and intermittent endurance in the present sample of elite youth soccer players.

Soccer players that are born later in the selection year and mature later are less present at elite youth level presumably due to physical disadvantages [33]. Nevertheless, several previous studies have shown that these players eventually achieve similar anthropometric dimensions, body mass, strength and power as those who mature earlier [5, 27, 35]. To compete with taller and stronger peers, these players may improve other qualities or strategies, such as technical and tactical skills and improve psychological characteristics such as mental toughness and resilience. If late born and late maturing players avoid early deselection and remain in their sport until late adolescence/early adulthood (when the physical disadvantages disappear), they often outperform their early born or early mature counterparts. For instance, Carling et al. [6] reported that once players were selected into an elite youth academy (from the age of 13 years), their date of birth did not influence the opportunity to turn professional. Moreover, Vaeyens et al. [40] demonstrated no differences in the likelihood of being selected and playing minutes between early and late born adult Belgian semi-professional soccer players. Although whilst, a RAE was observed in these Belgian semi-professional soccer players, it was suggested that early dropout of youth soccer players born later in the year accounted for the skewed birth date distribution. Indeed, there is evidence, a greater rate of dropout in youth soccer players [19] and ice hockey [4] that from as early as 12 years. In accordance with these previous studies, the present results showed a RAE through all age categories (U10-U19), suggesting that many gifted, but relatively young players may be systematically overlooked simply because they are born late(r) in the selection year or late matures [28]. Additionally, within the last quarter late maturing boys seem no longer represented (drop out). In conclusion, it appears that the combination of being born later in a selection year and also have later maturation provide a significant disadvantage for being selected into elite youth soccer teams.

Finally, the present study reported no differences in intermittent endurance performance between early and late born players. Several possible explanations may account for this observation. First, the amount of practice hours, irrespective of birth quarter, within the two professional soccer clubs examined in this study is similar. These similarities in physical training stimulus may have resulted in noticeable homogenous training outcome for all players participating in this study. It seems that the talent selection procedures focus on the formation of homogenous groups of players having similar intermittent endurance capacities. Further research is wanted for other physical and physiological parameters, such as speed and explosive strength. Additionally, even players who were not selected in the starting 11 for each match were prescribed additional physical conditioning to ensure that they received similar training stimuli as the starting players for each age group. Furthermore, it has previously been reported that early and late maturing soccer players do not differ in running economy [36]. Indeed, in the two teams investigated in the present study, specific coordination programs were implemented and there was specific focus to ensure that each player was trained to move efficiently in soccer specific movements (i.e. change of direction and regular acceleration / decelerations). It was therefore likely that most players had similar movement proficiency which also may explain the lack of differences in the YoYoIR1 performance. Finally, since APHV was no confounding factor for the performance on the Yo-Yo IR1, the relatively advantages of maturation were likely to have a relatively small influence on the Yo-YoIR1 results.

In conclusion, the present findings provide no rationale for identifying and selecting primarily players born in the first quarter of the selection year. Our data revealed no differences in the Yo-Yo IR1 which assesses the soccer-specific aerobic capacity, one of the most important performance determinants. Searching for soccer players who display greater physical dominance (i.e., taller and heavier) over their peers during the selection process is likely to delimit selected players to early maturers or those who are relatively older than their peers. Since selection into elite development pathways for youth players often provide increased development and coaching opportunities, these older and more physically mature players are often inappropriately identified as being '*gifted'*. Indeed, there is the risk that players who are equally gifted but physically less mature at younger ages may be deselected on the basis of their poorer physical characteristics and not on their adult potential. At present, few programs that identify and develop young soccer players have the ability to account for these advantages in age and maturational status. Therefore, to overcome these limitations we suggest that greater consideration should be given to assessing individual biological maturation in the selection of adolescent players.

The present study indicated identification and development procedures that are focused on the formation of strong physical and physiological homogeneous groups. In elite youth soccer, within a specific age-group, a higher chronological age is not associated with a better Yo-Yo IR1 performance which suggests that the relative age of the players does not provide a significant advantage in terms of soccer-specific endurance. Therefore, coaches and talent scouts should understand that a player who is born late(r) in the selection year is not always a late maturing boy (conversely, a player who is born early in the selection year is not per definition early maturing). Therefore, coaches and talent scouts should aim to identify players with the potential for success in the long term, and focus on the holistic potential of players, including technical, tactical and psychological skills whilst also accounting for relative age and maturational status. The present observations may change the currently selection policies in elite soccer and facilitate the selection of greater number of players born in the late part of the selection year.

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STUDY 6

RELATIVE AGE, BIOLOGICAL MATURATION AND ANAEROBIC CHARACTERISTICS IN ELITE YOUTH SOCCER PLAYERS

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Abstract

Being relatively older and having an advanced biological maturation status have been associated with increased likelihood of selection in young elite soccer players. The aims of the study were to investigate the presence of a relative age effect and the influence of birth quarter on anthropometry, biological maturity and anaerobic parameters in 374 elite, Belgian youth soccer players. The sample was divided into 3 age-groups, each subdivided into four birth quarters (BQ). Players had their APHV estimated and height, weight, SBJ, CMJ, sprint 5 and 30 m were assessed. Overall, more players were born in BQ1 (42.3%) compared with players born in BQ4 (13.7%). Further, MANCOVA revealed no differences in all parameters between the four BQ's, controlled for age and APHV. These results suggest that relatively youngest players can offset the RAE if they enter puberty earlier. Furthermore, the results demonstrated possible differences between BQ1 and BQ4, suggesting that caution is necessary when estimating differences between players because of large discrepancies between statistical and practical significance. These findings also show that coaches should develop realistic expectations of the physical abilities of younger players and these expectations should be made in the context of biological characteristics rather than chronological age-based standards.

Introduction

Similar to many other sports, youth soccer competitions are organized into annual age groups according to chronological age with specific cut-off dates. Consequently, players who are born early in the selection year (e.g. first birth quarter) take advantage of this subtle chronological lead and are more likely to be selected compared with peers born later in the selection year (e.g. fourth birth quarter). This difference in chronological age is referred to as relative age, and its consequences are known as the relative age effect (RAE). Being chronologically older within an annual age cohort provides significant attainment advantages when compared with those who are chronologically younger. As a consequence, this RAE leads to skewed birth date distributions in many sports with overrepresentation of youth and professional level athletes born in the first part of the selection year [12, 13, 22, 29].

Similar to relative age advantages, advanced biological maturity has also been associated with an increased likelihood of selection in youth athletes. It has been previously shown that youth athletes who are advanced in biological maturation perform better in strength, speed, power and endurance compared with less mature age-matched counterparts [9, 18, 30], others have demonstrated that athletes born earlier in the selection year tend to be taller and heavier than their later born peers [4, 13]. As a result, coaches and talent scouts have been likely to favour the physically advanced players. Indeed, Sherar et al. [25] reported that team selectors more frequently select taller, heavier and early maturing ice-hockey players who have birthdates early in the selection year. In contrast, Hirose [13] and Deprez et al. [8] revealed no differences in height and body mass between the four birth quarters in elite Japanese soccer players, aged 9-15 years and elite Belgian soccer players, aged 9-17 years, respectively. Notably however, the small number of players born later in the selection year possessed advanced physical and biological maturation, which likely explains why these players were successfully selected into elite representative teams [8, 13]. Carling et al. [4] showed similar trends in French 14-year-old elite soccer players reporting that relatively older players are not always linked to advantages in physical and physiological components. In addition, Segers et al. [24] reported no differences in endurance between early and late maturing youth soccer players when adjusted for lean body mass. Collectively, these studies show that biological maturity can also influence selection of youth athletes. Indeed, the combination of increased biological maturity and an older age, and their relation to physical performance appears to provide young athletes significant advantage.

The physical factors that are associated with successful soccer have been well described [27]. Whilst improved high intensity running capacity has been shown to distinguish between players of different levels [21], other skills that require increased anaerobic capacity and neuromuscular power such as sprints, jumps, duels and kicking have also been shown to discriminate between different levels of soccer players [6]. For example, Vaeyens et al. [30] revealed better performances of skills requiring increased anaerobic power (sprint performance, vertical jump and standing broad jump) in elite youth soccer players when compared with sub-elite and non-elite youth soccer players (U13-U14).

To our knowledge, little is known about the age-related variation in anaerobic performance in elite youth soccer players. Additionally, only a few studies investigated the relationship between the RAE, biological maturation and anaerobic performance [4, 13]. Therefore, the aims of the study were to investigate 1) the presence of a RAE and 2) the influence of the possible RAE (or birth quarter) on anthropometric variables, an estimation of biological maturity and some important anaerobic parameters in Flemish, elite youth soccer players aged 11 to 16 years.

Methods

Participants and design

Elite youth soccer players from two professional clubs from the Belgian first division (Jupiler Pro League) participated in the study. The age-range of the players was 10.6 – 16.6 y. All players and their parents or legal representatives were fully informed of experimental procedures before giving their written informed consent. The study was approved by the Ethic Committee of the Ghent University Hospital and the study was performed in accordance to the ethical standards of the International Journal of Sports Medicine [10].

The sample included 555 data points from 374 individual soccer players, all born between 1993 – 2003. Players were divided into three different age categories: U13 (aged 10.6–12.6 y; *n=146*), U15 (aged 12.6–14.6 y; *n=162*) and U17 (aged 14.6–16.6 y; *n=247*).

Data were collected on 15 different test periods over 5 years between August 2007 and August 2011. Within each season, the test periods were scheduled at the same time within the soccer season: preparation period (*August*), game period 1 (before winter break, *October-November*), game period 2 (after winter break, *February*) and at the end of the season (*April*, this only in 2008 and 2009). Accordingly, a small number of players had several measures taken within each age category. To ensure that only one measurement was taken for each player within each age category, the best performance on all variables was taken. Data included only one measurement for each player per test year to ensure that players had a maximum of five measurements from each of the different age categories (n players with one measurement = 255; n players with two measurements = 76; n players with three measurements = 29; n players at four measurements = 9; n players with five measurements = 5).

All participants were categorized into four birth quarters (BQ) according to their month of birth. The cut-off date for the selection year for youth soccer players in Belgium runs from January 1 to December

31, so players were categorized in these four birth quarters: BQ1: January-March, BQ2: April-June, BQ3: July-September, BQ4: October-December.

Measurements

Prior to the testing of anaerobic performance characteristics, the anthropometrical characteristics of each player were assessed: with height (0.1 cm, Harpenden Portable Stadiometer, Holtain, UK), sitting height (0.1 cm, Harpenden Sitting Height Table, Holtain, UK) and body mass (0.1 kg, total body composition analyzer, TANITA BC-420SMA, Japan) according to previously described procedures (Lohman, 1988) and manufacturer's guidelines.

Estimation of biological maturation of each individual was calculated by the non-invasive method, based on anthropometric variables described by Mirwald et al. [20]. Equation 3 predicts the years from peak height velocity as a measure of maturity offset. The age of peak height velocity (APHV) is than calculated as the difference between the chronological age and the predicted time (in years) from peak height velocity. APHV is an indicator of biological maturity representing the time of maximum growth during adolescence.

After a 10 min standardized warm-up period, the players completed a test battery in a fixed order to assess motor competence and physiological fitness. In this study, three measurements of anaerobic performance were applied for further analysis. To evaluate explosive leg power, counter movement jump (CMJ) and standing broad jump (SBJ) were performed. CMJ was conducted according to the methods described by Bosco et al. [3] with the arms kept in the akimbo position to minimize their contribution recorded by an OptoJump (MicroGate, Italy). The highest of three jumps was used for further analysis (0.1 cm). The SBJ is part of the Eurofit test battery and was conducted according to the guidelines of the Council of Europe [7] (1 cm). The players also performed four maximal sprints of 30 m with split times at 5 m, 10 m, 20 m and 30 m, with the fastest 5 m and the fastest 30 m used for analysis in order to ensure a maximal value (i.e. the fastest 5 m is not necessarily the split time from the fastest 30 m sprint). Between each 30 m sprint, players had 25 s to recover. The sprint performance was recorded using MicroGate RaceTime2 chronometry and Polifemo light photocells (Bolzano, Italy) (0.001 s). All tests were completed on an indoor tartan running track with a temperature between 15−20°C. All subjects were familiarized with the test procedures and performed the tests with running shoes, except for the SBJ which was conducted on bare feet.

Statistical analyses

All statistical analyses were completed using SPSS for windows (version 19.0). Descriptive statistics are presented as means ± standard deviations (SD). First, differences between the observed and the expected birth date distributions were investigated with chi-square statistics. Expected birth date distributions were calculated in accordance with the birth rate of the Flemish population between 1991 and 2000 (National Institute of Statistics) using weighted means. Second, within each age category, differences between birth quarters (independent variable) were calculated using one-way ANOVA with chronological age (CA) and APHV as dependent variables. Multivariate analysis of covariance (MANCOVA) with CA and APHV as covariates and height, weight, CMJ, SBJ, 5m and 30m sprint as dependent variables, was used to investigate differences between birth quarters (independent variable). Chronological age and APHV were controlled for as these are potential confounding factor in the analysis. Minimal statistical significance was set at $P<0.05$. Follow-up univariate analyses using Bonferroni *post hoc* test were used where appropriate.

Since several authors described large differences in anthropometrical characteristics and physical capacities between chronologically older and younger players within the same age-group [9, 18, 30], further analysis was conducted to identify smallest worthwhile differences between players born in the first and fourth birth quarter, using the method outlined by Hopkins [14, 15]. This approach represents a contemporary method of data analysis that uses confidence intervals in order to calculate the probability that a difference is clinically beneficial, trivial or harmful. The smallest worthwhile difference was set at Cohen's effect size of 0.2, representing the hypothetical, smallest difference between birth quarter one and four. Cohen's *d* effect sizes (ES) and thresholds (0.2, 0.6, 1.2, 2.0, 4.0 for trivial, small, moderate, large, very large and extremely large) were also used to compare the magnitude of the differences in anthropometrical characteristics and physical parameters between BQ1 and BQ4 [15]. Where the chance of benefit and harm were both calculated to be ≥ 5%, the true effect was deemed unclear. When clear interpretation was definitively possible, a qualitative descriptor was assigned to the following quantitative chances of benefit: <0.5%: *most unlikely*; 0.5-5%: *very unlikely*; 5-25%: *unlikely*; 25-75%: *possibly*; 75-95%: *likely*; 95-99.5%: *very likely*; >99.5: *most likely* [15].

Results

Birth date distribution

From the total sample of U13-U17 players, the birth date distribution differed significantly from the Flemish population ($\chi^2_3=104.6$, $P<0.001$). Significantly more players were born in the first quarter of the selection year compared with the fourth quarter with a decreasing number of players from BQ1 to BQ4 (*BQ1*: 42.3%; *BQ2*: 26.1%; *BQ3*: 17.8%; *BQ4*: 13.7%). This observation was apparent for each age-group. The proportion of players born in BQ1 varied between 40.1 and 44.4%, while proportion of players born in BQ4 varied between 12.3 and 14.8%. ***Table 1*** shows birth date distributions across all birth quarters for the total sample and for each age group.

Anthropometric variables

Table 2 shows no differences for height and weight between BQ groups in all age-groups except for height in the U15 age-group. In the U15 age-group, players born in BQ2 (162.7 ± 8.5 cm) and BQ3 (162.1 ± 7.9 cm) were significantly ($P<0.05$; $F=2.923$) taller than players born in BQ4 (157.8 ± 7.9cm). Both chronological age and APHV were significant covariates for height and weight in all age-groups. ANOVA revealed no significant differences for APHV between birth quarters in all age-groups.

Anaerobic parameters

Within all age-groups, MANCOVA demonstrated no significant differences between birth quarters for all anaerobic performance characteristics when CA and APHV were controlled for (U13: $P=0.570$, $F=0.907$; U15: $P=0.337$, $F=1.112$; U17: $P=0.770$, $F=0.741$). Besides, the covariates, CA and APHV significantly confound all investigated variables in all age-groups (*CA*: U13, $P<0.001$, $F=99.593$; U15, $P<0.001$, $F=75.958$; U17, $P<0.001$, $F=26.805$; *APHV*: U13, $P<0.001$, $F=140.739$; U15, $P<0.001$, $F=263.965$; U17, $P<0.001$, $F=117.312$).

Further ANCOVA analyses for each variable revealed that for all age-groups, chronological age was significant as a covariate between birth quarters for all anaerobic parameters, except for the 5-m and 30-m sprint times within the U13 age-group (***Table 2***). In addition, within the U13 age-group, the covariate APHV did not significantly confound the anaerobic performance characteristics. This is in contrast with the U15 and U17 age-group, where APHV did significantly confound all anaerobic performance characteristics.

Practical/clinical significance

Where the statistical analyses revealed no differences between birth quarters in each age-group, analyses of practical significance showed contrasting results. Especially in the U13 age-group, differences were assigned as possible to likely benefits for players in BQ1 relative to BQ4, supported by small to moderate ES's (0.31 to 0.97). Trivial to small ES's (0.00-066) were found in the U15 and U17 age-group resulting in unclear to likely chances of benefit for players born in BQ1 (***Table 3***). Comparison of semester 1 and 2 values revealed similar results.

Table 1 *Birth date distribution per quarter (BQ) by age group (n (%))*

Age Category	*n*	BQ 1	BQ 2	BQ 3	BQ 4	χ^2_3 *(BQ)*
U13-U17	*555*	235 *(42.3%)*	145 *(26.1%)*	99 *(17.8%)*	76 *(13.7%)*	104.610*
Flanders		*81,921 (25.0%)*	*83,539 (25.4%)*	*84,741 (25.8%)*	*78,124 (23.8%)*	
U13	*146*	64 (*43.8%*)	40 (*27.4%*)	24 (*16.4%*)	18 (*12.3%*)	34.498*
Flanders		*15,827 (24.9%)*	*16,135 (25.3%)*	*16,525 (26.0%)*	*15,178 (23.8%)*	
U15	*162*	72 (*44.4%*)	36 (*22.2%*)	30 (*18.5%*)	24 (*14.8%*)	34.202*
Flanders		*16,292 (24.9%)*	*16,687 (25.5%)*	*16,816 (25.7%)*	*15,610 (23.9%)*	
U17	*247*	99 (*40.1%*)	69 (*27.9%*)	45 (*18.2%*)	34 (*13.8%*)	38.240*
Flanders		*16,999 (25.1%)*	*17,214 (25.4%)*	*17,502 (25.8%)*	*15,997 (23.6%)*	

* *P<0.001*

Table 2 *Chronological age (CA), estimation of biological maturity (APHV) and anthropometric variables of elite youth soccer players (U13-U17) across four birth quarters*

Age Category	Variable	BQ1	BQ2	BQ3	BQ4	Covariates F(CA)	Covariates P	Covariates F(APHV)	Covariates P	F(BQ)	P
U13		*n = 64*	*n = 40*	*n = 24*	*n = 18*						
	CAge (years)	$12.0 \pm 0.5_A$	$11.7 \pm 0.5_A$	$11.3 \pm 0.5_B$	$11.3 \pm 0.5_B$	-	-	-	-	*15.997*#	***
	APHV (years)	13.7 ± 0.4	13.6 ± 0.4	13.6 ± 0.3	13.6 ± 0.3	-	-	-	-	*1.106*#	*P=0.349*
	Height (cm)	151.1 ± 6.5	150.6 ± 6.5	145.8 ± 4.9	145.5 ± 5.0	*326.953*	***	*428.864*	***	*1.022*	*P=0.385*
	Weight (kg)	39.1 ± 4.9	39.2 ± 5.7	36.9 ± 5.2	36.1 ± 4.0	*247.464*	***	*344.424*	***	*1.345*	*P=0.262*
	SBJ (cm)	177 ± 14	176 ± 14	174 ± 13	173 ± 10	*5.619*	*	*0.574*	*P=0.450*	*0.081*	*P=0.970*
	CMJ (cm)	24.5 ± 3.5	24.6 ± 2.6	24.1 ± 3.2	23.3 ± 3.6	*5.368*	*	*3.708*	*P=0.056*	*0.487*	*P=0.692*
	Sprint 5m (sec)	1.23 ± 0.07	1.22 ± 0.07	1.26 ± 0.05	1.25 ± 0.06	*1.144*	*P=0.287*	*0.001*	*P=0.977*	*1.664*	*P=0.177*
	Sprint 30m (sec)	5.17 ± 0.21	5.17 ± 0.18	5.27 ± 0.17	5.23 ± 0.29	*1.453*	*P=0.230*	*0.458*	*P=0.500*	*0.776*	*P=0.509*
U15		*n = 72*	*n = 36*	*n = 30*	*n = 24*						
	CAge (years)	14.0 ± 0.5	13.8 ± 0.5	13.6 ± 0.5	13.2 ± 0.5	-	-	-	-	*12.696*#	***
	APHV (years)	14.0 ± 0.6	13.9 ± 0.6	14.0 ± 0.6	13.9 ± 0.6	-	-	-	-	*0.203*#	*.P=0.894*
	Height (cm)	$163.4 \pm 9.1_{A,B}$	$162.7 \pm 8.5_A$	$162.1 \pm 7.9_A$	$157.8 \pm 7.9_B$	*269.445*	***	*989.974*	***	2.923	*
	Weight (kg)	50.7 ± 8.6	50.7 ± 8.4	49.0 ± 8.4	46.8 ± 9.8	*158.300*	***	*635.674*	***	*0.584*	*P=0.627*
	SBJ (cm)	193 ± 17	196 ± 18	190 ± 14	190 ± 16	*20.610*	***	*29.025*	***	*0.886*	*P=0.450*
	CMJ (cm)	27.7 ± 4.2	29.2 ± 3.8	28.0 ± 4.6	26.7 ± 4.5	*16.294*	***	*16.199*	***	*1.933*	*P=0.127*
	Sprint 5m (sec)	1.18 ± 0.07	1.17 ± 0.07	1.17 ± 0.07	1.21 ± 0.07	*8.460*	**	*9.167*	**	*0.680*	*P=0.566*
	Sprint 30m (sec)	4.86 ± 0.24	4.80 ± 0.22	4.91 ± 0.32	4.96 ± 0.28	*41.916*	***	*27.999*	***	*1.567*	*P=0.200*
U17		*n = 99*	*n = 69*	*n = 45*	*n = 34*						
	CAge (years)	15.9 ± 0.5	15.8 ± 0.5	15.5 ± 0.5	15.3 ± 0.5	-	-	-	-	*18.663*#	***
	APHV (years)	14.0 ± 0.6	13.9 ± 0.5	14.0 ± 0.6	14.0 ± 0.6	-	-	-	-	*0.990*#	*P=0.398*
	Height (cm)	174.0 ± 6.5	175.1 ± 6.3	172.1 ± 6.3	171.9 ± 5.9	*82.329*	***	*492.053*	***	*0.325*	*P=0.807*
	Weight (kg)	62.2 ± 8.4	64.7 ± 7.3	60.3 ± 8.0	59.5 ± 7.8	*69.949*	***	*395.959*	***	*1.866*	*P=0.136*
	SBJ (cm)	219 ± 17	221 ± 18	214 ± 17	215 ± 16	*52.374*	***	*52.006*	***	*0.784*	*P=0.504*
	CMJ (cm)	33.6 ± 4.7	34.5 ± 4.5	32.9 ± 4.3	33.1 ± 4.0	*42.656*	***	*40.658*	***	*1.667*	*P=0.175*
	Sprint 5m (sec)	1.10 ± 0.07	1.09 ± 0.07	1.12 ± 0.07	1.10 ± 0.05	*10.204*	**	*4.008*	*	*1.283*	*P=0.281*
	Sprint 30m (sec)	4.46 ± 0.20	4.43 ± 0.18	4.52 ± 0.19	4.52 ± 0.20	*45.431*	***	*50.162*	***	*0.701*	*P=0.552*

Means having a different subscript are significantly different at $p<0.05$. Between-subjects effects for covariates and BQ are significant at: $p<0.05$; ** $p<0.01$; *** $p<0.001$; n.s. not significant. # F- and P-values for one way analysis of variance.*

Table 3 *Mean differences, effect sizes and chances of benefit for differences between BQ1 and BQ4 for anthropometrical and anaerobic parameters in each age-group.*

Age Category	Variable	BQ1 (Mean; ±*90% CL*)	BQ4 (Mean; ±*90% CL*)	Mean diff (*±90% CL*)	*ES*	*Magnitude*	SWD (%)	% chances *B (T/H)*	Chances of benefit (Qualitative)
U13		*n = 64*	*n = 18*						
	Height (cm)	151.1; ± *1.4*	145.5; ± *2.0*	5.6; ± *2.8*	*0.97*	*Moderate*	1.3 (*0.9*)	99 (1/0)	Very likely
	Weight (kg)	39.1; ± *1.0*	36.1; ± *1.6*	3.1; ± *2.1*	*0.67*	*Moderate*	1.0 (*2.5*)	47 (53/0)	Possibly
	SBJ (cm)	177; ± *2.8*	173; ± *4.0*	3.7; ± *5.7*	*0.33*	*Small*	2.6 (*1.5*)	34 (65/1)	Possibly
	CMJ (cm)	24.5; ± *0.7*	23.3; ± *1.5*	1.1; ± *1.6*	*0.34*	*Small*	0.7 (*3.0*)	61 (37/2)	Possibly
	Sprint 5m (sec)	1.23; ± *0.01*	1.25; ± *0.03*	-0.02; ± *0.03*	*-0.31*	*Small*	0.01 (*1.1*)	62 (37/1)	Possibly
	Sprint 30m (sec)	5.17; ± *0.04*	5.23; ± *0.12*	-0.06; ± *0.1*	*-0.24*	*Small*	0.05 (*0.9*)	52 (45/3)	Possibly
U15		*n = 72*	*n = 24*						
	Height (cm)	163.4; ± *1.8*	157.8; ± *2.8*	5.6; ± *3.5*	*0.66*	*Moderate*	1.8 (*1.1*)	94 (6/0)	Likely
	Weight (kg)	50.7; ± *1.7*	46.8; ± *3.4*	3.9; ± *3.5*	*0.42*	*Small*	1.8 (*3.6*)	4 (96/0)	Very unlikely
	SBJ (cm)	193; ± *3.3*	190; ± *5.7*	3.2; ± *6.5*	*0.18*	*Trivial*	3.4 (*1.8*)	16 (83/1)	Unlikely
	CMJ (cm)	27.7; ± *0.8*	26.7; ± *1.6*	1.0; ± *1.7*	*0.23*	*Small*	0.8 (*3.1*)	2 (98/0)	Very unlikely
	Sprint 5m (sec)	1.18; ± *0.01*	1.21; ± *0.03*	-0.03; ± *0.03*	*-0.43*	*Small*	0.01 (*1.2*)	76 (24/0)	Likely
	Sprint 30m (sec)	4.86; ± *0.05*	4.96; ± *0.10*	-0.10; ± *0.11*	*-0.38*	*Small*	0.05 (*1.1*)	74 (26/0)	Possibly
U17		*n = 99*	*n = 34*						
	Height (cm)	174.0; ± *1.1*	171.9; ± *1.7*	2.1; ± *2.1*	*0.34*	*Small*	1.3 (*0.7*)	51 (2/47)	Unclear
	Weight (kg)	62.2; ± *1.4*	59.5; ± *2.3*	2.7; ± *2.8*	*0.33*	*Small*	1.7 (*2.7*)	1 (86/0)	Unlikely
	SBJ (cm)	219; ± *2.9*	215; ± *4.8*	4.4; ± *5.6*	*0.24*	*Small*	3.4 (*1.6*)	39 (61/0)	Possibly
	CMJ (cm)	33.6; ± *0.8*	33.1; ± *1.2*	0.4; ± *1.5*	*0.11*	*Trivial*	0.9 (*2.7*)	1 (99/0)	Very unlikely
	Sprint 5m (sec)	1.10; ± *0.01*	1.10; ± *0.01*	0.00; ± *0.02*	*0.00*	*Trivial*	0.01 (*1.1*)	24 (69/7)	Unclear
	Sprint 30m (sec)	4.46; ± *0.03*	4.52; ± *0.06*	-0.06; ± *0.07*	*-0.30*	*Small*	0.04 (*0.9*)	71 (28/0)	Possibly

CL *= Confidence Limits;* ***Mean diff*** *= Mean difference;* ***ES*** *= Cohens' d effect size;* ***SWD*** *= Smallest Worthwhile Difference;* ***B (T/H)*** *= Beneficial (Trivial/Harmful)*

Discussion

The aim of this study was to investigate the influence of birth quarter on anthropometric variables, an estimation of biological maturational status and anaerobic parameters in 374 Belgian, elite youth soccer players. In general, significantly more players were born in the first quarter of the selection year compared with players born in all other quarters (Q1>Q2>Q3>Q4). Further, no statistical differences were observed in any anthropometric variables in all age-groups, except for height in the U15 age-group where players born in BQ2 and BQ3 were taller than players born in BQ4. Similarly, no differences were found in anaerobic performance characteristics between the birth quarters in all age-groups. Further, the results were supported by analyses of practical significance that suggested ‘possible benefits’ for players born in birth quarter 1 compared with players born in birth quarter 4 in the U13 age-group. The benefits in the older age-groups for players born in birth quarter 1 were smaller, supported by smaller effect sizes.

The present study revealed that at the highest level of Belgian youth soccer competition (U13−U17) a large relative age effect exists. That is, players born in the first birth quarter of the selection year (40.1−43.8%) are more likely to have been selected compared with peers born in the other birth quarters (BQ2: 22.2–27.9%, BQ3: 16.4–18.5%, BQ4: 12.3–14.8%). The birth date distribution of selected players is in contrast to the evenly distribution of birth dates in the Flemish population. These findings are in agreement with many other studies in Belgian and other European elite youth soccer players [8, 12, 22, 29], where there was a large bias in the proportional distribution of birth date of selected players towards the first quarter of the selection year. Moreover, research from other team sports such as ice hockey, volleyball, basketball and rugby, have also reported skewed birth date distributions towards an earlier birth date from cut-off date [2, 5, 25].

To date, only a few studies related quarter of birth to physical and physiological capacities and maturation in young soccer players [4, 8, 13]. The results of the present study, among others, suggest that chronologically older players benefit from early recognition from coaches and talent scouts [11, 19, 29]. Indeed, a recent review revealed that the relatively younger sports participants under 14 years of age are less likely to participate in competitive sports [5]. Moreover, it was also suggested that both competitive sports participation and a career in professional sports is less likely for relatively younger individuals. In soccer however, it has been suggested that both the combination of being relatively older and having increased biological maturation status underlie the increased likelihood of being selected in youth soccer [5, 11]. In addition, interacting psychological factors, linked with selection and experience differences according to relative age have also been presented to account for RAE’s. Relatively older players may be more likely to develop higher perceptions of competency and self-efficacy. Otherwise, relatively younger players, faced with consistent sport selection disadvantages may be more likely to have negative experiences, develop low competence perceptions, and thus terminate the sport involvement [5, 23].

It has been suggested that both biological maturation and selection of young players within their developmental phase and the organization of soccer competition are responsible for large RAE's observed in team sports such as soccer [5, 11]. Indeed, many studies in youth sports explain the overrepresentation of players born early in the selection year by their larger anthropometric dimensions and other physical performance advantages, especially in sports where strength, speed and endurance are key factors [18, 23, 25].

In contrast however, the present results showed no statistical differences in anthropometric characteristics and functional capacities between players across all birth quarters. This finding agrees with a study in 332 Japanese youth soccer players (U10-U15) that revealed no differences in height and body mass across the four birth quarters [13]. Additionally, both Malina et al. [19] and Carling et al. [4] found similar results for anthropometric parameters and functional capacities in 39 elite Portuguese soccer players aged 14 years and 160 elite French youth soccer players aged 14 to 16 years, respectively. Also, Deprez et al. [8] reported no differences in anthropometric characteristics across the four birth quarters in 606 elite Belgian soccer players aged 9 to 17 years. The lack of difference between the physical characteristics (aerobic and anaerobic) of the athletes of each birth quarter in these studies most likely reflects the pubertal variation within each of the samples [19].

The overrepresentation of players born in the first birth quarter of the selection year compared with the fourth birth quarter has been suggested to be attributed to an identification and selection policy in soccer based on physical qualities rather than technical or tactical skills [11]. However, in the present study, we observed no significant differences in anthropometric dimensions and anaerobic parameters across all birth quarters in all age-groups. Moreover, there were no differences in APHV between players of all birth quarters in all age cohorts. Taken together, the present results agree with others who suggested that the relatively small number of players born later in the selection year but with advanced biological maturity are successful in being selected for elite teams [8, 13]. Therefore, it seems that the relatively youngest soccer players may be able to counteract the RAE (i.e. to cope with the potential physical disadvantages of being born relatively later in the selection year) if they enter puberty at a relatively earlier age than their chronologically older counterparts. To further examine this suggestion, the present sample of soccer players were divided in three different maturity groups per age-group, based on the APHV: early maturing players (percentile 1 to 33), average maturing players (percentile 33 to 66) and late maturing players (percentile 66 to 100). The distribution of the early, average and late maturing players within each quarter was then analyzed. This analysis demonstrated for all age-groups, that within the first birth quarter, late maturing players were overrepresented when compared with early maturing players (U13, late: 41.3%, early: 27.0%; U15, late: 33.3%, early: 30.6%; U17, late: 35.6, early: 27.3%). On the other hand, within the fourth birth quarter, early maturing players were more present when compared with late maturing players (U13, early: 33.3%, late: 27.8%; U15, early: 37.5%, late: 33.3%; U17, early: 36.4%, late: 35.3%). This suggests that being born in the first birth quarter increases the chance of being present at elite level, independently from the maturation status. However, players born in the last quarter may have increased their chance for selection at the elite level if they enter puberty at a relatively earlier chronological age. We do however acknowledge that this method of categorizing players into maturity groups does not correspond with the method described by Sherar et al. [25] based on equation 3 from Mirwald et al. [20], which defined early maturers as preceding the average APHV by 1 year, average maturers were ±1 year from APHV and late maturers were >1 year after APHV. Moreover, since it has been suggested that soccer systematically excludes late maturing boys and tend to favour early and average maturing players as chronological age and sports specialization increase [17], it is possible that the present sample of elite soccer players might also exclude these late maturing players. Further research should compare different maturity status per birth quarter using skeletal age as classification index (cf. Figueiredo et al. [9]).

Despite the lack of statistical significance between all birth quarters in each age-group, analyses of practical significance between the first and fourth birth quarter revealed possible benefits for players born in the first birth quarter, especially in the U13 age-group. This has certainly implications for the talent identification and development programs at this age. In the field, the coach does not have the opportunity to account for chronological age and maturity in the evaluation and assessment of young soccer players. Therefore, standard for smallest worthwhile differences (SWD) between birth quarters could assist the coach (*Table 3*).

A notable observation was that the differences reduced when players are growing older, resulting in smaller effect sizes. Several reasons might account for this observation. First, each player will eventually reach the adult stage and achieve full maturation, leveling off the differences existing in the younger age-groups. Second, youth athletes differ in timing and tempo of development, growth and maturation, demonstrating large inter-individual differences in anthropometrical characteristics and physical capacities, independent of the birth quarter the player is born in [18, 20]. Finally, drop-out of harmed players and selection policies in favor of players with similar anthropometrical characteristics and physical capacities could result in more homogeneous birth quarters when players are growing older. Further longitudinal research is required to investigate these observations.

The anaerobic performance results obtained in this study are comparable with several previous studies. For example, Vaeyens et al. [30] reported values for SBJ between 170.1 ± 14.5 cm and 201.5 ± 13.6 cm, for U13 and U16 elite Belgian soccer players, respectively. Also, Sporis et al. [26] found similar results for 5-m sprint (1.39 ± 0.13 s), SBJ (219.0 ± 15.2 cm) and CMJ (45.7 ± 3.85 cm) in 45 elite Croatian soccer players. A study with 69 elite Portuguese soccer players, aged 14 years showed similar results on the 30 m sprint (4.88 ± 0.30 s) and CMJ (29.3 ± 4.6 cm) performance [18]. When interpreted in the context of these previous studies, the present results demonstrate high physical performance levels of the young Belgian soccer players.

The present study has its limitations which should be acknowledged. First, other potential predictors of talent, like training history, psychological and sociological characteristics, were not included in the analysis, although these affect the talent identification and selection process. Second, further research concerning the validation of the age at peak height velocity protocol in a soccer population within a large age-range is warranted. The method has in a general population been successfully validated against the golden standard (X-rays, Mirwarld et al. [20]), but not in a soccer-specific sample. These limitations should be considered when considering further research in this area. An individual's maturity status can also be estimated by using x-rays, assessment of secondary sex characteristics or the parent's adult stature [16, 17, 28]. However, these methods also entail ethical, practical, financial and accuracy issues.

The identification and selection policies in the present sample of elite youth soccer players have led to the formation of homogenous groups of players having similar body size dimensions and anaerobic performances, regardless of their birth date within their age-group. The present results suggest this selection phenomena may start before the age of 11 years. Unfortunately, this implies that relatively younger players, especially those who have a delayed maturity status are unlikely to develop their sporting potential or continue participation in sports, due to their physical and physiological disadvantages. Likewise, being relatively older provides a performance and selection advantage when assessed or evaluated against annual age-group peers which increases the likelihood of access to higher levels of competition, training and coaching [5, 12]. Youth coaches and scouts should be aware that physical and biological maturation is important in the selection process and they should not discriminate against younger or late-maturing players who may develop their abilities later [1]. Therefore we suggest that national soccer associations should implement specific development programs that consider biological maturation and maturity independent performance tests in the identification and selection of youth soccer players. However, in contrast with the statistical lack of differences between birth quarters, analyses of practical significance demonstrated possible practical/clinical differences between birth quarters, especially in the younger age-group. Therefore, youth coaches and scouts should be cautious about the estimation of differences between birth quarters because of large discrepancies between statistical and practical/clinical significance.

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Chapter 3:
Longitudinal research

STUDY 7

MODELING DEVELOPMENTAL CHANGES IN YO-YO INTERMITTENT RECOVERY TEST LEVEL 1 IN ELITE PUBERTAL SOCCER PLAYERS

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Abstract

Purpose: To model the development of soccer-specific aerobic performance, assessed by the Yo-Yo IR1 in 162 elite pubertal soccer players, aged 11 to 14 years at baseline. **Methods**: Longitudinal multilevel modeling analyses comprised predictors related to growth (chronological age, body size [height and weight] and composition [fat mass, fat free mass]), motor coordination [3 *Körperkoordination Test für Kinder* subtests: jumping sideways, moving sideways, backward balancing] and estimated biological-maturation groups (earliest [<percentile 33] and latest maturers [>percentile 66]). **Results**: The best-fitting model on soccer-specific aerobic performance could be expressed as -3639.76 + 369.86 x age + 21.38 x age^2 + 9.12 x height – 29.04 x fat mass + 0.06 x backward balance. Maturity groups had a negligible effect on soccer-specific aerobic performance (-45.32 ± 66.28; $P > .05$). **Conclusion**: The current study showed that the development of aerobic performance in elite youth soccer is related to growth and muscularity and emphasized the importance of motor coordination in the talent identification and -development process. Note that biological maturation was excluded from the model, which might endorse the homogeneity in estimated biological-maturation status in the present elite pubertal soccer sample.

Introduction

Research from a variety of team sports, such as soccer, basketball and handball, have shown that the ability to perform intermittent high intensity activity seems to be an important discriminating factor between elite and subelite players.[1] Moreover, it has been suggested that increased aerobic fitness is an important physiological quality that allows players to recover faster between high intensity efforts and exercise at higher intensities during prolonged high intensity intermittent exercise.[1] The Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IRT1) is a soccer specific field test that maximizes the aerobic energy system through intermittent exertion.[2] Several previous studies in adults have shown that the Yo-Yo IR1 performance has a high level of reproducibility[2,3] and is a valid measure of prolonged, high intensity intermittent running capacity.[4]

It has been reported that around the age of 13-14 years, soccer systematically excludes the late maturing players when chronological age and sports specialization increase.[5] Also, Philippaerts et al.[6] showed that the average age at peak height velocity (13.8 ± 0.8 y) in 33 male youth soccer players was slightly earlier compared to the general population. Also, corresponding data for peak oxygen uptake indicated maximal gains coincident with peak height velocity and continued to improve during adolescence.[7] It seems that around the age of 14 years, maturational status has a critical impact on the further development of physiological characteristics in pubertal athletes and has implications for talent identification and development programs.[8] Maturational status should be considered when evaluating young athletes. Therefore, longitudinal designs are necessary in defining pathways to excellence.[9]

Longitudinal observations in 453 young athletes, aged 8 to 16 years in four different sports suggested that in athletes, the increase in VO_2max with advancing pubertal development is caused by an increase in the metabolic capacity, but that training before puberty was having little if any effect on aerobic power.[8] Moreover, it has been shown that in 160 Flemish youth soccer players, aged 10-13 years (Ghent Youth Soccer Project), aerobic endurance assessed by the endurance shuttle run is an important discriminating characteristic between elite and sub-/non-elite players near the end of puberty (U15-U16) in favour of elite players.[10] Also, a study with 83 Portuguese soccer players, aged 11-13 years, revealed that the development of aerobic performance was significantly related to chronological age, biological development, and volume of training.[11] However, the development of aerobic power by chronological age decreased after the end of puberty (~15 y), which is in accordance with findings from Roesher et al.[12]

The importance of non-specific motor coordination in predicting future success in young athletes has been highlighted by others.[13,14] A study in youth soccer reported that an advanced biological maturity did not correspond to a better motor coordination, suggesting that the inclusion of coordination tests in talent identification programs might prevent the deselection of late maturing boys.[15] Correspondingly, running economy was independent of maturational status in a sample of youth soccer players, even after allometric scaling for body mass, suggesting that running style might have an explanatory value.[16]

The aim of the present study was to model the development of soccer-specific aerobic performance in elite pubertal soccer players varying in biological maturity status, based on the contribution of growth, body size and coordination parameters.

Methods

Subjects and study design

The present longitudinal study included 162 male youth soccer players from two professional Flemish soccer clubs, aged 10-14 years (mean age of 12.2 ± 1.3 y) at baseline (***Table 1***). The total measurements of each individual player varied between 3 and 14 measurements, spread over 1-5 years between 2007 and 2012. A total of 850 observations (average 5.2 observations per player) were available. All subjects were divided into four age groups at baseline: 11 y (n=68), 12 y (n=32), 13 y (n=26) and 14 y (n=36). Within all age groups, age varied between 10.2-11.8 y, 11.7-12.7 y, 12.7-13.7 y and 13.5-14.8 y, for the 11 y, 12 y, 13 y and 14 y age groups, respectively. All players and their parents or legal representatives were fully informed about the experimental procedures of the study, before giving their written informed consent. The study was performed conform the Declaration of Helsinki and approved by the Ethics Committee of the University Hospital. This research was performed without financial support and the authors assure no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Chronological age and biological maturity

Chronological age was calculated as the difference between date of birth and date on which the assessments were made. Predicted age at peak height velocity was obtained using the algorithm derived from two longitudinal studies of Canadian youth and one of Belgian twins[17]. The time before or after peak height velocity in years, labeled maturity offset was determined as follows[17]:

$$
\begin{aligned}
\text{Maturity offset .years} = \; & -9{:}236 \\
& + (0.0002708 * (\text{Leg Length} * \text{Sitting Height}) \\
& - 0.001663 * (\text{Age} * \text{Leg Length}) \\
& + 0.007216 * (\text{Age} * \text{Sitting Height}) \\
& + 0.02292 * ((\text{Weight} / \text{Height}) * 100)
\end{aligned}
$$

$[R = 0{:}94;\ R^2 = 0{:}89;\ \text{and}\ S_{x,y} = 0.59]$

Predicted age at peak height velocity (years) was estimated as chronological age minus maturity offset. For each age group at baseline, the sample was divided into 3 maturity groups according to percentiles[18]: APHV<P33 (= earliest maturing players), P33<APHV<P66 (= average maturing players), P66<APHV (= latest maturing players), resulting in equal number of players in each maturity group.

Anthropometry

Height (Harpenden portable stadiometer, Holtain, UK) and sitting height (Harpenden sitting table, Holtain, UK) were assessed to the nearest 0.1 cm, and body mass and body fat (total body composition analyser, TANITA, BC-420SMA, Japan) were assessed to the nearest 0.1 kg and 0.1 %, respectively, according to the manufacturer's guidelines. Leg length (0.1 cm) was then calculated as the difference between height and sitting height. Fat mass (FM, 0.1 kg) was calculated as [body mass x (body fat / 100)], and then subtracted from body mass to obtain fat free mass (FFM, 0.1 kg).

All anthropometric measures were taken by the same investigator to ensure test accuracy and reliability. The intra-class correlation coefficient for test-retest reliability and technical error of measurement (test-retest period of 1 h) in 40 adolescents were 1.00 ($p < 0.001$) and 0.49 cm for height and 0.99 ($p < 0.001$) and 0.47 cm for sitting height, respectively.

Motor coordination

Motor coordination was investigated using three non-specific subtests from the "Körperkoordination Test für Kinder" (KTK): moving sideways (MS), backward balancing (BB) and jumping sideways (JS), conducted according to the methods of Kiphard and Shilling[19]. This test battery demonstrated to be reliable and valid in the age-range of the present population[14]. Hopping for height, the fourth subtest, was not included in the present study.

Soccer-specific aerobic performance: Yo-Yo IR1

The Yo-Yo IR1 was conducted according to the methods of Krustrup et al.[2]. Participants were instructed to refrain from strenuous exercise for at least 48 hours before the test sessions and to consume their normal pre-training diet before the test session. A standardized warming-up preceded each Yo-Yo IR1. All Yo-Yo IR1 tests were completed on an indoor tartan running track with a temperature between 15-20°C. The total duration of the test was 2-25 min and the individual scores were expressed as covered distance (m). All subjects were familiarized with the test procedures and ran the test with running shoes.

Statistical anaysis

Means and standard deviations ± SD were calculated for each age group at baseline for chronological age, APHV, height, body mass, FM, FFM, MS, BB, JS and Yo-Yo IR1. Next, earliest and latest maturing players at baseline were compared for age, APHV, body size and composition, coordination parameters and soccer-specific aerobic performance using analysis of covariance (ANCOVA) with age as covariate. Cohen's *d* effect sizes (ES) and thresholds (0.2, 0.6, 1.2, 2.0 and 4.0 for trivial, small, moderate, large, very large and extremely large, respectively) were also used to estimate the magnitude of the differences between earliest and latest maturers[20].

Multicollinearity was examined using a correlation matrix and diagnostic statistics. Variables with small tolerance (<0.10) and a variance inflation factor (VIF) of >10 are considered indicative of harmful multicollinearity[21]. The incidence of large bivariate correlations (fat mass vs. body mass, r=0.74; fat mass vs. fat free mass, r=0.62), suggested an unacceptable multicollinearity occurrence. To avoid harmful multicollinearity, body mass and fat free mass were discarded by the auxiliary regression. Additionally, Pearson product moment correlation coefficients were used to examine the relationships between the dependent variable (Yo-Yo IR1 performance) and the explanatory variables (age, r=0.66; height, r=0.52; FM, r=0.14; BB, r=0.21). Correlations were considered as trivial (r<0.1), small (0.1<r<0.3), moderate (0.3<r<0.5), large (0.5<r<0.7), very large (0.7<r<0.9) and nearly perfect (r>0.9)[22].

For the longitudinal analyses, a multilevel regression analysis was performed using MLwiN 2.16 software to identify those factors (i.e., maturity groups differences) associated with the development of soccer specific aerobic performance, with adjustments for differences in age, body size, body composition and motor coordination. The repeated measurements were assessed within (level 1) and between individuals (level 2). The following additive polynomial random-effects multi-level regression model[23] was adopted to describe the developmental changes in soccer-specific aerobic performance:

$$y_{ij} = \alpha + \beta_j x_{ij} + k_1 z_{ij} + \cdots k_n z_{ij} + \mu_j + \varepsilon_{ij}$$

where y is the aerobic performance parameter on measurement occasion i in the jth individual; α is a constant; $\beta_j x_{ij}$ is the slope of the aerobic performance parameter with age for the jth individual; and k_1 to k_n are the coefficients of various explanatory variables at assessment occasion i in the jth individual. Both μ_j and ε_{ij} are random quantities, whose means are equal to zero; they form the random parameters in the model. They are assumed to be uncorrelated and follow a normal distribution; μ_j is the level 2 and ε_{ij} the level 1 residual for the ith assessment of aerobic performance in the jth individual. The model was built in a stepwise procedure, i.e., predictor variables (k fixed effects) were added one at a time, and likelihood ratio statistics were used to judge the effects of including further variables[24]. If the retention criteria were not met (mean coefficient greater than 1.96 the standard error of the estimate at an alpha level of 0.05), the predictor variable was discarded. The final model included only variables that were significant independent predictors.

In a first attempt, the constant and age were allowed to vary randomly between individuals. The intercept for each individual's line is the height of that line at x = 0. Since individuals were not measured at CA = 0 the model extrapolated the interceptions of developmental trajectories with y axis. Since participants were measured between the 11 and 14 years extrapolated lines at CA = 0 may reflect excessive variance[24]. Consequently, the technique would be estimating the variance of the intercepts at an age that never occurred in the sample. To overcome this problem, it was decided to shift the origin of the explanatory random variable (age) by centering on its mean value (i.e., 13.34 years). Subsequently, the inclusion of predictors in their raw measurements was tested to improve the statistical fit of the multilevel models. To allow for the nonlinearity of the soccer-specific aerobic performance development, age power functions (i.e., age^2) were introduced into the linear model[8]. It has demonstrated that maximal gains in aerobic power occurs around the timing of peak height velocity[6], and furthermore, at an older age, the improvement per year is expected to be smaller[11] which also allows for the use of age squared in the multilevel model. Finally, maturity groups (earliest vs. latest maturers) were incorporated into a subsequent analysis by introducing it as a fixed dummy coded variable with earliest as the reference category.

Results

Age, APHV, anthropometry, coordination parameters and soccer-specific aerobic performance, by age group at baseline are presented in ***Table 2***. Generally, players improved with age on all parameters, except for backward balancing (score of 59 at 11 y and 14 y). Significant differences between latest and earliest maturing players at baseline were found for anthropometrical characteristics and backward balancing, with moderate to very large effect sizes (0.62 – 2.83) (***Table 3***).

Predicted soccer-specific aerobic performance from the multilevel model is presented in ***Table 4***. After each explanatory variable was adjusted for co-variables, it can be seen that in the multilevel model (deviance from the intercept only model = 978.11), age ($p<0.01$), age^2 ($p<0.01$), height ($p<0.05$), fat mass ($p<0.01$) and backward balance ($p<0.05$) had significant effects on aerobic performance of these soccer players. The best fitting model on the soccer-specific aerobic performance could be expressed as: $-3639.76 + 369.86 \times age + 21.38 \times age^2 + 9.12 \times height – 29.04 \times fat\ mass + 0.06 \times backward\ balance$. Maturity groups had a negligible effect in the soccer-specific aerobic performance (-45.32 ± 66.28; $p>0.05$). The model can be interpreted as 1 cm of growth in height predicts 9.12 m of increment in the soccer-specific aerobic performance test.

The random-effects coefficients describe the two levels of variance (within individuals: level 1, and between individuals: level 2). The significant variance at level 1 indicates that all players significantly improved in soccer-specific aerobic performance at each measurement occasion within individuals (estimate > 1.96 x SE; $p<0.05$). The between-individual variance matrix (level 2) indicated that players had significantly different soccer-specific aerobic performance growth curves in terms of their intercepts (constant/constant; $p<0.05$) and slopes of their curves (age/age; $p<0.05$). The negative covariance between intercepts and slopes (-379.07 ± 2642.70; $p>0.05$) suggested that at the end of the pubertal years, the rate of improvement is decreasing, however not significant.

The real and estimated curves for soccer-specific aerobic performance were plotted by age in ***Figure 1***. Predicted aerobic performance (– solid line in *fig.1*) fluctuated below (11 to 13 years) and above (15 to 16 years) measured aerobic performance (---- dashed line in *Fig.1*). Performance markedly improved from 12 to 15 years (748.64 m, 35.0 %), with more modest gains at 16 years (206.03 m, 9.7 %).

Table 1 *Number of subjects and number of measurements per age group.*

	Number of measurements											
Age	3	4	5	6	7	8	9	10	11	13	14	*Total*
11 years	34	21	24	11	12	7	9	3	2	2	2	*127*
12 years	27	24	30	20	14	16	12	12	5	2	3	*165*
13 years	11	32	33	23	12	22	21	16	6	3	3	*182*
14 years	25	55	15	27	13	26	23	16	5	3	2	*210*
15 years	26	33	8	20	5	18	13	11	4	2	2	*142*
16 years	3	4	5	1	0	3	3	2	0	1	2	*24*
Total measurements	126	169	115	102	56	92	81	60	22	13	14	*850*
Number of subjects	42	42	23	17	8	11	9	6	2	1	1	*162*

Table 2 *Mean scores ± SD for age, APHV, anthropometrical characteristics, motor coordination and soccer-specific aerobic performance at baseline.*

	Units	*n*	11 years	*n*	12 years	*n*	13 years	*n*	14 years
Chronological age	y	*68*	11.2 ± 0.4	*32*	12.3 ± 0.3	*26*	13.2 ± 0.3	*36*	14.3 ± 0.3
APHV	y	*68*	13.5 ± 0.4	*32*	13.9 ± 0.5	*26*	14.0 ± 0.7	*36*	13.8 ± 0.8
Early (<P33)	n		34		16		13		18
Late (P66<)	n		34		16		13		18
Stature	cm	*68*	145.9 ± 6.4	*32*	152.5 ± 6.3	*26*	158.6 ± 8.0	*36*	166.9 ± 9.0
BodyMass	kg	*68*	35.5 ± 4.7	*32*	41.1 ± 6.2	*26*	45.4 ± 10.2	*36*	54.5 ± 10.3
Body fat	%	*68*	12.8 ± 3.0	*32*	13.2 ± 3.0	*26*	11.2 ± 3.7	*36*	11.6 ± 3.2
FM	kg	*68*	4.6 ± 1.5	*32*	5.5 ± 1.9	*26*	5.3 ± 3.4	*36*	6.6 ± 2.8
FFM	kg	*68*	30.9 ± 3.7	*32*	35.6 ± 4.9	*26*	40.1 ± 7.4	*36*	47.9 ± 7.9
Backward balancing	n	*28*	59 ± 9	*11*	60 ± 12	*6*	55 ± 9	*9*	59 ± 7
Moving sideways	n	*28*	60 ± 7	*11*	59 ± 6	*6*	61 ± 6	*9*	64 ± 4
Jumping sideways	n	*28*	95 ± 11	*11*	93 ± 9	*6*	94 ± 8	*9*	102 ± 5
Yo-Yo IR1	m	*68*	1024 ± 352	*32*	978 ± 417	*26*	1317 ± 343	*36*	1549 ± 365

Table 3 *ANCOVA between latest and earliest maturers for APHV, anthropometry, coordination parameters and soccer-specific aerobic performance, controlling for age.*

Variable	*n*	Latest maturers	*n*	Earliest maturers	F	Effect Size
APHV	*81*	14.3 ± 0.4	*81*	13.3 ± 0.3	$394.0^{\S}$	2.8
Stature	*81*	148.5 ± 8.1	*81*	159.3 ± 11.1	$281.4^{\S}$	1.1
Body Mass	*81*	36.8 ± 6.5	*81*	48.0 ± 10.8	$261.3^{\S}$	1.3
Body Fat	*81*	11.0 ± 2.3	*81*	13.7 ± 3.5	$31.2^{\S}$	0.9
FM	*81*	4.1 ± 1.1	*81*	6.6 ± 2.6	$82.7^{\S}$	1.3
FFM	*81*	32.8 ± 5.9	*81*	41.4 ± 9.0	$288.7^{\S}$	1.1
BB	*23*	63 ± 7	*31*	56 ± 10	$8.2^{\ddagger}$	0.6
MS	*23*	61 ± 6	*31*	60 ± 6	0.4	0.1
JS	*23*	97 ± 9	*31*	94 ± 10	0.6	0.2
Yo-Yo IR1	*81*	1178 ± 422	*81*	1179 ± 439	0.2	0.0

Data are expressed as means ± SD; § significant at the 0.001 level; ‡ significant at the 0.01 level

Table 4 *Multilevel regression analysis of aerobic performance, adjusted for players' age, body size, body composition, coordination and maturation (n = 850).*

Fixed explanatory variables	$-2 \times \log$ likelihood	*P*	Value at final step
Constant	12911.28	<0.01	- 3639.76 ± 977.14
Age	11980.76	<0.01	369. 86 ± 131.20
Age^2	11954.47	<0.01	21.38 ± 4.83
Stature	11950.17	<0.05	9.12 ± 2.83
Fat mass	11937.52	<0.01	- 29.04 ± 8.28
Backward balance	11933.17	<0.05	0.06 ± 0.02
Latest *vs* earliest maturers	11932.70	NS	
Variance-covariance matrix of random variables	Constant		Age
Level 1 (within individuals)			
Constant	45389.17 ± 2601.11		
Level 2 (between individuals)			
Constant	80608.07 ± 10516.52		
Age	- 379.07 ± 2642.70		2872.96 ± 1356.16
IGLS deviance from the null model = 978.11			

Values are means ± SE; NS (non-significant); random-effects values are estimated mean variance ± SE; fixed-effect values (explanatory variables) are estimated mean coefficients ± SE. Age was adjusted about origin using mean age ± 13 years.

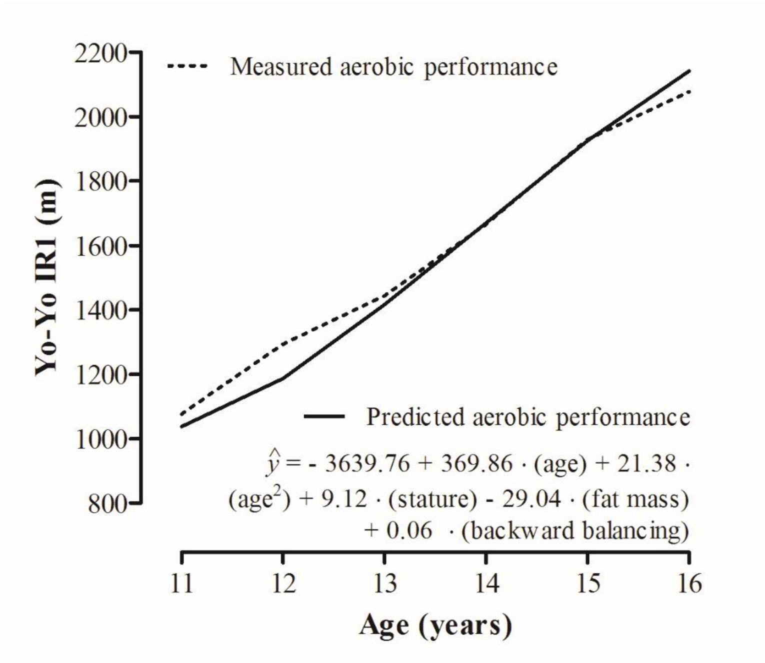

Figure 1 *Real and estimated aerobic performance aligned by chronological age.*

Discussion

The present study obtained a developmental model to predict longitudinal changes in aerobic performance assessed by the Yo-Yo IR1 in pubertal soccer players. The model is specific for this Flemish sample comprising 162 players aged 11-14 years at the baseline and emerged from a total number of 850 measurements. It emerged from the combination of chronological age and its squared value, body size given by height, body composition derived from a two-component model that permitted the determination of fat mass and one item extracted from a battery that evaluates motor coordination. To our knowledge, this the first study to report the importance of coordination in the development of soccer-specific aerobic performance. All together, the longitudinal predictors reflect the importance of growth, muscularity, and coordination in the development of aerobic performance. The term that corresponds to squared chronological age may be additive influence of years of training in the sports.

Future studies need to consider specific training parameters such as annual minutes of training and playing time, and probably an estimate of training intensity that is possible to estimate[25]. It was initially hypothesized that players contrasting in somatic maturation would differ in predictors and in the aerobic performance. The analyses also considered a somatic variation as dummy variable (earliest versus latest maturers) and as a candidate variable, but although some improvements in the model it was not substantially and significantly different from the one previously mentioned that included five variables. In contrast, a central study in the literature regarding the development of aerobic power in young athletes (TOYA study) noted that male athletes significantly increased their values with pubertal status, indicated by a coefficient of 0.15 $L.min^{-1}$ that was greater than its associated standard error (0.07 $L.min^{-1}$)[8]. The current subsamples of soccer players seem to correspond to what is already stated in the literature: the average means of the earliest maturers for height and body mass plotted above the 75% percentile of US reference data for normal population[26], in contrast to the latest maturers who plotted about the median for height and body mass. Note, however, that the present study adopted an arbitrary concept of maturity. In a previous study[5], Portuguese adolescent soccer players were classified as late, on time and early based on estimated age at peak height velocity and from 87 players aged 11-12 years only three were not classified as on time. In the same study, 77 from 93 players aged 13-14 years also classified as on time.

A recent study attempted to validate the anthropometric equation for predicting age at peak height velocity (APHV) in 193 school healthy Polish boys followed longitudinally 8-18 years (1961-1972) against actual APHV derived with Preece-Baines Model 1[27]. Actual APHV was underestimated at younger ages and overestimated at older ages and mean differences between predicted and actual APHV were reasonably stable between 13 and 15 years. It was concluded that predicted APHV has applicability among average maturing boys 12-16 years. The mean age of the current sample at baseline 12.2 ± 1.3 years and therefore the application of the maturity offset protocol to estimate APHV should be recognized as a limitation and this was the reason for the adoption of contrasting groups based on tertiles of estimated APHV. Moreover, a modest agreement between invasive methods (based on skeletal age) and non-invasive indicators of maturation (including the one using the maturity offset protocol) was noted in a previous study[28]. The equation to estimate maturity offset emerged from longitudinal studies from Canada and Belgium and many users tend to ignore the magnitude of standard error of estimation and the potential variation of agreements between estimated and real values at ages long before PHV and long after PHV. This limitation should be considered when considering further research in this area.

The sample of the current study when grouped by tertiles of estimated age at peak height velocity[18] did not permit the inclusion of biological maturation as a longitudinal predictor. It is possible that the criteria for the sample selection (at least three time-moments) excluded drop-out participants who tended to be later maturing and created a homogenous sample of players in terms of biological maturity status. The literature already evidenced a selective effect of early maturing players in soccer[5]. It was noted that the proportion of late maturing male soccer players in a Portuguese sample decreased with increasing chronological age. For example, among 11- to 12-year-olds, the percentage of late and early maturing players (classified on the basis of differences between skeletal and chronological ages) were equal, in contrast to subsequent ages (13-14 years and 15-16 years) that presented higher percentages of early maturing soccer players. The trend was consistently noted in another study with Portuguese adolescent soccer players[29] who compared the profile of 11- to 14-year-old players according to their followed-up status (those who dropped, continued and moved upwards).

Note that the literature in different team sports[29,30], and although studies differed in the indicator of biological maturation, it consistently seems that athletes who were classified as delayed attain better performances compared to their advanced peers suggesting maturation as a relevant source of inter-individual variability. However, in the current study, maturation does not seem to be a longitudinal predictor in aerobic performance. Recently, Deprez et al.[31] already reported in 606 Flemish elite soccer players that the Yo-Yo IR1 performance is not influenced by the somatic maturity status, suggesting that talent identification programs are leading to homogeneous group in terms of physiological and maturational characteristics. Moreover, it has previously been reported that early and late maturing soccer players do not differ in running economy[16].

Meanwhile, one very relevant topic highlighted by the current study is the inclusion of coordination in the developmental model. A previous study considered 13 soccer players aged 14 years of age and concluded that there was no significant difference in the running economy between the six early and the seven late mature soccer players because of differences in running style[16]. An additional study evidenced that maturity independent, non-specific motor coordination tests (i.e., three subtest from KTK, similar to the present study) are supportive in the identification and selection process of young, high-levelled soccer players[15]. Also, the importance of motor competence was highlighted in a 5-year longitudinal study by Hands[32], investigating differences in several items of physical fitness between groups of high and low motor competence in 186 boys and girls, aged 5-6 y. The fact that differences between high and low motor competence groups increased over five years for the endurance shuttle run (whilst differences of other fitness components decreased over time), supports the importance of introducing motor skills into talent development programs from a young age. Moreover, in adolescents, there is evidence of a relationship between cardiorespiratory endurance and fundamental movement skills[33].

Practical applications and conclusions

The present study showed that the development of aerobic performance in elite youth soccer is related to growth, muscularity and emphasized the importance of motor coordination in the talent identification and development process. Therefore, youth soccer coaches should implement motor coordination exercises in their regular training program, especially in the years around peak height velocity. Note that biological maturation was excluded from the model which might endorse the homogeneity in biological maturation status in the present elite pubertal soccer sample.

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STUDY 8

MULTILEVEL DEVELOPMENT MODELS OF EXPLOSIVE LEG POWER IN HIGH-LEVEL SOCCER PLAYERS

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Abstract

Purpose: The aim of the present study was to model developmental changes in explosive power based on the contribution of chronological age, anthropometrical characteristics, motor coordination parameters and flexibility.

Methods: Two different longitudinal, multilevel models were obtained to predict countermovement jump (CMJ) and standing broad jump (SBJ) performance in 356 high-level, youth soccer players, aged 11 to 14 years at baseline. Biological maturity status was estimated (age at peak height velocity, APHV) and variation in the development of explosive power was examined based on three maturity groups (APHV; earliest<P33, P33<average<P66, latest>P66).

Results: The best fitting model for the CMJ performance of the latest maturing players could be expressed as: 8.65 + 1.04 x age + 0.17 x age^2 + 0.15 x leg length + 0.12 x fat-free mass + 0.07 x sit-and-reach + 0.01 x moving sideways. The best models for average and earliest maturing players were the same as for the latest maturing players, minus 0.73 and 1.74 cm, respectively. The best fitting model on the SBJ performance could be expressed as follows: 102.97 + 2.24 x age + 0.55 x leg length + 0.66 x fat-free mass + 0.16 x sit-and-reach + 0.13 jumping sideways. Maturity groups had a negligible effect on SBJ performance.

Conclusion: These findings suggest that different jumping protocols (vertical vs. long jump) highlight the need for special attention in the evaluation of jump performance. Both protocols emphasized growth, muscularity, flexibility and motor coordination as longitudinal predictors. The use of the SBJ is recommended in youth soccer identification and selection programs, as biological maturity status has no impact on its development through puberty.

Introduction

In elite youth sport, identifying future success has proven to be problematic. Indeed talent identification processes are predominantly based on current performances (36), while only longitudinal designs can provide precise information about the individual development of growth and performance characteristics (14). In youth soccer, multilevel longitudinal models have been established for functional capacities and soccer-specific skills (39), repeated sprint ability (38), aerobic performance (37) and intermittent-endurance capacity (12). At present however, no such models are presented in the literature regarding the development of explosive power in a youth soccer population. Therefore, the present study focusses on understanding the factors determining explosive power and its longitudinal development in pubertal soccer players. Explosive power refers to the ability of the neuromuscular system to produce the greatest possible impulse in a given time period, and has been identified as one of the factors contributing to soccer performance (31).

It is well-known that strength-related motor performances are influenced by chronological age, anthropometrical characteristics and maturational status (5,20,21,35). For example, jumping performances (such as vertical jump and standing long jump) improve linearly from 5 until 18 years of age in normally growing boys, and until 14 years of age in girls (20). Furthermore, in young male soccer players, vertical and standing long jump performances improve with increasing body size dimensions (i.e., stature and body size) and sexual maturity (2,22). More mature players benefit from the hormonal changes occurring during puberty (e.g., increase in serum testosterone) which stimulates muscle growth and strength (17). Moreover, an experimental study implementing an eight-week strength program showed that mid- and post-pubertal athletes improved more in explosive power and maximal strength compared to their pre-pubertal peers (26). Consequently, pathways to develop explosive power should be selected according to young athletes' maturational status.

The impact of general motor coordination and lower extremity flexibility on several measures of physical fitness has previously been shown (1,10,16,19,27). For example, a five-year longitudinal study investigated differences in fitness measures and skill performance between 38 children with high and low motor coordination, aged between 5 and 7 years at baseline (16). Results revealed that the high motor coordination group outperformed the low motor coordination group in the standing long jump during each year of the follow-up study. Additional research has revealed a positive correlation between hip flexion range of motion and vertical jump performance in male volleyball players (20). Therefore, integrating motor coordination (12,19,41) and flexibility training programs (7,15) in the development of youth soccer players, may be beneficial for improving overall physical fitness.

The present study addressed the lack of multilevel longitudinal data for explosive leg power through different jumping protocols in young, high-level soccer players contrasting in biological maturation status (earliest, average, latest maturers). Two longitudinal models were obtained: one for the development of the countermovement jump (CMJ) and one for the standing broad jump (SBJ). We hypothesized that chronological age, body size dimensions and motor coordination would significantly contribute to the development of explosive leg power (5,20,40). To our knowledge, this is the first study to examine the contribution of hamstring flexibility to the development of jump performances in young soccer players. It has previously been reported that peak velocities for flexibility occur one year after peak height velocity (29), and improved flexibility allows for higher jump performance (8). Based on these findings it could be expected that flexibility significantly predicts explosive leg power during the pubertal years. Therefore, we hypothesized that the development of explosive leg power would differ between maturity groups, with early maturers performing higher jumps (13,22).

Materials and Methods

The present longitudinal data sample consisted of 2,274 data points from 356 male youth soccer players (average of 6.4 observations per player), aged between 11 and 14 years at baseline (mean age of 12.0 ± 1.3 y). All players were sourced from two professional Flemish soccer clubs and participated in a high-level youth soccer development program consisting of 3 training sessions and one game per week. Players were born between 1993 and 2002, and were assessed over 1 to 7 years between 2007 and 2014. The total measurements of each individual player varied between 3 and 16 measurements (***Table 1***). Subjects were divided into four age groups according to their birth year at baseline (e.g., a player born in 2000 who was assessed for the first time in 2011, was assigned to the 11 y age group): 11 y (n=163), 12 y (n=59), 13 y (n=70) and 14 y (n=64). Within all age groups, age varied between 10.5-11.5 y, 11.5-12.5 y, 12.4-13.5 y and 13.5-14.5 y, for the 11 y, 12 y, 13 y and 14 y age groups, respectively. All players and their parents or legal representatives were fully informed about the experimental procedures of the study before providing written informed consent. The Ethics Committee of the University Hospital approved the study. This research was performed without financial support and the authors assure no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

Table 1 *Number of subjects and number of measurements per age group.*

Age	Number of measurements														*Total*
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
11 years	45	65	46	58	29	24	34	18	9	13	8	7	3	5	*364*
12 years	54	63	33	46	39	32	44	25	17	15	12	13	5	7	*405*
13 years	41	35	31	41	45	40	48	27	32	23	15	18	7	11	*414*
14 years	50	44	30	36	51	46	57	22	39	23	15	21	7	7	*448*
15 years	25	29	19	16	38	31	42	21	39	22	15	17	8	9	*326*
16 years	8	7	9	17	17	26	23	12	28	16	8	16	8	5	*200*
17 years	2	4	2	8	18	9	22	5	17	8	5	6	7	4	*117*
Total measurements	225	248	170	222	238	208	270	130	176	120	78	98	45	48	*2274*
Number of subjects	75	62	34	37	34	26	30	13	16	10	6	7	3	3	***356***

Chronological age was calculated as the difference between date of birth and date on which the assessments were made andmaturity status was estimated using equation 3 from Mirwald et al. (28). This non-invasive method predicts the time before or after peak height velocity (i.e., maturity offset in years), based on anthropometrical variables (stature, sitting height, leg length, weight) (28).

Predicted age at peak height velocity (APHV; years) was estimated as chronological age minus maturity offset. According to Mirwald et al. (28), this equation accurately estimates the APHV of young males within an error of ±1.14 years in 95% of cases. This data was derived from 3 longitudinal studies of Canadian and Belgian youth who were 4 years from, and 3 years after peak height velocity (i.e., 13.8 years). Accordingly, the age range from which the equation can confidently be used is between 9.8 and 16.8 years; which corresponds well with the age-range of the present sample. For each age group at baseline, the sample was divided into 3 maturity groups according to percentiles (11,12): APHV<P33 (=*earliest* maturing players), P33<APHV<P66 (=*average* maturing players), P66<APHV (=*latest* maturing players), resulting in an equal number of players in each maturity group.

Stature (Harpenden portable stadiometer, Holtain, UK) and sitting height (Harpenden sitting table, Holtain, UK) were assessed to the nearest 0.1 cm; body mass and fat percentage (total body composition analyser, TANITA, BC-420SMA, Japan) were assessed to the nearest 0.1 kg and 0.1 %, respectively. Leg length (0.1 cm) was calculated as the difference between stature and sitting height. Fat mass (FM, 0.1 kg) was calculated as [body mass x (body fat / 100)]; this was subtracted from body mass to obtain fat free mass (FFM, 0.1 kg). All anthropometric measures were taken by the same investigator to ensure test accuracy and reliability. The intra-class correlation coefficient for test-retest reliability and technical error of measurement (test-retest period of 1 h) in 40 adolescents were 1.00 ($p < 0.001$) and 0.49 cm for height and 0.99 ($p < 0.001$) and 0.47 cm for sitting height, respectively.

Hamstring flexibility was assessed using the sit-and-reach test (SAR) to the nearest 0.5 cm. The SAR is part of the Eurofit test battery and was conducted according to the guidelines of the Council of Europe (9). Motor coordination was investigated using three non-specific subtests from the "Körperkoordination Test für Kinder" (KTK): moving sideways (MS), backward balancing (BB) and jumping sideways (JS), conducted according to the methods of Kiphard and Shilling (18). This test battery has been demonstrated as reliable and valid in the age-range of the present population (41). Hopping for height, the fourth subtest of the KTK, was not included in the present study for the following reasons: the discriminating ability is relatively low in a homogeneous group of high-level players; the injury risk is increased with the high jumping ability of soccer players (mainly due to stature and leg-length, rather than motor coordination); and the test is very time consuming within the present test battery.

To evaluate jumping performance, standing broad jump (SBJ) and counter movement jump (CMJ) were executed. These two strength tests are commonly used to evaluate explosive leg power. The SBJ is part of the Eurofit test battery and was conducted according to the guidelines of the Council of Europe (9). CMJ was recorded using an OptoJump system (MicroGate, Italy) and conducted according to the methods described by Bosco et al. (6) with the arms kept in the akimbo position to minimize their contribution. The highest of three jumps was used for further analysis (0.1 cm).

Means (± 95% confidence intervals, CI) were calculated for each age group at baseline for age, APHV, anthropometrical characteristics, flexibility, motor coordination and jumping performance. Earliest, average and latest maturing players at baseline were compared for APHV, body size and composition, flexibility, motor coordination parameters and jumping performance using analysis of covariance (ANCOVA) with age as covariate.

For the longitudinal analyses, two multilevel regression analyses (CMJ and SBJ) were performed using MLwiN 2.16 software (30). The repeated measurements were assessed within (level 1) and between individuals (level 2). The following additive polynomial random-effects multi-level regression model was adopted to describe the developmental changes in explosive leg power (30):

$$y_{ij} = \alpha + \beta_j x_{ij} + k_1 \zeta_{ij} + \cdots k_n \zeta_{ij} + \mu_j + \varepsilon_{ij}$$

where y is the jumping performance parameter on measurement occasion i in the jth individual; α is a constant; $\beta_j x_{ij}$ is the slope of the jumping performance parameter with age for the jth individual; and k_1 to k_n are the coefficients of various explanatory variables at assessment occasion i in the jth individual. Both μ_j and ε_{ij} are random quantities, whose means are equal to zero; they form the random parameters in the model. They are assumed to be uncorrelated and follow a normal distribution; μ_j is the level 2 and ε_{ij} the level 1 residual for the ith assessment of jumping performance in the jth individual. The model was built in a stepwise procedure; predictor variables (k fixed effects) were added one at a time, and likelihood ratio statistics were used to judge the effects of including further variables (4). If the retention criteria were not met (mean coefficient greater than 1.96 the standard error of the estimate at an alpha level of 0.05), the predictor variable was discarded. The final model included only variables that were significant independent predictors.

Age, as an explanatory random variable, was centered on its mean value (i.e., 13.44 years). To allow for the nonlinearity of the explosive leg power development, age power function (i.e., age centered^2) was introduced into the linear model (3). It has been demonstrated that maximal gains in explosive leg power occur in the later stages of the pubertal years (i.e., after the timing of peak height velocity) (20, 29). Furthermore, at an older age, the improvement per year is expected to be smaller (29) which also allows for the use of age squared in the multilevel model. Finally, maturity groups (latest vs. average vs. earliest maturers) were incorporated into a subsequent analysis by introducing it as a fixed dummy-coded variable with latest maturers as the reference category.

Finally, multicollinearity was examined for each longitudinal model (CMJ: Model A; SBJ: Model B) using correlation matrix and diagnostic statistics (32). Variables with a variance inflation factor (VIF) > 10 and with small tolerance (1/VIF ≤ 0.10; corresponding to an R^2 of 0.90) were considered indicative of harmful multicollinearity (33).

Results

Age, APHV, anthropometry, flexibility, motor coordination parameters and explosive leg power with the 95% CI, by age group at baseline are presented in ***Table 2***. Generally, players improved with age on all parameters, except for backward balancing, which remained relatively stable (score around 57-58). Overall, significant differences between latest, average and earliest maturing players at baseline were found for anthropometrical characteristics, SAR and SBJ, with the following gradient: earliest > average > latest maturers. Motor coordination parameters and CMJ did not differ between maturity groups (***Table 3***).

Table 2 *Mean scores ± sd for age, APHV, anthropometrical characteristics, flexibility, motor coordination and jumping performance at baseline.*

	Units	*n*	11 years	*N*	12 years	*n*	13 years	*n*	14 years
Chronological age	y	*163*	10.8 ± 0.3	*59*	12.1 ± 0.3	*70*	13.0 ± 0.3	*64*	14.0 ± 0.3
APHV	y	*163*	13.4 ± 0.3	*59*	13.9 ± 0.3	*70*	13.9 ± 0.5	*64*	13.8 ± 0.7
Earliest (<P33)	n		53		20		24		21
Average (P33<x<P66)	n		55		19		22		21
Latest (P66<)	n		55		20		22		22
Stature	cm	*163*	144.4 ± 5.4	*59*	149.8 ± 5.8	*70*	158.4 ± 7.9	*64*	165.9 ± 8.9
Sitting height	cm	*163*	75.8 ± 2.7	*59*	77.6 ± 3.2	*70*	81.8 ± 4.2	*64*	85.9 ± 5.2
Leg length	cm	*163*	68.6 ± 3.4	*59*	72.3 ± 3.7	*70*	76.7 ± 4.3	*64*	80.0 ± 4.6
Body mass	kg	*163*	34.9 ± 4.1	*59*	38.6 ± 5.4	*70*	46.4 ± 7.7	*64*	53.6 ± 10.1
Body fat	%	*163*	14.0 ± 3.1	*59*	13.0 ± 3.8	*70*	11.9 ± 3.0	*64*	11.7 ± 3.4
FM	kg	*163*	5.0 ± 1.5	*59*	5.2 ± 2.2	*70*	5.6 ± 1.9	*64*	6.5 ± 3.0
FFM	kg	*163*	29.9 ± 3.1	*59*	33.4 ± 3.8	*70*	40.8 ± 6.4	*64*	47.1 ± 7.8
SAR	cm	*163*	20.2 ± 5.1	*59*	19.0 ± 5.9	*70*	21.6 ± 6.4	*64*	22.0 ± 6.3
Backward balancing	n	*123*	58 ± 9	*31*	57 ± 12	*36*	58 ± 11	*40*	57 ± 8
Moving sideways	n	*123*	59 ± 7	*31*	58 ± 8	*36*	62 ± 6	*40*	62 ± 8
Jumping sideways	n	*123*	91 ± 9	*31*	92 ± 10	*36*	95 ± 9	*40*	98 ± 8
CMJ	cm	*163*	23.7 ± 3.4	*59*	24.8 ± 3.1	*70*	27.6 ± 3.5	*64*	30.2 ± 4.6
SBJ	cm	*163*	169 ± 12	*59*	177 ± 15	*70*	190 ± 13	*64*	202 ± 19

FM=fat mass; FFM=fat free mass; SAR=sit-and-reach; CMJ=counter movement jump; SBJ=standing broad jump

Table 3 *ANCOVA between maturity groups for APHV, anthropometry, flexibility, motor coordination and jumping performance, controlling for age.*

Variable	*n*	Latest maturers	*n*	Average maturers	*n*	Earliest maturers	F	Post hoc
APHV	*118*	14.1 ± 0.4	*117*	13.6 ± 0.3	*121*	13.2 ± 0.3	341.4§	1 > 2 > 3
Stature	*118*	146.5 ± 7.6	*117*	151.6 ± 9.8	*121*	157.9 ± 11.3	222.3§	1 < 2 < 3
Sitting height	*118*	75.7 ± 3.4	*117*	78.9 ± 4.3	*121*	82.7 ± 5.5	393.1§	1 < 2 < 3
Leg length	*118*	70.8 ± 4.6	*117*	72.7 ± 6.0	*121*	75.1 ± 6.2	59.7§	1 < 2 < 3
Body mass	*118*	35.8 ± 5.5	*117*	41.1 ± 8.9	*121*	46.6 ± 10.9	190.1§	1 < 2 < 3
Body fat	*118*	11.8 ± 3.0	*117*	13.0 ± 3.0	*121*	14.3 ± 3.7	19.0§	1 < 2 < 3
FM	*118*	4.2 ± 1.3	*117*	5.3 ± 1.6	*121*	6.7 ± 2.5	60.3§	1 < 2 < 3
FFM	*118*	31.6 ± 5.0	*117*	35.8 ± 8.0	*121*	39.9 ± 9.4	195.9§	1 < 2 < 3
SAR	*118*	19.1 ±5.7	*117*	21.1 ± 5.4	*121*	21.6 ± 6.0	6.7 ‡	1 < 2 = 3
BB	*80*	58 ± 10	*75*	59 ± 9	*75*	57 ± 10	0.4	n.s.
MS	*80*	59 ± 7	*75*	60 ± 7	*75*	60 ± 8	1.0	n.s.
JS	*80*	92 ± 9	*75*	94 ± 10	*75*	93 ± 9	1.6	n.s.
CMJ	*118*	25.6 ± 3.7	*117*	26.0 ± 4.1	*121*	25.9 ± 5.2	0.6	n.s.
SBJ	*118*	177 ± 14	*117*	183 ± 19	*121*	181 ± 23	8.3§	1 < 2 = 3

Data are expressed as means ± sd; § significant at the 0.001 level; ‡ significant at the 0.01 level; post hoc: 1=latest maturers, 2=average maturers, 3=earliest maturers; n.s.=not significant

Both predicted jump performances (CMJ: Model A; SBJ: Model B) from the multilevel model are presented in ***Table 4***. It can be seen in model A (deviance from the intercept only model = 5758.811) that after each explanatory variable was adjusted for co-variables, age ($p<0.01$), age² ($p<0.01$), leg length ($p<0.01$, FFM ($p<0.01$), SAR ($p<0.01$), MS ($p<0.01$) and maturity status ($p<0.01$) had significant effects on CMJ. Equations for the three maturity groups were also derived. The best fitting model for CMJ performance in the latest maturing players could be expressed as: 8.65 + 1.04 x age + 0.17 x age² + 0.15 x leg length + 0.12 x fat-free mass + 0.07 x sit-and-reach + 0.01 x moving sideways. The best models for average and earliest maturing players were the same as for the latest maturing players, minus 0.73 and 1.74 cm, respectively.

The significant parameters predicting SBJ performance in the multilevel model B (deviance from the intercept only model = 7031.520) were age ($p<0.01$), leg length ($p<0.01$), FFM ($p<0.01$), SAR ($p<0.01$) and JS ($p<0.01$). Maturity groups had a negligible effect on SBJ performance (-45.32 ± 66.28; $p>0.05$). The best fitting model on SBJ performance could be expressed as follows: 102.97 + 2.24 x age + 0.55 x leg length + 0.66 x fat-free mass + 0.16 x sit-and-reach + 0.13 jumping sideways.

The random-effects coefficients describe the two levels of variance (within individuals: level 1, and between individuals: level 2). The significant variances for both models (A and B) at level 1 indicates that all players significantly improved jumping performance at each measurement occasion within individuals (estimate > 1.96 x SE; $p<0.05$). The between-individual variance matrix (level 2) indicated that players had significant explosive power growth curves in terms of curve-intercepts (constant/constant; $p<0.05$) and slopes (age/age; $p<0.05$). The positive covariance between intercepts and slopes (Model A: 1.02 ± 0.22; $p<0.05$; Model B: 8.75 ± 2.78; $p<0.05$) suggests that at the end of the pubertal years, the rate of improvement for both CMJ and SBJ continues to increase.

Table 4 *Multilevel regression models for counter movement jump and standing broad jump (2274 measurements).*

Variance-covariance matrix of random variables	*Counter Movement Jump* (Model A): Constant	*Counter Movement Jump* (Model A): Chronological age	*Standing Broad Jump* (Model B)	*Standing Broad Jump* (Model B): Constant	*Standing Broad Jump* (Model B): Chronological age
Level 1 (within individuals)					
Constant	3.557 (0.140)		*Level 1*	57.586 (2.244)	
Level 2 (between individuals)					
Constant	8.645 (0.816)	1.019 (0.219)	*Level 2*	125.138 (11.702)	8.752 (2.788)
Chronological age	1.019 (0.219)	0.734 (0.116)		8.752 (2.788)	6.841 (1.381)

Step	Fixed explanatory variables	*P*	*VIF*	*1/VIF*	Value at final step *k*	Value at final step SE	Step	*P*	*VIF*	*1/VIF*	Value at final step *k*	Value at final step SE
1	Intercept (constant)				8.652	2.787	1				102.974	9.899
2	Chronological age	< 0.01	1.27	0.79	1.043	0.142	2	< 0.01	1.22	0.82	2.235	0.491
3	Chronological age^2	< 0.01	1.07	0.94	0.171	0.025	3	NS				
4	Leg length	< 0.01	1.06	0.95	0.154	0.041	4	< 0.01	1.05	0.95	0.552	0.139
5	Fat-free mass	< 0.01	1.21	0.83	0.118	0.027	5	< 0.01	1.17	0.86	0.659	0.097
6	Fat mass	NS					6	NS				
7	Sit-and-reach	< 0.01	1.01	0.99	0.071	0.018	7	< 0.01	1.01	0.99	0.164	0.070
8	Backward balancing	NS					8	NS				
9	Moving sideways	< 0.01	1.03	0.97	0.027	0.009	9	NS				
10	Jumping sideways	NS					10	< 0.01	1.02	0.98	0.131	0.029
11	Average *vs* latest maturers	< 0.01	1.04	0.96	–0.728	0.427	11	NS				
	Earliest *vs* latest maturers				–1.741	0.459						
IGLS deviance from the null model					5758.811						7031.520	
– 2 × log likelihood					8549.929						13575.770	

Note: random-effects values are estimated mean variance ± SE; fixed-effect values (explanatory variables) are estimated mean coefficients ± SE; chronological age was adjusted about origin using mean age ± 13.5 years. *k* (mean coefficients of various explanatory variables); SE (standard error); NS (non-significant). Latest maturers were used as baseline measure and other maturity groups were compared with it. Multicollinearity statistics: VIF (variance inflation factors; 1/VIF (tolerance).

The measured and predicted curves for CMJ and SBJ performance were plotted by age in ***Figure 1***. Predicted CMJ performance (— solid line in *fig.1*) almost perfectly followed the measured CMJ performance (--- dashed line in Fig.1). The predicted SBJ performance fluctuated below (11 to 13 years) and above (13 to 17 years) the measured SBJ performance. Notably, from the age of 15 years, the discrepancy between predicted and measured SBJ performance increased with age.

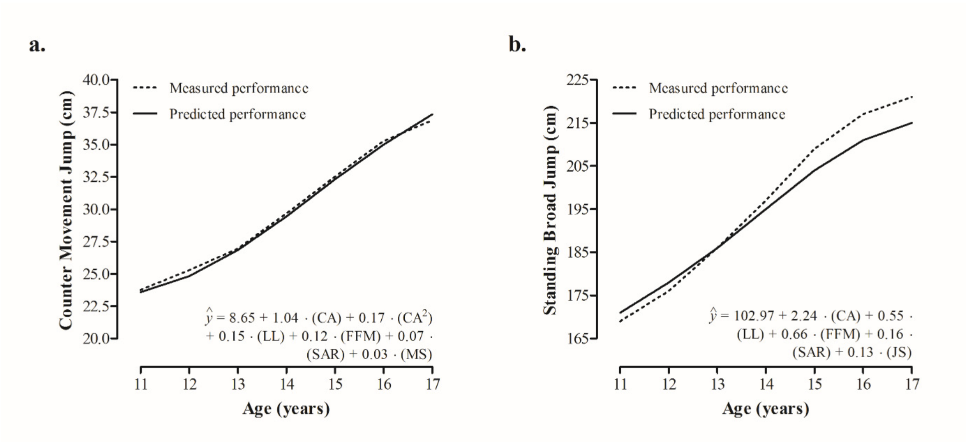

Figure 1 *Measured and predicted performance for counter movement jump (a.) and standing broad jump (b.) aligned by chronological age.*

Discussion

The present study aimed to model the development of explosive power, assessed by CMJ and SBJ in 356 Flemish, high-level youth soccer players during the pubertal years. Two longitudinal multilevel models (for CMJ and SBJ) were obtained from 2,274 measurements. Generally, results revealed that chronological age and its squared value, body size (given by leg length), body composition (fat-free mass derived from a two-component model), flexibility (sit-and-reach) and motor coordination (one item from a three-component test battery) are predictors of explosive power. To our knowledge, this is the first study to report the importance of hamstring flexibility in the development of explosive power. Remarkably, the variability in maturity status seems to benefit later maturing soccer players when assessing the counter movement jump, but not the standing broad jump. These findings suggest that different jumping protocols (vertical vs. long jump) highlight the need for special attention in evaluating jump performances. Both protocols emphasized growth, muscularity, flexibility and motor coordination as longitudinal predictors. The use of the SBJ is recommended in youth soccer identification and selection programs, since biological maturity status has no impact in SBJ development through puberty.

It was initially hypothesized that the predicted longitudinal models for explosive power would differ between players contrasting in maturity status. Therefore, an estimate of biological maturation was considered as a dummy variable (later vs. average vs. earlier maturing players based on tertiles), and as a candidate variable in the analyses. Introducing maturity groups into the model predicting CMJ substantially differed from the model that included six predictor variables. Notably, compared to the latest maturing players, the average and earliest maturing players jumped significantly lower (-0.73 cm and -1.74 cm, respectively; ***Table 4***). In contrast, introducing maturity groups into the model predicting SBJ was not significantly different from the model that included five predictor variables. We do however acknowledge the limitation of the present method of categorizing players into maturity groups based on tertiles (11,12), which does not correspond to previously described methods (28). Indeed, Mirwald et al. defined pubertal players as follows: early = preceding the average APHV by more than one year; average = ± one year from APHV; and late = more than one year after APHV. Moreover, it has been stated that the sport of soccer systematically excludes late(r) maturing boys and tends to favour more early and average maturing players as chronological age and sport specialization increase (13,23).

A recent study attempted to validate the estimated timing of peak height velocity against actual APHV obtained using Preece-Baines Model 1 in an 11-year longitudinal study of 193 Polish school boys (24); actual APHV was underestimated at younger ages and overestimated at older ages. Moreover, mean differences between actual and predicted APHV were reasonably stable between 13 and 15 years. It was concluded that predicted APHV has applicability among average maturing boys, aged 12 to 16 years. The mean age of the current sample at baseline was 12.0 ± 1.3 years and therefore the application of the maturity offset protocol to estimate APHV should be recognized as a limitation.

To our knowledge, this is the first study to report higher values for explosive power (CMJ) in later maturing soccer players during the pubertal years. This contrasts with previous findings in Portuguese soccer players (varying in maturity status between 11 and 15 years) (13,22), Where players advanced in maturity status outperformed their less mature counterparts on vertical jump tests. With this in mind, as soccer players grow older, late maturing players are systematically excluded (13,23). Indeed, the proportion of late maturing male soccer players in a Portuguese sample (classified on the basis of differences between skeletal and chronological ages) decreased from 19.5% to 5.6% between the ages of 11-12 years to 13-14 years, respectively (13). Therefore, it is possible that the present high-level youth soccer sample might also exclude these late maturing players, and that the selection process favours a homogeneous group of early to average maturing soccer players. Nevertheless, baseline values for CMJ revealed similar performances for all maturity groups (***Table 3***). Further research should focus on the inclusion of other maturity indicators such as skeletal age or Tanner stage of pubic hair development (13,21,25).

In contrast to CMJ, no differences between maturity groups were found for SBJ performance, despite the smaller performance for the latest maturers at baseline compared with the average and earliest maturers (***Table 3***). Arm-swing and countermovement prior to jumping have been identified as important factors for SBJ performance (1). Indeed, the standing long jump performed with arm-swing increased the take-off velocity of the centre of gravity by 15% compared with arms restricted, resulting in a possible benefit of 40 cm (1). Inter-limb coordination seems to heavily influence SBJ performance, evidenced by the significant role for certain subtests of the KTK (i.e., moving sideways for the CMJ and jumping sideways for the SBJ) in the prediction of explosive power. Therefore, less explosive players can counter their more explosive peers by a proper jumping technique, which may lead to further benefits in the later stages of puberty when muscle mass is increases (20). Therefore, the inclusion of specific programs focusing on general motor coordination is recommended within the pubertal years as it is beneficial for improving the explosive power of all players. Additionally, motor coordination tasks are independent of maturational status (40) and provide more insight into the future potential of young athletes (40).

In agreement with our hypothesis, chronological age and body size dimensions significantly contribute to the development of explosive power. A cross-sectional study in French school children explored the relationship between anthropometrical characteristics and three different jumping tasks (34). The authors found similar and increasing jumping performances in boys and girls until the age of 14 years. From then on, boys significantly outperformed girls. This is likely explained by the increase in leg length and leg muscle volume. Indeed, the present findings revealed that, on average, an increase of 1 cm in leg length would improve CMJ and SBJ performance by 0.15 cm and 0.55 cm respectively. Additionally, during the pubertal years, the role of fat-free mass, which correlates with the 'muscularity' of the player, seems significant in predicting explosive power. Moreover, the growth curve for muscular strength is almost identical to that of body size during childhood and adolescence (20). However in elite soccer players, after the age of 13-14 years, estimated velocities for vertical jump and standing long jump performances remained constant, which might reflect the growth in muscle mass and the influence of systematic sports training (29). Therefore, monitoring increases in anthropometrical characteristics (i.e., stature, leg length and fat-free mass) on a regular basis would allow youth coaches to better understand the players' individual development of explosive power.

No information is currently available in the literature regarding the influence of flexibility on different jumping tasks in an athletic population, without implementing different stretching protocols. Several studies have focussed on the acute effects of different stretching protocols on fitness performances in soccer players (7,15). However many of their outcomes are confusing and contain contrasting conclusions. Moreover, relationships between improved hamstring flexibility and fitness performances remain unclear. To date, the influence of hamstring flexibility on the development of explosive power in young soccer players has not been investigated. This study revealed that sit-and-reach performance significantly contributed to CMJ and SBJ performances during the pubertal years. An inverse relationship between the development of growth in stature and flexibility for a short period around peak height velocity has been reported (29). The estimated velocity curve for flexibility peaks one year after peak height velocity, suggesting that more flexible hamstrings enhance jump performances from 13-14 years of age.

From the age of 13-14 years (i.e., around peak height velocity), the slope of the developmental curves for CMJ and SBJ (***Figure 1***) become steeper, suggesting a substantial increase in muscle mass (20,29). Therefore, we strongly recommend the implementation of additional strength programs from the age of 13-14 years in regular soccer training, with respect to individual growth and maturation. Furthermore, the positive covariance between intercepts and slopes for both jumping models (***Table 4***) suggests that explosive power is still increasing even after the age of 17 years, which explains why the developmental curves do not plateau (***Figure 1***).

This study showed that the longitudinal development of explosive power in young soccer players is related to growth, muscle mass, flexibility and general motor coordination. Maturity related variation in the development of CMJ seems to benefit the more late maturing players. Although, we acknowledge that the use of the maturity offset protocol is a limitation and future studies need to include skeletal age as a classification index. Finally, this study provides a rationale for youth coaches to approach the development of explosive power on an individual basis, with scientifically based identification and evaluation processes. Further studies should consider specific training parameters such as annual minutes of training and playing time, and an estimate of training intensity.

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STUDY 9

LONGITUDINAL DEVELOPMENT OF EXPLOSIVE LEG POWER FROM CHILDHOOD TO ADULTHOOD IN SOCCER PLAYERS

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Abstract

The aim of this study was to investigate the development of explosive leg power using two similar jumping protocols (countermovement jump and standing broad jump) in 555 Belgian, high-level young soccer players, aged between 7 and 20. The total sample was divided into three longitudinal samples related to growth and maturation (childhood: 6 to 10 years; early adolescence: 11 to 16 years; and late adolescence: 17 to 20 years), and six multilevel regression models were obtained. Generally, both jumping protocols emphasized that chronological age, body size dimensions (by means of fat mass in the childhood and early adolescence groups, fat-free mass in the late adolescence group and stature - not for CMJ in childhood group) and motor coordination (one item of a three-component test battery) are longitudinal predictors of explosive leg power from childhood to young adulthood. The contribution of maturational status was not investigated in this study. The present findings highlight the importance of including non-specific motor coordination in soccer talent development programs.

Introduction

During a soccer match, energy delivery is dominated by aerobic metabolism. However, explosive actions (short sprints, tackles, jumps and duel play) are covered by means of anaerobic metabolism, and are often considered crucial for match outcome [4,34,46]. Anaerobic performance measures have been used in talent identification programs for young soccer players to predict both short-term [21] and long-term [15] competition level. Several protocols such as short-term cycling power tests, vertical jump tests or running tests have been used to evaluate short-term power output in children [43]. Within the field of soccer, assessing jump performances (e.g. countermovement jump, squat jump, drop jump, standing broad jump) to evaluate anaerobic power are well established [3,10,12,22]. Therefore, the purpose of the present study was to provide insight into the factors accounting for longitudinal development of explosive leg power.

Recently, several longitudinal studies have investigated the development of functional capacities and soccer-specific skills [37], repeated sprint ability [38], aerobic performance [39] and intermittent-endurance capacity [11] within young soccer players during the pubertal years (10 to 17 years). No such models are presented in the literature for explosive leg power and little is known about the development before and after puberty in young soccer players. Although, information about the multilevel development of anaerobic power in school children is available [1,30]. However, recently, a cross-sectional study in 275 male competitive soccer players between 8 and 31 years investigated age-related differences in explosive leg power by means of a countermovement jump (CMJ) [26]. The author reported age-related increases in CMJ with the largest increase in explosive power between 11 and 15 years. No differences were found from the age of 17 years.

Increases in strength and power with age in young boys cannot be explained by growth alone. Indeed, it has been reported that strength increases more rapidly than stature in prepubertal boys [7]. Additionally, longitudinal models have revealed that at the age of peak height velocity, boys' quadriceps strength is developing at a greater rate or disproportionally to their body size (height and body mass) compared to girls [25,30]. This is likely to be due to an interrelationship between several factors such as age, stature, body mass, fat-free mass, muscle size, testicular volume, salivary DHEAS concentration, testosterone concentration and pubertal developmental stages [2,3,17,26,35]. For example, Aouichaoui et al. [2] demonstrated the positive relationship between CMJ and lower limb length in male professional volleyball players, aged 21 years on average. The players with longer lower limbs had better CMJ performances and their anaerobic power was higher compared with players with shorter lower limbs. Moreover, the selection of 70 Chinese youth soccer players (U14) was based on their anthropometry for short-term benefits such as taller players for vertical jump height [45]. A further study considered the contribution of chronological age, anthropometrical characteristics (i.e., stature and body mass), sexual maturity status and years of training to functional capacities in 69 Portuguese soccer players, aged 13-15 years [22]. The authors found that both stature and maturity status were significant contributors to vertical jump performance when young soccer players progress into puberty.

As previously stated, several factors have impact on muscle force development, however only a few studies have highlighted the influence of motor coordination [16,24,27]. A review by Van Praagh and Doré [43] suggested that improved movement coordination is a more important contributor to muscle force gain in complex, multi-joint exercises, such as vertical jump and sprinting. Furthermore, a five-year longitudinal study in 38 pre-pubertal children, aged between 5 and 7 years at baseline investigated differences in fitness measures between children with high and low motor competence [16]. The low motor competence group performed worse on the standing long jump and 50-m run test compared with the high motor competence group in each year of the follow-up study. Similar results were found in a two-year follow-up study in 501 children of different levels of motor competence, aged between 6 and 10 years [14]. The high motor competence group outperformed their low levelled counterparts in several physical fitness tests, including the standing broad jump. In agreement with O'Beirne and colleagues [27] who found a significant relationship between anaerobic power and motor coordination, these results highlight the impact of motor competence on measures of anaerobic power over time. From a kinematic point of view, Vanrenterghem et al. [44] found that the countermovement and rotation of proximal segments increased with increasing jump height in 10 male volleyball players. Therefore, a countermovement is required to enable kinetic energy to build up towards take-off, but a deeper countermovement involves a larger potential energy reduction of the centre of mass relative to that at stance.

It is already well-known that larger body size dimensions provide advantages in strength and power-related tasks, especially during the pubertal years [23,45]. On the other hand, as motor coordination is not related to maturational status, motor coordination parameters should be part of a selection strategy in young promising players in order to estimate their future potential [41]. However, little is known about the longitudinal development of explosive leg power in young soccer players during the years before and after puberty, particularly with respect to the contribution of motor coordination. The rationale for the present study emerged from the lack of multilevel longitudinal models for explosive leg power based on the contribution of age, anthropometry and motor coordination parameters in a high-level soccer population of that age-range. Therefore, the development of concurrent jump performances (i.e. counter movement jump and standing broad jump) was further investigated in three longitudinal samples related to growth and maturation from childhood to adulthood (i.e. late childhood, early adolescence and late adolescence). The contribution of maturational parameters was not further investigated. Based on previous literature, we hypothesized that motor coordination has an impact on explosive leg power in the younger years [16,43] and that body size dimensions (i.e., stature and fat-free mass) is decisive at older ages [22].

Materials and methods

Subjects and design

The present longitudinal data sample consisted of 3,674 data points from 555 male youth soccer players (average of 6.6 observations per player). Players were aged between 7 and 17 years at baseline (mean age of 11.4 ± 3.4 y) and recruited from two professional Belgian soccer clubs in the highest division. All players participated in a high-level youth soccer development program, which consisted of 3 (U8) to 5 (U21) training sessions and one game per week. Players were born between 1990 and 2005, and were assessed over 1 to 7 years between 2007 and 2013.

The total sample of soccer players between 7 and 20 years consisted of three different baseline groups (i.e., three longitudinal samples), related to the growth from childhood to adulthood: late childhood (7-8 years), early adolescence (11-12 years) and late adolescence group (16-17 years). Players were assigned to an age group at baseline according to their birth year (e.g., a player born in 2000 who was assessed for the first time in 2011, was assigned to the 11 y age group): late childhood: 7 y (n=91) and 8 y (n=122); early adolescence: 11 y (n=163) and 12 y (n=58); late adolescence: 16 y (n=159) and 17 y (n=26). Mean ages at baseline were 7.6 ± 0.5 y (age range 6.6-8.4 y), 11.1 ± 0.6 y (10.5-12.5 y) and 16.0 ± 0.5 y (14.6-17.5 y), for the late childhood, early and late adolescence group, respectively. Longitudinal data were available for the late childhood group from 7 to 10 years, for the early adolescence group from 11 to 15 years, and for the late adolescence group from 16 to 20 years. The total measurements of each individual player varied between 3 and 15 measurements (***Table 1***).

All players and their parents or legal representatives were fully informed about the experimental procedures of the study, before providing written informed consent. The Ethics Committee of the University Hospital approved the study, and the study was performed according to the ethical standards of the International Journal of Sports Medicine [18]. This research was performed without financial support and the authors assure no affiliations with, or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Table 1 *Number of subjects and number of measurements per age group.*

		Number of measurements													
Period	Age	3	4	5	6	7	8	9	10	11	12	13	14	15	*Total*
Pre-teens	7 years	27	5	22	25	12	11	6	7	12	5	4	2	0	*138*
	8 years	69	29	73	55	35	47	34	30	21	11	5	2	0	*411*
	9 years	26	27	49	62	44	64	45	39	22	14	6	4	0	*402*
	10 years	4	9	15	30	29	54	36	35	17	16	5	2	0	*252*
	Total measurements	126	70	159	172	120	176	121	111	72	46	20	10	0	*1203*
	Number of subjects	42	18	32	30	19	25	17	14	8	5	2	1	0	***213***
Puberty	11 years	45	69	48	65	42	48	67	46	18	25	15	12	6	*515*
	12 years	55	61	34	45	40	34	43	26	28	13	16	11	7	*403*
	13 years	17	21	20	30	35	27	34	29	27	14	17	13	11	*296*
	14 years	8	12	2	10	22	20	33	18	22	8	14	15	8	*197*
	15 years	2	1	1	1	11	4	14	13	15	10	15	12	7	*113*
	Total measurements	127	164	105	151	150	133	191	132	110	70	77	63	39	*1524*
	Number of subjects	43	40	21	24	20	14	18	11	11	5	6	5	3	***221***
Late adolescence	16 years	72	76	52	69	37	25	11	11	15	4	7	11	6	*396*
	17 years	63	59	54	62	43	19	9	6	0	0	0	0	0	*315*
	18 years	28	24	30	39	31	18	7	5	0	0	0	0	0	*182*
	19 years	4	5	8	11	11	5	3	3	0	0	0	0	0	*50*
	20 years	0	0	2	0	0	0	0	2	0	0	0	0	0	*4*
	Total measurements	167	164	146	181	122	67	30	27	15	4	7	11	6	*947*
	Number of subjects	55	41	29	30	17	8	3	2	0	0	0	0	0	***185***
Grand total	Total measurements	420	398	410	504	392	376	342	270	209	120	104	84	45	*3674*
	Number of subjects	130	93	78	77	51	40	32	21	14	7	6	4	2	***555***
	*	(10)	(6)	(4)	(7)	(5)	(7)	(6)	(6)	(5)	(3)	(2)	(2)	(1)	

**Numbers between brackets represent the number of players who were assessed over 2 periods*

Chronological age

Chronological age (to the nearest 0.1 year) was calculated as the difference between date of birth and date on which the assessments were made.

Anthropometry

Stature was assessed to the nearest 0.1 cm using a portable stadiometer (Harpenden, Holtain, UK). Body mass and body fat were assessed to the nearest 0.1 kg and 0.1 %, respectively, using a total body composition analyser (TANITA, BC-420SMA, Japan) according to the manufacturer's guidelines. Fat mass (FM, 0.1 kg) was calculated as [body mass x (body fat / 100)], and then subtracted from body mass to obtain fat free mass (FFM, 0.1 kg).

All anthropometric measures were taken by the same investigator to ensure test accuracy and reliability. For stature, the intra-class correlation coefficient for test-retest reliability and technical error of measurement (test-retest period of 1 h) in 40 adolescents were 1.00 ($p < 0.001$) and 0.49 cm, respectively.

Motor coordination

Motor coordination was investigated using three non-specific subtests from the "Körperkoordination Test für Kinder" (KTK): moving sideways (MS); backward balancing (BB); and jumping sideways (JS), conducted according to the methods of Kiphard and Shilling [19]. This test battery has been demonstrated to be reliable and valid in the age-range of the present population [42]. Hopping for height, the fourth subtest, was not included in the present study. The main reasons for excluding the hopping for height subtest were because the discriminating ability is rather low in a homogeneous group of high-level players, the injury risk is very high since soccer players are able to jump high (this is more related to stature and leg-length, rather than motor coordination), and because this test is very time consuming within the present test battery.

Jumping performance

To evaluate jumping performance, the soccer players executed the standing broad jump (SBJ) and counter movement jump (CMJ). These two strength tests are commonly used to evaluate explosive leg power. The SBJ (to the nearest 1 cm) is part of the Eurofit test battery and was conducted according to the guidelines of the Council of Europe [9]. The CMJ (to the nearest 0.1 cm) was conducted according to the methods described by Bosco et al. [8] with the arms kept in the akimbo position to minimize their contribution. Jumps were recorded using an OptoJump system (MicroGate, Italy) and the highest of three jumps was used for further analysis.

Statistical analyses

Means and standard deviations (*SD*) were calculated for each baseline group for chronological age, stature, body mass, body fat, FM, FFM, motor coordination parameters (BB, MS, JS), CMJ and SBJ. Multicollinearity was examined for the six multilevel regression models (Model 1 to 3: potential predictors of CMJ; Model 4 to 6: potential predictors of SBJ), using correlation matrix and diagnostic statistics [26]. Variables with a variance inflation factor (VIF) > 10 and with small tolerance (1/VIF ≤ 0.10; corresponding to an R^2 of 0.90) were considered indicative of harmful multicollinearity [33]. The robustness of the multilevel models was not compromised by multicollinearity between explanatory variables. Tolerance (0.22-0.54) and a variance inflation factors (1.85-4.57) were well within the normal ranges (>0.10, <10, respectively) [29].

For the longitudinal analyses, multilevel regression analyses (CMJ and SBJ) were performed using *MLwiN 2.16* software to identify those factors associated with the development of explosive leg power. The multilevel model technique allows the number of observations and temporal spacing between measurements to vary among subjects, thus using all available data. It is assumed that the probability of data being missing is independent of any of the random variables in the model. As long as a full information estimation procedure is used, such as maximum likelihood in *MLwiN* for normal data, the actual missing mechanism can be ignored [29]. A detailed description of the multilevel modelling procedure has been previously reported [11,37,38] and complete details of this approach are presented elsewhere [5]. In brief, CMJ and SBJ were measured repeatedly in individuals (level 1 of hierarchy) and between individuals (level 2 of hierarchy). The following additive polynomial random-effects multi-level regression model was adopted to describe the developmental changes in explosive leg power [29]:

$$y_{ij} = \alpha + \beta_j x_{ij} + k_1 z_{ij} + \cdots k_n z_{ij} + \mu_j + \varepsilon_{ij}$$

where y is the jumping performance parameter on measurement occasion i in the jth individual; α is a constant; $\beta_j x_{ij}$ is the slope of the jumping performance parameter with age for the jth individual; and k_1 to k_n are the coefficients of various explanatory variables at assessment occasion i in the jth individual. The structure of the multilevel models consisted of testing the inclusion a step at a time of explanatory variables (k fixed effects). The first step was to obtain models that fitted non-linear age changes [5]. Age, as explanatory random variable, was centered on its mean value (i.e., 8.9 y, 12.6 y and 16.9 y for the late childhood, early adolescence and late adolescence groups, respectively). To allow for the nonlinearity of the explosive leg power development, age power function (i.e., age centered^2) was introduced into the linear model [40]. Subsequently, the inclusion of additional explanatory variables was tested; the order of entrance in the multilevel analyses was based on biological and analytical assumptions (i.e., Pearson's product moment correlation coefficients). If the retention criteria were not met (i.e., significant likelihood ratio statistics and mean coefficient greater than 1.96 the standard error of the estimate), the explanatory variable was discarded. The final model included only variables that were significant independent predictors. Alpha level was set at 0.05.

Results

Age, anthropometry, motor coordination parameters and explosive leg power, by age group at baseline are presented in ***Table 2***. Generally, players improved with age on all parameters.

Table 2 *Mean scores ± sd for age, anthropometrical characteristics, flexibility, motor coordination and jumping performance at baseline for the three groups.*

		PRE-TEEN				PUBERTY				LATE ADOLESCENCE			
	Units	*n*	7 years	*n*	8 years	*n*	11 years	*n*	12 years	*n*	16 years	*n*	17 years
Chronological age	y	*91*	7.2 ± 0.2	*122*	8.0 ± 0.3	*163*	10.8 ± 0.3	*58*	12.1 ± 0.3	*159*	15.8 ± 0.3	*26*	16.9 ± 0.3
Stature	cm	*91*	123.8 ± 4.9	*122*	129.0 ± 5.4	*163*	144.4 ± 5.4	*58*	149.9 ± 5.8	*159*	173.6 ± 6.5	*26*	179.5 ± 5.8
Body mass	kg	*91*	23.9 ± 3.0	*122*	26.2 ± 3.2	*163*	34.9 ± 4.1	*58*	38.6 ± 5.4	*159*	62.6 ± 8.0	*26*	71.9 ± 8.5
Body fat	%	*91*	16.7 ± 2.6	*122*	15.9 ± 3.1	*163*	14.0 ± 3.1	*58*	13.0 ± 3.8	*159*	11.4 ± 3.3	*26*	12.6 ± 3.0
FM	kg	*91*	4.1 ± 1.1	*122*	4.2 ± 1.2	*163*	5.0 ± 1.5	*58*	5.1 ± 2.2	*159*	7.3 ± 2.7	*26*	9.3 ± 3.1
FFM	kg	*91*	19.8 ± 2.1	*122*	22.0 ± 2.5	*163*	29.9 ± 3.1	*58*	33.5 ± 3.9	*159*	55.3 ± 6.1	*26*	62.7 ± 6.1
Backward balancing	n	*70*	39 ± 11	*81*	43 ± 10	*123*	58 ± 9	*30*	58 ± 12	*109*	64 ± 8	*11*	58 ± 10
Moving sideways	n	*70*	39 ± 5	*81*	42 ± 5	*123*	59 ± 7	*30*	58 ± 8	*108*	72 ± 9	*11*	65 ± 7
Jumping sideways	n	*69*	60 ± 9	*81*	68 ± 10	*123*	91 ± 9	*30*	92 ± 10	*109*	111 ± 11	*11*	104 ± 8
CMJ	cm	*91*	18.3 ± 2.7	*122*	19.2 ± 3.4	*163*	23.7 ± 3.4	*58*	24.9 ± 3.1	*159*	34.7 ± 4.9	*26*	35.5 ± 4.4
SBJ	cm	*91*	135 ± 12	*122*	143 ± 15	*163*	169 ± 12	*58*	177 ± 15	*159*	219 ± 17	*26*	225 ± 15

FM=fat mass; FFM=fat free mass; SAR=sit-and-reach; CMJ=counter movement jump; SBJ=standing broad jump

Multilevel analyses results

Tables 3 and ***4*** summarize the results of the multilevel models for the development of explosive leg power in the late childhood, early adolescence and late adolescence groups, assessed by CMJ and SBJ protocols, respectively. Age centered was introduced into the six models as both fixed as random coefficients. The random effect coefficients describe the two levels of variances (level 1: within individuals; level 2: between individuals). The significant variances at level 1 for all six models (***Tables 3*** and ***4***), indicates that explosive leg power was significantly increasing at each measurement occasion within individuals (mean>2*SEE; $p<0.05$). The between-individual variance matrix at level 2 for each model indicated that individuals had significantly different explosive leg power growth curves, both in terms of their intercepts (constant/constant; $p<0.05$), and the slope of their lines (age centered/age centered; $p<0.05$), except for the variance of the slopes in CMJ performance in the late adolescence group (0.365 ± 0.225; $p>0.05$) (***Table 3***). The variance of these intercepts and slopes was positively, however not significantly correlated, except for the variance in CMJ performance in the puberty group (0.682 ± 0.257; $p<0.05$) (***Table 3***). Within the late adolescence group, the variance between intercepts and slopes of the SBJ was negatively, non-significantly correlated (-3.233 ± 7.527; $p>0.05$) (***Table 4***). The negative sign of the variance between intercepts and slopes means that at older age, the improvement in explosive leg power occurs at a lower rate, and the lack of correlation indicates that individuals with higher intercepts do not necessarily have steeper slopes.

Table 3 *Multilevel regression models for counter movement jump for pre-teen (1203 measurements), puberty (1524 measurements) and late adolescence (947 measurements) groups.*

Variables	Pre-Teen (7 – 10 years)		Puberty (11 – 15 years)		Late Adolescence (16 – 20 years)	
Fixed effect	Estimates		Estimates		Estimates	
Constant	19.524 ± 0.757		11.849 ± 4.005		20.803 ± 2.700	
Age centered	1.358 ± 0.120		1.355 ± 0.182		0.898 ± 0.178	
Age centered^2	NS		0.317 ± 0.034		NS	
Stature	NS		0.084 ± 0.026		NS	
Fat mass	– 0.282 ± 0.084		– 0.205 ± 0.069		NS	
Fat-free mass	NS		NS		0.182 ± 0.042	
Backward balancing	NS		NS		NS	
Moving sideways	0.043 ± 0.012		0.033 ± 0.012		0.062 ± 0.015	
Jumping sideways	NS		NS		NS	
Random effects	Level 1		Level 1		Level 1	
Constant	2.741 ± 0.134		3.331 ± 0.163		3.801 ± 0.251	
	Level 2		Level 2		Level 2	
	Constant	Age centered	Constant	Age centered	Constant	Age centered
Constant	7.824 ± 0.845	0.360 ± 0.215	7.578 ± 0.867	0.682 ± 0.257	16.682 ± 1.906	0.808 ± 0.502
Age centered	0.360 ± 0.215	0.319 ± 0.101	0.682 ± 0.257	0.697 ± 0.142	0.808 ± 0.502	0.365 ± 0.225

Fixed effect values are Estimated Mean Coefficients ± SEE (Standard Error Estimate) of counter movement jump (cm).

Random effect values Estimated Mean Variance ± SEE.

Age centered is age in years centered around 8.9, 12.6 and 16.9 years of age (years), for the 3 periods, respectively.

Numerical values are all significant, $P < 0.05$ (mean>2*SEE). NS = Not significant and variable removed from the final model.

Table 4 *Multilevel regression models for standing broad jump for late childhood (1203 measurements), early adolescence (1524 measurements) and late adolescence (947 measurements) periods.*

Variables	Late Childhood (7 – 10 years)				Early Adolescence (11 – 15 years)				Late Adolescence (16 – 20 years)			
Fixed effect	–2 × LL	Estimates	VIF	1/VIF	–2 × LL	Estimates	VIF	1/VIF	–2 × LL	Estimates	VIF	1/VIF
Constant	11469.84	47.574 ± 18.470			12466.16	64.736 ± 14.926			7504.49	150.181 ± 10.909		
Age centered	10051.39	2.467 ± 0.900	2.66	0.38	10517.27	2.181 ± 0.676	3.03	0.33	6811.65	0.059 ± 0.745	1.02	0.98
Age centered^2	10051.13	NS			10497.38	0.614 ± 0.127	1.32	0.76	6809.59	NS		
Stature	10029.05	0.740 ± 0.138	2.95	0.34	10451.11	0.680 ± 0.095	2.86	0.35	6807.91	NS		
Fat mass	9996.66	– 2.028 ± 0.356	1.20	0.83	10432.59	– 0.971 ± 0.258	1.01	0.99	6808.54	NS		
Fat-free mass	9996.28	NS			10432.20	NS			6770.06	0.850 ± 0.157	1.02	0.98
Backward balancing	9994.41	NS			10431.13	NS			6769.43	NS		
Moving sideways	9994.12	NS			10430.83	NS			6768.17	NS		
Jumping sideways	8640.14	0.166 ± 0.037	1.03	0.98	8636.77	0.149 ± 0.035	1.02	0.99	5555.16	0.199 ± 0.049	1.01	0.99
Random effects	Level 1				Level 1				Level 1			
Constant		57.518 ± 2.795				50.272 ± 2.443				64.631 ± 4.331		
	Level 2				Level 2				Level 2			
		Constant	Age centered			Constant	Age centered			Constant	Age centered	
Constant		92.448 ± 10.621	0.408 ± 3.275			96.790 ± 11.205	1.554 ± 3.133			166.832 ± 20.403	–3.233 ± 7.527	
Age centered		0.408 ± 3.275	6.143 ± 2.007			1.554 ± 3.133	7.533 ± 1.740			– 3.233 ± 7.527	15.955 ± 5.449	

Fixed effect values are Estimated Mean Coefficients ± SEE (Standard Error Estimate) of standing broad jump (cm).

Random effect values Estimated Mean Variance ± SEE.

LL (Log likelihood). Multicollinearity statistics: VIF (variance inflation factors; 1/VIF (tolerance).

Age centered is age in years centered around 8.9, 12.6 and 16.9 years of age (years), for the 3 periods, respectively.

Numerical values are all significant, $P < 0.05$ (mean>2*SEE). NS = Not significant and variable removed from the final model.

In the late childhood group, age centered, stature (only for SBJ), FM, and one item of the KTK-test battery (MS for CMJ, and JS for SBJ) significantly contributed to the prediction of explosive leg power development. The best fitting model on the CMJ performance for the pre-teen players could be expressed as: 19.52 + 1.36 x age centered – 0.29 x fat mass + 0.04 x moving sideways. For SBJ, the obtained multilevel model was expressed as follows: 47.57 + 2.47 x age centered + 0.74 x stature – 2.03 x fat mass + 0.17 x jumping sideways. In the early adolescence group, age centered, age centered^2, stature, FM and one motor coordination parameter (MS for CMJ, and JS for SBJ) significantly contributed to the development of explosive leg power. The equations derived from the multilevel models could be expressed as: CMJ = 11.85 + 1.36 x age centered + 0.32 x age centered^2 – 0.21 x fat mass + 0.03 x moving sideways; SBJ = 64.74 + 2.18 x age centered + 0.61 x age centered^2 + 0.68 x stature – 0.97 x fat mass + 0.15 x jumping sideways. Within the late adolescence group, age centered, FFM and one coordination parameter (MS for SBJ, and JS for SBJ) were significant contributors to the development of explosive leg power. The obtained equations from the multilevel models were: CMJ = 20.80 + 0.90 x age centered + 0.18 x fat-free mass + 0.06 x moving sideways; SBJ = 150.18 + 0.06 x age centered + 0.85 x fat-free mass + 0.20 x jumping sideways.

The real and estimated curves for CMJ and SBJ performance were plotted by age in ***Figure 1***. Predicted CMJ performance nearly perfectly (– solid line in *fig.1*) followed the measured CMJ performance (---- dashed line in Fig.1). Similarly, the predicted SBJ performance nearly perfectly followed the measured SBJ performance until the age of 13-14 years. From then, the predicted SBJ performance was lower than measured SBJ performance, however the discrepancy was small and remained constant as players grow older.

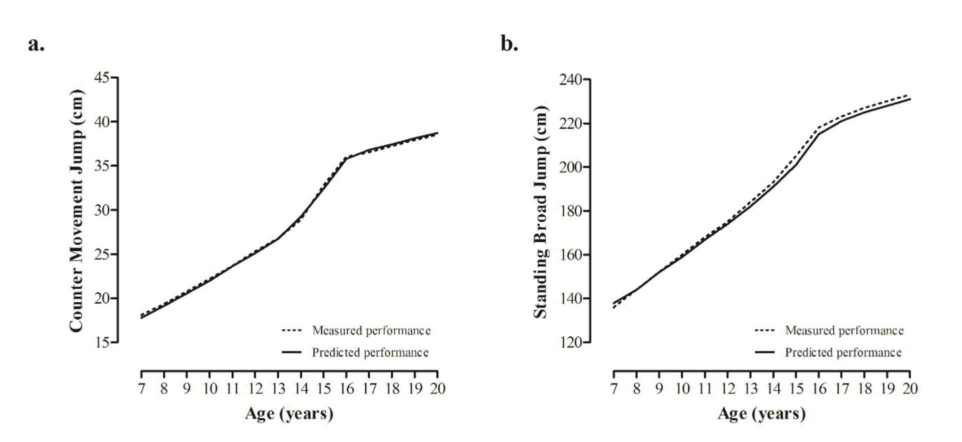

Figure 1 *The real and estimated curves for (a.) CMJ and (b.) SBJ by chronological age.*

Discussion

The present study investigated the development of explosive leg power in 555 Belgian, high-level soccer players between 7 and 20 years of age using similar jumping protocols (CMJ and SBJ). The total sample was divided into three longitudinal samples related to growth and maturation (late childhood, early and late adolescence), and six multilevel regression models were obtained. Generally, both jumping protocols emphasized that chronological age, body size dimensions (by means of fat mass in the childhood and early adolescence groups, fat-free mass in the late adolescence group and stature - not for CMJ in childhood group) and motor coordination (one item of three-component test battery) are longitudinal predictors of explosive leg power from childhood to young adulthood. The contribution of maturational status was not investigated in this study. The present findings highlight the importance of including non-specific motor coordination in soccer development programs.

It has widely been reported that strength- and power-related motor performance increases with increasing chronological age in children. Age is positively related to strength and motor performance, even when stature and body mass are controlled for [6,23]. Jumping performances (standing long jump (SLJ) and vertical jump (VJ)) increase linearly from 5 until 18 years of age in boys and until 14 years of age in girls [23]. The VJ in boys shows a slight acceleration compared with SLJ from 13-14 years of age in normal growing children. The growth curve for muscular strength is generally similar to that of body size during childhood and adolescence [23]. However, after the age of 13-14 years in elite youth soccer players (after age at peak height velocity), estimated velocities for VJ and SLJ remained positive, which might reflect the growth in muscle mass and the influence of systematic sports training [28].

The contribution of specific body dimensions such as calculated fat mass and fat-free mass as longitudinal predictors of explosive leg power was of interest. The role of fat-free mass, which correlates with the 'muscularity' of the player, seems significant in predicting jump performances when players enter late adolescence. Within the late childhood and early adolescence groups, entering fat-free mass into the four models did not substantially differ from the models previously mentioned (***Tables 3*** and ***4***). Previous research among 7- to 12-year-old boys revealed relationships between both absolute fat-free mass and relative fat-free mass as percentage of total body mass were moderately related to motor performances such as standing long jump and vertical jump [32]. An additional study in 208 Tunisian athletic boys, aged between 7 and 13 years reported that improvements in counter movement jump performance are related to age, stature, body mass and fat-free mass [2]. Conversely, a higher fat mass negatively influenced the prediction of explosive leg power, similar to findings reported by Armstrong et al. [1] who found body mass (positively) and skin-fold thickness (negatively) to be the best anthropometrical predictors of the Wingate Anaerobic Test. From a mechanical perspective, fat mass is an inert load (dead weight) that has to be removed when performing jumping tasks, and thus obstructs performance. Indeed, it was reported in a cross-sectional sample of 163 Portuguese soccer players (11-14 years) that adiposity, calculated as the sum of four skinfolds, contributed negatively and body mass positively to countermovement jump performance [13]. Furthermore, Temfemo and colleagues [35] concluded that chronological age, leg muscle volume and lean body mass were significant explanatory variables for average power measured by the countermovement jump in children between 11 and 16 years. Therefore, within youth soccer development programs, coaches should keep appropriate training stimuli and a balanced diet in mind, although reducing the fat mass to a minimum to maximize explosive leg power needs no special attention as young soccer players tend to be lean anyway.

In agreement with previous literature, stature was significantly related to explosive leg power performance between 7 and 15 years [2,35]. When age and body mass are statistically controlled, stature tends to have a positive influence on strength performance, whereas body mass negatively impacts performance outcomes when controlling for age and stature, especially in motor tasks in which the body is projected [23]. This finding is reflected in the negative contribution of fat mass to explosive leg power between 7 and 15 years, since total body mass was divided into fat and fat-free mass. Remarkably, the longitudinal model for countermovement jump performance in the late childhood group did not allow for stature. It has been suggested that the increase in leg power in the years before puberty is essentially a result of neural adaptations and coordination [2], and that the developments of the coordinative neuromuscular systems are most effectively achieved during this period [36]. From the age of 6-7 years, movement patterns which underlie basic motor skills are well developed, are more refined during practice and instruction and can be integrated into more complex motor skills which are fundamental to many games and sports [23]. It has also been reported that the stiffness of the musculotendinous unit increases with age during childhood [20]. Combining the latter findings with the present results, it could be suggested that young, well-coordinated players improve with age in explosive leg power due to increased tendon stiffness and that they still benefit in late adolescence from their well-developed neuromuscular system during childhood.

The significant contributions of stature and fat mass in the late childhood and early adolescence groups suggest that the development of explosive leg power is related to individual differences in timing and tempo of growth in stature. Youth soccer players who are taller with little fat mass benefit more when compared with shorter players with more fat mass. Although maturational status was not investigated, these results suggest that players who are growing at a higher rate (i.e., more advanced in maturational status) have an advantage over players who grow at a lower rate or just experience their peak growth later (i.e., delayed in maturational status). Conversely, when players enter late adolescence (i.e., after peak height velocity), the only longitudinal predictor for explosive leg power, next to chronological age was fat-free mass. This finding emphasizes the important role of muscularity in the development of explosive power in the transition from puberty to adulthood, and therefore promotes the inclusion of functional strength programs into the soccer development program. The selection process during childhood and puberty might focus on the formation of homogeneous groups of players, whereas the 'strongest' players are selected at older ages.

Several studies have reported the importance of including motor coordination in development programs and selection processes in elite gymnasts and soccer players [41,42]. It has been shown that a better baseline motor coordination is advantageous in physical fitness outcomes compared to those with low baseline motor coordination levels, even after a five-year follow-up [16]. Similarly, the present results revealed the significant contribution of one item of a three-component general motor coordination test battery in the prediction of explosive power from childhood to young adulthood. We hypothesized that motor coordination would contribute to explosive leg power in the younger years. Remarkably, moving sideways seems to predict countermovement performance, whereas jumping sideways is related to standing broad jump outcome. This might be explained by similarities in the specific protocol for countermovement jump and moving sideways on the one hand, and standing broad jump and jumping sideways on the other hand. Indeed, countermovement requires a high degree of multi-joint movements, similar to moving sideways performance and jumping sideways requires a high degree of lower limb work rate and stability, which is also needed in executing a standing broad jump. Therefore, the inclusion of specific programs focusing on general motor coordination is recommended as it benefits all players to improve their explosive power, even from a young age. Furthermore, motor coordination tasks are independent of maturational status [41] and provide more insight in the future potential of young athletes [41].

Unfortunately, indicators of maturity status were not assessed in the present study. Future studies may benefit from measuring these indicators and assessing their role (i.e., age at peak height velocity, Tanner stages of pubic hair, skeletal age, leg length etc.) in the development of explosive power. For example, due to the disproportional growth in leg length, it would be appropriate to determine leg length which is related to jump height. In conclusion, the development of explosive power, assessed by counter movement jump and standing broad jump performance, from childhood to young adulthood seems to be positively influenced by stature and negatively by fat mass in late childhood and early adolescence. In late adolescence, fat-free mass was the only (positive) influential anthropometrical parameter. Furthermore, as players grow older, the performance in explosive leg power increases. The results emphasize the importance of including non-specific motor coordination tasks in the development of explosive leg power.

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STUDY 10

A RETROSPECTIVE STUDY ON ANTHROPOMETRICAL, PHYSICAL FITNESS AND MOTOR COORDINATION CHARACTERISTICS THAT INFLUENCE DROP OUT, CONTRACT STATUS AND FIRST-TEAM PLAYING TIME IN HIGH-LEVEL SOCCER PLAYERS, AGED 8 TO 18 YEARS

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Abstract

The goal of this manuscript was twofold and a two-study approach was conducted. The first study aimed to expose the anthropometrical, physical performance and motor coordination characteristics that influence drop out from a high-level soccer training program in players aged 8-16 years. The mixed-longitudinal sample included 388 Belgian youth soccer players who were assigned to either a '*club* group' or a '*drop out* group'. In the second study, cross-sectional data of anthropometry, physical performance and motor coordination were retrospectively explored to investigate which characteristics influence future contract status (*contract* vs. *no contract* group) and first-team playing time for 72 high-level youth soccer players (mean age=16.2 y).

Generally, *club* players outperformed their *drop out* peers for motor coordination, soccer-specific aerobic endurance and speed. Anthropometry and estimated maturity status did not discriminate between *club* and *drop out* players. *Contract* players jumped further (p=0.011) and had faster times for a 5m sprint (p=0.041) than *no contract* players. The following prediction equation explains 16.7% of the variance in future playing minutes in adolescent youth male soccer players: -2869.3 + 14.6 * standing broad jump.

Practitioners should include the evaluation of motor coordination, aerobic endurance and speed performances to distinguish high-level soccer players further succeeding a talent development program and future drop out players, between 8 and 16 years. From the age of 16 years, measures of explosivity are supportive when selecting players into a future professional soccer career.

Introduction

Sports participation in a general population of children and adolescents has many benefits: improving health (18,35), improving social and psychological well-being (9), promoting (future) physical activity (36), improving motor competence (41) and skill development (6). Not only does the general public benefit from sports participation, it has also been shown that elite performances require childhood skill development through the exposure to high-level training programs (2). In these talent development programs, exposing youngsters to high-level training programs may in turn lead to better performance with age through the development of a more extensive physical, technical and strategical competency (43). However, it has been shown that many sports participants - from 23% of all ice-hockey players (22) to a staggering 75% of 14-16 year old track and field athletes (10) - drop out along the way.

The precise mechanisms that account for dropping out from organized sports are multifactorial. For example, Enoksen (10) stated that, in a follow-up study on drop out rates in 14- to 18-year-old Norwegian track and field athletes, 66.4% of the reasons for ceasing competitive track and field was related to injuries (24.3%), school priority (21.4%) and lack of motivation (20.7%). With regard to the stagnation of athletic performance and the early exposure to highly specialized training, Fraser-Thomas et al. (13) showed that drop outs, as opposed to their peers with longer engagements in swimming, reached performance milestones earlier and reported spending less time in unstructured play. Also, Gagné (14) showed in his DMGT-model that a certain degree of 'natural abilities' is critical to end up as being a talent (top 10 percent), which indicates a large influence of heritability in the developmental progress in young children. Furthermore, variation in relevant anthropometrical and physiological predispositions in soccer is subject to strong genetic influences or is largely environmentally determined and susceptible to training effects (32).

In Flanders (northern part of Belgium), soccer is the most popular team sport played by boys. For example, in 2003, it was estimated that 46% of all Flemish boys between ages 13 and 18 years were involved in competitive soccer at different levels. Many of these children desire professional soccer careers but achieving expert performance is not straightforward as many children who start soccer training as young as age five, drop out along the way. Therefore, understanding the mechanisms that underpin drop out from high-level soccer training programs might help to decrease drop out rates and increase engagement in talented young soccer players. Although not abundant, there has been some research on mechanisms on the factors that might influence drop out from soccer (4,12,15,21,42). For example, Figuereido et al. (11) compared baseline maturity status, body size, functional capacities and sport-specific skills of youth soccer players aged 11-12 and 13-14 years classified as drop outs and club (same level) or elite (higher level) two years later. These authors reported that elite players at follow-up were larger in body size and performed better in functional capacities at baseline in both age groups when compared with club players and drop outs.

Once young players are retained within talent development programs, the goal presumably for them is now to develop into adult players capable of being competitive at the highest level. Therefore, understanding which factors determine contract status and eventually first team playing time could help in shaping talent development programs to maximize performance output. A retrospective study by le Gall and colleagues (21) found that players who eventually attained an international or professional soccer status outperformed players who only attained an amateur status in anaerobic power, jumping height and 40-m sprint performance. Recently, Gonaus & Müller (15) showed that the combination of soccer-specific speed and power of upper limbs best discriminated future playing status, irrespective of age category in Austrian soccer players, aged between 14 and 17 years. Altogether, measuring fitness characteristics at young age can provide useful information for future career success (31).

Hardly any studies have investigated the physical performance and motor coordination characteristics specifically that discriminate high-level soccer program drop outs from those with longer engagements. And even if a youngster is retained throughout the course of a talent development program, there is little evidence suggesting that these players ever actually play at the highest level as adults. Recently, the importance of including non-specific motor coordination tests in the search for gifted Belgian international young soccer players has been stressed (39). It seems that motor coordination is independent of maturational status, and therefore might prevent drop out of late maturing promising players. Moreover, motor coordination has proven its discriminative and predictive power in the identification and selection in a relatively homogenous group of young female gymnasts (41). Therefore, the novelty of this study focusses, in part, on the contribution of non-specific motor coordination in the selection of a large sample of gifted youth soccer players over a large age range.

The goal of this manuscript was twofold and therefore, a two-study approach was conducted. **Study 1** aimed to expose the anthropometry, physical performance and non-specific motor coordination characteristics that influence drop out from a high-level soccer training program in players aged 8-16 years. **Study 2** used retrospective data of anthropometry, physical performance and motor coordination to investigate which characteristics influence current contract status and first-team playing time in (current adult) graduated soccer players from an elite top sports school. Therefore, combining the two studies, a model based on anthropometrical, maturational, physical and motor coordination characteristics could provide more insight in talent identification and selection processes in the career of young, promising soccer players.

STUDY 1

Methods

Experimental approach to the problem

A mixed-longitudinal study was conducted to investigate differences in anthropometry, motor coordination and physical characteristics of youth soccer players at the Belgian professional level and players who dropped out of the study. All players were assigned to either a '*club* group' or a '*drop out* group', according to their playing status throughout the study. *Club* players (n=247, mean age=12.2±2.4 y) were players who were still playing for a youth team in one of the two participating professional soccer clubs at the start of the 2013-2014 soccer season, whilst *drop out* players (n=141, mean age=12.3±2.2 y) were players who dropped out of a high-level training program (consisted of 4 training sessions (1 physical overload training, 1 strength training and 2 tactical training sessions which took up to 1.5 to 2 h per training session) and 1 game (on Saturday) a week). Dropping out in this study is defined as changing to a lower level or quitting soccer altogether within two years after the first test assessment. Therefore, *drop out* players could have maximal two test assessments before dropping out, whilst *club* players were able to have a total of six test assessments. This study did not discriminate further between playing levels following drop out (dropping out to second, third, fourth or regional divisions).

Subjects

The sample consisted of 864 data points from 388 youth soccer players, aged between 8.6 and 16.6 years from two professional Belgian soccer clubs. All players were born in 1991 through 2003, and were assessed between 2007 and 2012, each time in the month August. The total sample was divided into eight age groups according to birth date (e.g., a player born in 1995 who was assessed in 2010 was assigned to the U16 age group). ***Table 1*** shows the number of players assessed within each testing year according to the age group and the number of players with different testing moments per playing status. The study received approval from the Ethics Committee of the University Hospital. All players (age range: 8 to 16 years) and their parents or legal representatives were fully informed and written informed consent was obtained.

***Table 1** The total number of players assessed within each testing year [a] and the number of players with different testing moments per playing status [b].*

a	Testing year						
	2007	2008	2009	2010	2011	2012	*total*
U10	20	23	24	31	18	31	*147*
U11	15	19	22	24	25	27	*132*
U12	12	11	16	23	21	29	*112*
U13	11	14	12	19	22	24	*102*
U14	9	14	18	18	19	30	*108*
U15	8	10	16	18	21	24	*97*
U16	1	6	14	14	24	28	*87*
U17	16	3	8	14	15	23	*79*
total	*92*	*100*	*130*	*161*	*165*	*216*	*864*
b	Number of testing moments						
	1	2	3	4	5	6	*total*
Club	90	42	47	37	16	15	*247*
Drop out	85	56	/	/	/	/	*141*
total	*175*	*98*	*47*	*37*	*16*	*15*	*388*

Procedures

Anthropometry. Height (Harpenden portable stadiometer, Holtain, UK) and sitting height (Harpenden sitting table, Holtain, UK) were assessed to the nearest 0.1 cm, and body mass and body fat (total body composition analyser, TANITA, BC-420SMA, Japan) were assessed to the nearest 0.1 kg and 0.1 %, respectively, according to the manufacturer's guidelines. Leg length (0.1 cm) was then calculated as the difference between height and sitting height. All anthropometric measures were taken by the same investigator to ensure test accuracy and reliability. The intra-class correlation coefficient for test-retest reliability and technical error of measurement (test-retest period of 1 h) in 40 adolescents were 1.00 ($p < 0.001$) and 0.49 cm for height and 0.99 ($p < 0.001$) and 0.47 cm for sitting height, respectively. A study by Stomfai et al. (34) revealed for weight (assessed with TANITA, BC-420SMA, total body composition analyser) a technical error of measurement of 0.05 kg (coefficient of variation = 0.2%) in 342 children between 2 and 9 years. The same observer measured each child three consecutive times within 1h.

Maturity status. An estimation of maturity status was calculated using equation 3 from Mirwald et al. (28) for boys. This non-invasive method predicts years from peak height velocity as the maturity offset (MatOffset), based on anthropometric variables (height, sitting height (SitHeight), weight and leg length).

According to Mirwald et al. (28), this equation accurately estimates the APHV (Age – (MatOffSet)) within an error of ±1.14 years in 95% of the cases in boys, derived from 3 longitudinal studies on children who were 4 years from and 3 years after peak height velocity (i.e., 13.8 years). Accordingly, the age range from which the equation confidently can be used is between 9.8 and 16.8 years; which corresponds well with the age-range of the sample in part one of this study.

Physical fitness and motor coordination. To evaluate explosive leg power, two strength tests, standing broad jump (SBJ) and counter movement jump (CMJ) were executed. The SBJ is part of the Eurofit test battery and was conducted according to the guidelines of the Council of Europe to the nearest 1 cm (7). CMJ was conducted according to the methods described by Bosco et al. (1) and Castagna et al. (3) with the arms kept in the akimbo position to minimize their contribution recorded by an OptoJump (MicroGate, Italy). The highest of three jumps was used for further analysis (0.1 cm). Furthermore, soccer-specific endurance was investigated using the Yo-Yo Intermittent Recovery Test level 1 (YYIR1) (1 m). This test was conducted according to the methods of Krustrup et al. (20). Speed performances were measured through four maximal sprints of 30 m with split times at 5 m and 30 m, with the fastest 5 m and the fastest 30 m used for analysis in order to ensure a maximal value. Between each 30 m sprint, players had 25 s to recover. The sprint performance was recorded using MicroGate RaceTime2 chronometry and Polifemo light photocells (Bolzano, Italy) (0.001 s). The Ghent University (UGent) dribbling test was used to measure soccer-specific motor coordination according to previously described procedures (39). The participants performed the test twice: the first time without the ball ("*Dribble foot*" to measure agility), the second time with the ball ("*Dribble ball*" to measure dribbling skill). Players who were not able to keep control of the ball (ball crossing a border of 2 m away from the trajectory) got a second chance. A single observer measured the time (0.01 s) from start to finish with a handheld stopwatch. The UGent dribbling test was tested for its reliability in a sample of 40 adolescents. An intra-class correlation analysis (single measure) indicated moderate to high reliability values for both tasks (running without ball = 0.78, and dribbling with ball = 0.81) (39). Gross motor coordination was investigated using three non-specific subtests from the "Körperkoordination Test für Kinder" (KTK): moving sideways (MS), backward balancing (BB) and jumping sideways (JS), conducted according to the methods of Kiphard and Shilling (19). This test battery demonstrated to be reliable and valid in the age-range of the present population (40). Hopping for height, the fourth subtest was not included in the present study.

All test sessions were completed on an indoor tartan running track with a temperature between 15–20°C. At each testing moment, all tests of the test battery were executed in a strict order and sufficient recovery time between each test was assured (i.e. anthropometrics and gross motor coordination, warming-up, physical fitness tests and followed by the YYIR1 test after completing all other tests). All players were familiarized with the testing procedures and performed the tests with running shoes, except for MS, BB, JS, SBJ and the UGent dribbling test (with and without ball), which was conducted on bare feet (39). Prior to each testing moment, examiners were informed about the testing guidelines and consequently performed the test in a test sample of 40 adolescents. Participants were instructed to refrain from strenuous exercise for at least 48 hours before the test sessions and to consume their normal pre-training diet before the test session.

Statistical analyses

Descriptive statistics for *club* and drop *out* players in each age group are presented as mean (±*SD*) values. Differences in anthropometry, physical performance and non-specific motor coordination between *club* and *drop out* players were investigated within several age groups, rather than differences between younger and older players, which was not the focus of the present study. Multivariate analysis of variance (MANOVA) for each age group was used to describe the differences between *club* and *drop out* players for anthropometry since all players were assessed for height, sitting height, weight and body fat. Independent sample T-tests were conducted for differences in motor coordination and physical fitness characteristics within all age groups, since several missing values were counted. Also, Cohen's *d* effect sizes (ES) and thresholds (0.2, 0.6, 1.2, 2.0 and 4.0 for trivial, small, moderate, large, very large and extremely large, respectively) were also used to compare the magnitude of potential differences (17). All statistical analyses were performed using SPSS for windows (version 19.0). Statistical significance was set at $p<0.05$.

Results

No significant differences between *club* and *drop out* players were found for all anthropometrical characteristics, except for weight ($t=-2.085$; $p=0.039$) in the U10 age group, for weight ($t=2.335$; $p=0.021$) in the U14 age group, for height ($t=2.057$; $p=0.042$) and weight ($t=2.494$; $p=0.014$) in the U15 age group, and for MatOffSet ($t=2.233$; $p=0.028$) and SitHeight ($t=2.127$; $p=0.037$) in the U17 age group (***Table 2***). These significant differences are in accordance with moderate ES's for weight (ES = 0.6) in the U15 age group and MatOffSet (ES = 0.6) in the U17 age group, and a large ES for SitHeight (ES = 1.6) in the U17 age group (***Table 4***).

Table 2 *Anthropometrical characteristics (mean (SD)) of players who stayed at the club and drop-out players between U10 and U17.*

	U10		U11		U12		U13		U14		U15		U16		U17	
	Club n=100	D-O n=47	Club n=97	D-O n=35	Club n=85	D-O n=27	Club n=77	D-O n=25	Club n=80	D-O n=28	Club n=75	D-O n=22	Club n=68	D-O n=19	Club n=51	D-O n=28
Age (y)	9.2	9.3	10.3	10.2	11.3	11.2	12.3	12.2	13.2	13.3	14.3	14.2	15.2	15.3	16.2	16.1
	(0.3)	*(0.2)*	*(0.3)*	*(0.3)*	*(0.3)*	*(0.3)*	*(0.3)*	*(0.2)*	*(0.3)*	*(0.2)*	*(0.3)*	*(0.3)*	*(0.3)*	*(0.3)*	*(0.3)*	*(0.3)*
MatOS (y)	-3.6	-3.6	-3.0	-2.9	-2.3	-2.3	-1.6	-1.6	-0.7	-0.9	0.4	0.1	1.3	1.3	2.2	1.9
	(0.3)	*(0.3)*	*(0.3)*	*(0.5)*	*(0.4)*	*(0.4)*	*(0.5)*	*(0.4)*	*(0.7)*	*(0.5)*	*(0.7)*	*(0.7)*	*(0.6)*	*(0.6)*	*(0.5)*	*(0.6)*
Height (cm)	136.2	136.0	141.4	140.7	146.4	145.8	151.9	152.4	159.2	156.8	167.0	162.9	175.1	173.4	175.1	173.1
	(5.1)	*(4.9)*	*(5.6)*	*(5.4)*	*(5.5)*	*(5.7)*	*(6.5)*	*(4.9)*	*(7.9)*	*(7.3)*	*(7.9)*	*(8.9)*	*(5.0)*	*(5.8)*	*(5.0)*	*(6.6)*
SitHeight (cm)	72.3	72.2	74.6	75.1	76.5	76.8	78.9	78.5	82.2	80.7	86.6	84.6	89.6	89.6	91.7	90.1
	(2.6)	*(2.8)*	*(2.8)*	*(4.6)*	*(2.7)*	*(2.8)*	*(3.4)*	*(2.7)*	*(4.7)*	*(3.4)*	*(4.7)*	*(5.3)*	*(4.1)*	*(4.2)*	*(2.9)*	*(3.9)*
Weight (kg)	29.7	31.1	33.3	33.9	36.2	36.5	39.8	39.1	46.6	43.0	53.3	48.7	59.8	58.0	64.3	62.4
	(3.6)	*(4.3)*	*(4.3)*	*(4.7)*	*(4.4)*	*(5.3)*	*(5.4)*	*(4.4)*	*(7.4)*	*(5.7)*	*(7.8)*	*(7.6)*	*(7.9)*	*(6.2)*	*(6.9)*	*(8.0)*
Body fat (%)	14.6	15.6	13.9	15.1	13.0	13.9	11.9	12.2	11.0	10.2	10.1	10.1	10.3	9.9	10.5	11.4
	(2.7)	*(3.7)*	*(2.9)*	*(3.4)*	*(3.0)*	*(2.9)*	*(3.2)*	*(4.1)*	*(2.7)*	*(2.6)*	*(2.8)*	*(2.6)*	*(3.1)*	*(3.6)*	*(3.0)*	*(3.3)*
MANOVA																
F	2,452		1,348		1,174		1,241		1,879		1,542		1,820		1,454	
p	0.028		0.241		0.326		0.293		0.092		0.174		0.106		0.206	

D-O= drop-out players; MatOS=maturity offset; SitHeight=sitting height; data underlined are significantly different at p<0.05 for between-subject effects per age group.

In all age groups, significant differences between *club* and *drop out* players were found for JS, MS, YYIR1, 5 m and 30 m sprint (in favour of the *club* players), except for JS in the U15 age group, for MS in the U15 and U17 age group, for YYIR1 in the youngest age groups (U10 and U11) and the U16 age group, for 5 m sprint in the U12, U13 and U16 age group, and for 30 m sprint in the U11 and U17 age group (***Table 3***). Also, the dribbling test without ball significantly differed in the U11 and U17 age group, and the dribbling test with ball in the U10 and U12 age group. Furthermore, *club* players had significantly more explosive leg power in the U13 (CMJ), and U14 and U15 (SBJ and CMJ) age groups compared with *drop out* players. Cohen's *d* statistics revealed large ES's for JS and MS in the U12 age group (ES = 1.2), for JS in the U13 age group (ES = 1.2) and for SitHeight in the U17 age group (ES = 1.6). Further, ***Table 4*** shows all other moderate ES's between *club* and *drop out* players.

Table 3 *Motor coordination and physical characteristics (Mean (SD)) of players who stayed at the club and drop-out players (U10 - U17).*

	U10		U11		U12		U13		U14		U15		U16		U17	
	Club	D-O	Club	D-O	Club	D-O	Club	D-O	Club	D-O	Club	D-O	Club	D-O	Club	D-O
JS	85	74	91	85$^{\Sigma}$	99	87	103	91	106	99*	110	103	116	103	118	109$^{\Sigma}$
(n)	(10)	(10)	(9)	(9)	(10)	(9)	(11)	(7)	(13)	(9)	(12)	(13)	(12)	(10)	(12)	(13)
n	*84*	*20*	*83*	*15*	*70*	*17*	*57*	*15*	*63*	*19*	*62*	*11*	*59*	*11*	*45*	*13*
MS	53	47	58	52	63	55	66	59*	69	65$^{\Sigma}$	71	66	75	69$^{\Sigma}$	74	71
(n)	(7)	(7)	(7)	(4)	(6)	(8)	(8)	(6)	(9)	(7)	(10)	(8)	(9)	(6)	(9)	(8)
n	*84*	*20*	*82*	*15*	*70*	*17*	*59*	*15*	*65*	*20*	*63*	*12*	*64*	*12*	*47*	*13*
BB	54	52	58	53	62	58	62	57	62	60	62	58	65	59	66	60*
(n)	(9)	(9)	(10)	(9)	(6)	(13)	(9)	(10)	(9)	(7)	(8)	(7)	(6)	(9)	(6)	(9)
n	*84*	*20*	*83*	*15*	*71*	*18*	*61*	*16*	*65*	*20*	*66*	*13*	*67*	*12*	*47*	*13*
DrFoot	12.8	12.9	12.3	12.8$^{\Sigma}$	12.0	12.3	11.8	11.7	11.6	11.8	11.5	11.8	11.1	11.2	11.0	11.4*
(s)	(0.7)	(0.6)	(0.6)	(0.7)	(0.6)	(0.6)	(0.7)	(0.7)	(0.8)	(0.8)	(0.7)	(1.0)	(0.6)	(0.5)	(0.6)	(0.4)
n	*84*	*20*	*82*	*14*	*70*	*17*	*57*	*15*	*63*	*19*	*63*	*11*	*62*	*11*	*45*	*13*
DrBall	23.8	25.6	22.4	22.8	20.6	22.1	20.4	20.8	20.2	21.0	19.5	20.5	19.2	19.8	18.7	19.7$^{\Sigma}$
(s)	(1.8)	(1.9)	(1.8)	(1.7)	(1.5)	(2.0)	(1.4)	(0.9)	(1.6)	(1.6)	(1.8)	(2.0)	(1.6)	(1.4)	(1.2)	(2.0)
n	*84*	*20*	*82*	*14*	*70*	*17*	*57*	*15*	*63*	*19*	*63*	*11*	*62*	*11*	*45*	*13*
SBJ	156	153	164	161	171	168	180	181	192	184$^{\Sigma}$	203	194$^{\Sigma}$	214	214	224	220
(cm)	(14)	(13)	(12)	(12)	(12)	(11)	(13)	(14)	(15)	(11)	(16)	(19)	(16)	(22)	(16)	(18)
n	*100*	*47*	*95*	*34*	*83*	*26*	*72*	*24*	*76*	*27*	*71*	*21*	*62*	*17*	*49*	*25*
CMJ	21.0	20.2	22.5	21.4	23.7	22.2	25.7	24.1	28.4	25.1	31.1	26.7	33.8	33.0	37.0	37.0
(cm)	(3.4)	(3.3)	(3.7)	(2.4)	(3.2)	(3.2)	(3.1)	(2.7)	(3.4)	(3.2)	(4.0)	(4.2)	(4.5)	(4.7)	(4.6)	(4.9)
n	*93*	*34*	*89*	*23*	*73*	*20*	*68*	*19*	*71*	*24*	*68*	*17*	*63*	*17*	*47*	*15*
YYIR1	698	585	874	691	1094	894*	1212	1040$^{\Sigma}$	1485	1197*	1711	1405*	1897	1765	2175	1914*
(m)	(291)	(203)	(369)	(204)	(308)	(284)	(375)	(315)	(365)	(297)	(385)	(319)	(362)	(380)	(322)	(274)
n	*16*	*27*	*14*	*19*	*83*	*26*	*68*	*24*	*62*	*14*	*64*	*15*	*54*	*15*	*39*	*22*
5m sprint	1.29	1.32*	1.26	1.29$^{\Sigma}$	1.24	1.25	1.21	1.23	1.18	1.22*	1.14	1.22	1.12	1.13	1.10	1.11
(s)	(0.07)	(0.07)	(0.07)	(0.06)	(0.06)	(0.06)	(0.06)	(0.05)	(0.06)	(0.07)	(0.08)	(0.08)	(0.07)	(0.06)	(0.06)	(0.08)
n	*97*	*40*	*95*	*33*	*84*	*26*	*73*	*24*	*76*	*24*	*71*	*20*	*60*	*18*	*48*	*26*
30m sprint	5.54	5.70	5.38	5.45	5.20	5.31*	5.09	5.20$^{\Sigma}$	4.89	5.10	4.69	4.95	4.51	4.62$^{\Sigma}$	4.39	4.47
(s)	(0.26)	(0.29)	(0.22)	(0.21)	(0.17)	(0.20)	(0.21)	(0.15)	(0.21)	(0.17)	(0.25)	(0.22)	(0.19)	(0.19)	(0.15)	(0.19)
n	*100*	*47*	*95*	*33*	*84*	*26*	*73*	*24*	*76*	*24*	*71*	*20*	*60*	*18*	*48*	*26*

D-O=drop-out players; JS=jumping sideways; MS=moving sideways; BB=backward balance; DrFoot=dribble test without ball; DrBall=dribble test with ball; SBJ=standing broad jump; CMJ=counter movement jump; YYIR1=Yo-Yo intermittent recovery test level 1; data underlined are significantly different at $p<0.001$; * $p<0.01$; $^{\Sigma}$ $p<0.05$

Table 4 *Cohen's d effect sizes between drop-out players and club players for anthropometry, motor coordination and physical characteristics.*

	U10	U11	U12	U13	U14	U15	U16	U17
MatOffSet	0.0	0.3	0.0	0.0	0.3	0.4	0.0	0.6*
Height	0.0	0.1	0.1	0.1	0.3	0.5	0.3	0.4
SitHeight	0.0	0.4	0.1	0.1	0.3	0.4	0.0	1.6^{Σ}
Weight	0.4	0.1	0.1	0.1	0.5	0.6*	0.2	0.3
Body fat	0.1	0.4	0.3	0.1	0.3	0.0	0.1	0.3
JS	1.1*	0.7*	1.2^{Σ}	1.2^{Σ}	0.6*	0.6*	1.1*	0.7*
MS	0.9*	1.0*	1.2^{Σ}	0.9*	0.5	0.5	0.7*	0.4
BB	0.2	0.5	0.5	0.5	0.2	0.5	0.9*	0.8*
DrFoot	0.2	0.8*	0.5	0.1	0.3	0.4	0.2	0.8*
DrBall	1.0*	0.2	0.3	0.3	0.5	0.5	0.4	0.7*
SBJ	0.2	0.3	0.3	0.1	0.6*	0.5	0.0	0.2
CMJ	0.2	0.3	0.5	0.5	1.0*	1.1*	0.2	0.0
YYIR1	0.4	0.6*	0.7*	0.5	0.8*	0.8*	0.4	0.9*
5m sprint	0.4	0.4	0.2	0.3	0.6*	1.0*	0.1	0.1
30m sprint	0.6*	0.3	0.6*	0.6*	1.1*	1.1*	0.6*	0.5

*D-O=drop-out players;MatOffSet=mat0.6urity offset; SitHeight= sitting height; JS=jumping sideways; MS=moving sideways; BB= backward balance; DrFoot=dribble test without ball; DrBall=dribble test with ball; SBJ=standing broad jump; CMJ=counter movement jump; YYIR1=Yo-Yo intermittent recovery test level 1; * moderate effect size;* $^{\Sigma}$ *large effect size*

Discussion

The present study investigated differences in anthropometrical, motor coordination and physical characteristics between youth soccer players (8 to 16 y) who persisted in or dropped out of a high-level talent development program. The main findings highlighted the importance of motor coordination and speed in the identification of gifted young soccer players, even from a young age. Furthermore, other specific physical characteristics (endurance, strength, soccer-specific skills) are also relevant to distinguish players who persisted or dropped out, and the development seems to be associated with the timing of peak height velocity: for example, soccer-specific skills before PHV, soccer-specific aerobic endurance concurrent and after PHV, and strength after PHV. Remarkably however, both anthropometry and maturational status did not confound the drop out process in young soccer players. It is already well-known that soccer systematically excludes smaller and later maturing boys and favours taller, early maturing soccer players (11,23,24). For example, Figueiredo and colleagues (12) found in a sample of 72 Portuguese soccer players, aged 13 to 15 y that players who moved to higher playing standard (elite) were taller and skeletally more mature (169.2±5.1 cm and 15.3.±0.9 y, respectively) compared with players who continued to participate at the same club level (162.7±9.8 cm and 14.5±1.2 y, respectively), and players who dropped out (157.5±8.7 cm and 14.0±0.9 y, respectively). However, in the latter study, when club and drop out players were compared, similarities in anthropometry and skeletal age were reported, which is in agreement with the present study. Indeed, the absence of differences in anthropometry and maturity offset suggests that the selection process may focus on the formation of morphologically homogeneous groups, already before the age of 9 years. On the contrary, a longitudinal study by Hansen and colleagues (16) in 98 Danish youth soccer players (aged 10-14 years) reported that elite players were taller, heavier and more advanced in sexual maturation compared with non-elite players. Notably however, the classification of young soccer players into different levels (i.e. elite, non-elite, sub-elite, high and low level, drop-out,…) in the literature is not unified, as selection criteria rely on coaches, clubs and/or federations. Therefore, comparisons between many studies in many countries are not straightforward.

However, caution is warranted when using maturity offset as an estimation of biological maturation. According to Mirwald et al. (28), the equation is appropriate for children between 9.8 and 16.8 years, although it appears that the estimation is more accurate in the middle of this range. Since players in the present study matched the latter age-range and players were only compared within the same age group, these limitations of the predictive equation were restrained and the use of maturity offset justified (8). Also, recent studies showed poor to moderate agreement between invasive and non-invasive methods to predict maturational status (26,27). Further research is necessary to validate the maturity offset method in a young soccer population.

The importance of the inclusion of non-specific and soccer-specific motor coordination skills in the identification and selection of Belgian international soccer players (15 to 16 years) has been described elsewhere (39). Moreover, talent development programs often adopt a one-dimensional approach or include a combination of morphological and physical tests (e.g. speed, endurance and power) which are sensitive to differences in maturation (23,37). Yet, motor coordination is not related to biological maturity or any experience in soccer (25,29,39). In the present sample of soccer players, it seems that non-specific motor coordination is essential in discriminating players from a high-level training program and drop out players, even from the age of 9 years until late puberty. Therefore, as suggested by Vandendriessche and colleagues (39), motor coordination skills should be part of a selection strategy in high-level talent development programs. Therefore, these non-specific motor coordination tests may provide more insight in the future potential of a young athlete when compared with fitness tests, which mainly highlight the current performance.

Similar to motor coordination skills, it emerged from the present results that speed performance favours players who are still playing at a high level from players who drop out of the program two years after baseline. It has been reported that speed performance is important in discriminating elite from non-elite, but not sub-elite Flemish soccer players, aged between 12 and 15 years (37). Also, Waldron & Murphy (42) reported better 30 m sprint performances in elite compared with sub-elite U14 English soccer players, although skeletal maturation was not controlled for which might account for differences between levels. In contrast, a retrospective analysis in U14 to U16 French soccer players revealed no differences in speed performances amongst players reaching future international, professional or amateur status (21). Contrasting findings between successful and non-successful youth soccer players when compared with previous research may be a consequence of the different eventual requirements of soccer at the professional level in different countries. While performance at the youth level is unlikely to match that of an adult environment, it is possible that there are a variety of different demands associated with competing in different European leagues, which will inform the way that players are developed through their youth (21,37,42). Our findings bring into focus the selection policies in Flanders, which seems to emphasize the importance of upon motor coordination skills and speed performance to distinguish players from a high-level development program and drop out players between 8 and 16 year.

Although, the development and periodization of training programs from childhood through adolescence was not the focus of the present study, it seems that specific motor coordination and physical characteristics (i.e., speed, endurance, strength) distinguish between future club and drop out players at various moments throughout a high-level training program. Indeed, it emerged from the present results that (soccer-specific) aerobic performance (i.e., YYIR1) discriminates future drop out players from the age of 11 y, and that later on (explosive) strength (SBJ and CMJ) favors future club players from the age of 13 y. Differences in growth and maturational development, and the specificity of training loads are factors mainly responsible for the latter age-related differences. Apparently, within a group of youth soccer players with similar anthropometrical and maturational characteristics, coaches are more likely to retain players with better motor coordination (both non-sport and sport specific) and speed throughout a long-term high-level development program, with better aerobic endurance from the age of 11 y, and with better explosive strength from the age of 13 y when compared mutually.

However, the influence of training volume, intensity and frequency on performance outcomes, which was not investigated, together with the mixed-longitudinal design would make conclusions about differences in sensitiveness to certain training loads between club and drop out players more prudent. Other possible mechanisms accounting for drop out amongst youth soccer players, such as the relative age effect, injury incidence, motivation and social environment were yet not considered. Further, a longitudinal follow-up study investigating club players' future playing status (e.g., professional, amateur, drop out) could help to better understand underlying determinative physical characteristics at younger ages.

STUDY 2

Methods

Experimental approach to the problem

A cross-sectional descriptive study on performance related characteristics used retrospective testing data to examine differences in anthropometry, physical fitness and gross motor coordination between age- and position matched Belgian players between 14.0 and 18.6 years. Players were divided in two group: those who ended up receiving a contract in a professional soccer club (n=36) in the 2012-2013, and those who did not get a professional contract (n=36). Also, in this subsample of 29 future contracted players (mean age before the start of the 2012-2013 season = 18.8±1.6 y), the anthropometrical, physical fitness and gross motor coordination characteristics at the age of testing (mean age=16.3±1.2 y) that predict future total playing minutes 2.5 years later in the league stage of the 2012-2013 season were investigated.

Subjects

At the time of the test assessments, all players were part of the Flemish top sport school for soccer: a pool of soccer players from professional clubs selected into a six-year training program (from 12 to 18 y) with the intention to develop future professional soccer players. All players were assessed between 2009 and 2012, each time in September. Because of their unique position within the team and hence the possible different reasons as to why goalkeepers receive a contract or not, goalkeepers (n=14) were excluded from the analysis, reducing the final sample for analysis to 58 players. This study received approval from the Ethics Committee of the University Hospital. All players (age range: 12 to 18 years) and their parents or legal representatives were fully informed and written informed consent was obtained.

Procedures

Anthropometrical characteristics (height, weight and body fat), and measures of motor coordination (JS, MS, and BB) and physical fitness (CMJ, SBJ, Dribble foot, Dribble ball, 5m and 30m sprint) were assessed according to the testing procedures as described in Study 1. Since 18 players from the total of 58 players (31%) in the second study were older than 16.8 y, we didn't include the estimation of biological maturation. Moreover, the homogeneity in anthropometry and biological maturation in highly selected soccer players described in study 1 and by many others (7,11,22,23), reinforced this conviction. Also, the YYIR1 in study 2 was excluded because the players' training schedule didn't fit the inclusion of a test, which maximally stresses the aerobic system at the time of test assessment.

Statistical analyses

Descriptive statistics for players who end up with (C*ontract*) and without (*No contract*) professional contracts are presented as mean (±*SD*). A Multivariate Analysis of Variance (MANOVA) was used to identify differences between groups for anthropometry, physical fitness and motor coordination. Cohen's *d* effect sizes (ES) and thresholds (0.2, 0.6, 1.2, 2.0 and 4.0 for trivial, small, moderate, large, very large and extremely large, respectively) were also used to compare the magnitude of potential differences (17). To analyze which variables would predict future first division playing minutes, a stepwise multiple linear regression with anthropometry, physical fitness and motor coordination tests as predictors were used. All statistical analyses were performed using SPSS for windows (version 19.0). Statistical significance was set at $p<0.05$.

Results

No significant multivariate effect of future contract status on measures of anthropometry, physical fitness and gross motor coordination were found ($F=1.804$, $p=0.080$). Although multivariate analysis did not reveal overall differences between contract and no-contract players in general, it was also in the interest of this study to reveal univariate differences in specific performance-related characteristics.

No significant univariate differences between contract and no-contract players were found for anthropometrical characteristics (***Table 5***). Univariate differences were found between players with a different future contract status for SBJ ($F=6.990$, $p=0.011$, moderate ES=0.72) and for 5m sprint ($F=4.371$, $p=0.041$, moderate ES=0.62). Players who would receive a professional contract later on jumped further and had faster times for a 5m sprint than players who did not end up receiving a contract at a professional club (***Table 5***).

***Table 5** Mean (SD), F and p values and effect sizes for a MANOVA investigating retrospective differences in anthropometry and maturity status, physical fitness and motor coordination between players who end up receiving a professional contract and those who do not.*

	No Contract (n = 29)	Contract (n = 29)	F	P	Effect Size
Anthropometry and maturity					
Age (y)	16.5 (*1.2*)	16.3 (*1.2*)	0.244	0.624	0.17
Height (cm)	172.5 (*6.4*)	175.0 (*6.4*)	2.098	0.153	0.40
Weight (kg)	64.2 (*8.2*)	63.0 (*5.5*)	0.440	0.510	0.17
Body Fat (%)	11.1 (*2.8*)	10.1 (*2.5*)	2.047	0.159	0.38
Physical fitness					
SBJ (cm)	218 (*13*)	230 (*20*)	6.990	0.011	0.72
CMJ (cm)	35.8 (*3.9*)	36.8 (*4.4*)	0.691	0.409	0.24
5m Sprint (s)	1.09 (*0.07*)	1.05 (*0.06*)	4.371	0.041	0.62
30m Sprint (s)	4.41 (*0.21*)	4.33 (*0.17*)	2.279	0.137	0.43
Dribble Ball	17.4 (*1.0*)	17.2 (*1.1*)	0.388	0.536	0.19
Motor coordination					
Jumping Sideways (n)	112 (*12*)	108 (*10*)	1.613	0.210	0.37
Moving Sideways (n)	75 (*10*)	71 (*13*)	1.551	0.219	0.35
Balancing Backwards (n)	64 (*7*)	63 (*8*)	0.102	0.750	0.14

Note: effect size is Partial Eta Squared; MatOffset=maturity offset

Stepwise multiple regression showed that SBJ performance was a significant predictor of the amount of minutes played during the 2012-2013 season (***Table 6***). The following prediction equation explains 16.7% of the variance in future playing minutes in adolescent youth male soccer players: -2869.3 + 14.6 * SBJ.

***Table 6** Pearson correlation coefficients and significance levels for a multiple regression analysis used to predict future playing minutes in adolescent soccer players.*

	Total Minutes Played (TMP)	
	r	p
Anthropometry and maturity		
Height (cm)	.14	0.241
Weight (kg)	.14	0.253
Body Fat (%)	-.13	0.272
Physical fitness		
SBJ (cm)	.41	0.019*
CMJ (cm)	.17	0.198
5m Sprint (s)	-.28	0.086
30m Sprint (s)	-.28	0.082
Dribble Foot (s)	-.06	0.383
Dribble Ball (s)	.13	0.265
Motor coordination		
Jumping Sideways (n)	.12	0.276
Moving Sideways (n)	.06	0.379
Balancing Backwards (n)	.21	0.149

** Pred.equation: TMP = -2869.3 + 14.6 x SBJ*

[F=4.799, p=0.038, R^2=0.167]

MatOffset=maturity offset

Discussion

In this study, anthropometrical, motor coordination and fitness characteristics were compared across Flemish high-level youth soccer players who ended up with or without a professional contract. Also, within contracted players, a multiple linear regression analysis using anthropometrical, motor coordination and fitness variables was conducted to predict future playing minutes over a relatively short term (on average two year after test assessment). It emerged from the results that explosivity, embodied by SBJ performance, is the key physical factor at young age (mean age=16.3±1.2 y) determining future contract status. Once players reached the professional status, explosivity is responsible for 16.7% of the variance that predict future playing minutes in male adolescent soccer players. In a relatively homogenous group, those players with favorable explosive power are more frequently offered a professional contract and receive more playing time during the season 2.5 year after signing their first professional contract at the highest level of competition in Belgium. These findings highlight the importance of assessing explosive power to predict future career success in a group of already highly skilled soccer players at young age and to predict future playing minutes in a group of young professional soccer players.

In the past decades, the game of soccer has evolved 'physically', demanding high standards of aerobic and anaerobic capacities. Many match activities are forceful (e.g. tackling, jumping, kicking) requiring a high amount of anaerobic power. These explosive actions require a anaerobic-alactacid metabolism and making up about 15-20% of total playing time (35). The power output during such activities is related to the strength of the muscles involved in such movements and is often instrumental in determining the outcome of a game. For example, a study by Reilly and Thomas (30) already reported that professional soccer players with higher muscle strength in the lower limbs were the most consistent members of a first team representative squad over the entire season. Although, many studies in young soccer players focused on anthropometrical and physical characteristics between 'current' high and low level players (4,12,37), studies directed to predicting future soccer career success are scarce (15,21).

An 11-year retrospective study in 161 French youth soccer players (U14-U16) demonstrated higher fitness levels in favor of future international and professional players compared with amateur players (21). Similar to the present study, the latter elite youth soccer players were already selected into a French 'National Institute of Football'. Also, a longitudinal study used physiological data to predict future career progress in elite Austrian youth soccer players between 14 and 17 years (15). The results demonstrated superior physiological performances of players who had been drafted to play in a national youth team compared with players who had never been drafted to play for a national youth team. For example, at the age of 16 years, drafted players performed the 5m sprint significantly faster (1.01±0.06s) than non-drafted players (1.04±0.07s; $F=18.547$; $P<0.001$), corresponding to some extent with the present differences between contracted and non-contracted players (*contract*=1.05±0.06s; *no contract*=1.09±0.07s; $F=4.371$; $P=0.041$). Also, at adult level, it has been reported that muscle strength and short-distance speed is favorable in French professional compared with amateur soccer players (5). Altogether, it appears that measuring physical and physiological characteristics (e.g., explosive power) in young soccer players can provide helpful information in terms of predicting future career progression (21,15,31).

When analyzing more profoundly individual playing minutes at the professional level, only 6 out of 29 young professional soccer players played more than fifty percent (mean=64.8±11.4%) of the possible playing time in the soccer season 2012-2013. Considering this cut-off of fifty percent, these six players outperformed players with less playing time in explosive power (SBJ: 244 vs. 227 cm, respectively). Also, the six players with more playing time were older (19.4±1.0 y) compared with players with less playing (18.6±1.7 y), suggesting that players are likely to need a period of physical adaptation to build up playing time in a professional setting. In line with this, the total playing minutes were investigated shortly after test assessment (two year on average), and long-term effects of anthropometrical, motor coordination and fitness characteristics on playing minutes were yet not investigated. A greater emphasis on this aspect of soccer performance could help the coach to effectively develop specific training programs and thus further improve the level of play in soccer.

In conclusion, it seems that in a relative homogenous group of high-level soccer players in terms of anthropometry, physical fitness and motor coordination, explosive power is likely to be the key physical factor that predicts future career status and playing minutes in Flemish young soccer players. However, using these measures solely is probably not sensitive enough. Other dispositions of soccer success (i.e., technical, tactical and mental characteristics) could provide helpful information in the identification of future successful young soccer players (31,38).

We do however acknowledge some limitations of this study. First, a measure of soccer-specific aerobic endurance (e.g., YYIR1) was lacking. The players' training schedule didn't fit the inclusion of a maximal soccer-specific endurance test at the time of test assessment (we could not ensure complete recovery before a competition game). Nevertheless, it has been demonstrated that future successful soccer players possessed a higher aerobic endurance capacity than their less successful counterparts between 14 and 17 years (15). Also, possible positional variation in predicting career success was not investigated due to the small number of players who ended up with a contract (defenders: n=6; midfielders: n=12; attackers: n=11).

Practical applications

Matching the present two studies, a talent identification and selection model based on anthropometrical, maturational, physical fitness and motor coordination characteristics predicted future success in the career of young soccer players, although different young, high-level soccer populations were investigated. Moreover, growth and development processes alongside the soccer development program highlighted a more soccer-specific approach aligned to the timing of peak height velocity in this selection strategy: soccer-specific coordination before, soccer-specific aerobic endurance concurrent with and explosive power after peak height velocity. Practitioners should include an estimation of years from peak height velocity for a more individualized training process. Remarkably, anthropometrical and maturational characteristics did not confound the selection strategy, demonstrating the anthropometrical homogeneity of young players entering a high-level soccer development program. When investigating the next step in the career of gifted young soccer players, it seems that the most explosive players are more likely to be given a professional contract and even more playing minutes once they reached the professional status. Therefore, players who were estimated after peak height velocity should be submitted to a specialized training program improving their explosive power. The discriminative ability of non-specific motor coordination and speed, distinguishing future club and drop out players, seems to fade out in a highly selected group of talented soccer players after the age of 16 y. However, this does not imply the unimportance of motor coordination, speed, agility and aerobic endurance in future soccer success (30).

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Chapter 4:

Positional differences in performance

STUDY 11

CHARACTERISTICS OF HIGH-LEVEL YOUTH SOCCER PLAYERS: VARIATION BY PLAYING POSITION

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Abstract

The present study aimed to investigate positional differences in 744 high-level soccer players, aged 8 to 18 years. Players were assigned to six age groups (U9-U19) and divided into four playing positions (goalkeeper, defender, midfielder and attacker). MANOVA and effect sizes were used to examine anthropometrical and functional characteristics between all positions in all age groups. The main findings of the study were that goalkeepers and defenders were the tallest and heaviest compared with midfielders and attackers in all age groups. Further, between U9-U15, no significant differences in functional characteristics were found, except for dribbling skill, which midfielders performed the best. In the U17-U19 age groups, attackers seemed to be the most explosive (with goalkeepers), the fastest and the more agile field players. These results suggest that inherent physical capacities (i.e. speed, power, agility) might select players in or reject players from an attacking position, which is still possible from U15-U17. Apparently, players with excellent dribbling skills at younger age are more likely to be selected to play as a midfielder. Although, one might conclude that the typical physical characteristics for different positions at senior level are not yet fully developed among young soccer players between 8 and 14 years.

Introduction

Contributing factors to successful performances in soccer have widely been studied in both adult and adolescent players. For example, the predominant metabolic pathways during competitive soccer are aerobic (Bangsbo, 1994). Otherwise, anaerobic power and capacity are more involved in typical game skills, such as tackling, dribbling, jumping, sprinting and accelerating (Reilly, Bangsbo, & Franks, 2000). There is evidence that physiological demands of a soccer game vary with the work-rates in different positional roles (Boone, Vaeyens, Steyaert, Vanden Bossche, & Bourgois, 2001; Di Salvo et al., 2007). There are also likely to be anthropometrical predispositions for positional roles, with taller players being the most suitable for central defensive positions and for the 'target' player among strikers or forwards, although these studies included only adult soccer players (Boone et al., 2011; Sporis et al., 2011; Wong et al., 2008). However, these factors may be linked with the preselection in young soccer players of early maturers for key positional roles, where body size rather than playing skills provide an advantage (Gil, S.M., Gil, J., Ruiz, Irazusta, A., & Irazusta, J., 2007; Reilly, Bangsbo, & Franks, 2000). As concluded by Malina et al. (2000) and Strøyer, Hansen, and Klausen (2004), the sport of soccer systematically excludes gifted, but late maturing boys and favours average and early maturing boys as chronological age and sport specialization increase.

Talent identification and development programs are not only dealing with maturity-related problems. Also, predicting future success in senior professional soccer is commonly based on measuring the current performance of adolescents (Vaeyens, Lenoir, Williams, & Philippaerts, 2008). It is assumed that important factors of success in adulthood automatically can be extrapolated to identify soccer players at young age (Morris, 2000). However, required characteristics at young age will not necessarily retain throughout the maturational process and will not automatically be translated in excellence at senior level (Vaeyens et al., 2008). Moreover, it has been reported that it takes about 10 years of soccer experience for the development of senior elite soccer players (Ericsson, 2008; Helsen, Hodges, Van Winckel, & Starkes, 2000). Therefore, the development of anthropometrical, physical and physiological characteristics, required for an elite soccer match, might not be fully evolved in young soccer players, since they experienced formal training for just a few years with lower game intensity and shorter match duration. As a consequence, the selection of young players for a specific playing position based on their anthropometrical, physical and physiological profile might not be appropriate. Also, previous studies investigating positional differences are limited and the results have been inconsistent (Gil et al., 2007; Malina et al., 2000). For example, Coelho e Silva et al. (2010) reported no positional differences in 128 Portuguese young soccer players (13-14 y) for anthropometrical and physical characteristics, whereas Gil et al. (2007) found in 241 soccer players (14-21 y), that goalkeepers were the tallest and heaviest, defenders had a lower quantity of fat, midfielders were characterized by the best endurance, while forwards were the most explosive players, which is in accordance with a study by Lago-Peñas, Casais, Dellal, Rey, & Dominguez (2011). Moreover, others stated that the identification and selection processes of young elite players have created homogeneous groups of players possessing similar physical and physiological capacities (Carling, Le Gall, Reilly, & Williams, 2009; Deprez, Vaeyens, Coutts, Lenoir, & Philippaerts, 2012).

Therefore, the aim of the present study was to investigate differences in anthropometrical characteristics and general fitness level through aerobic and anaerobic tests according to the playing position on the field in youth soccer players from a high-level development program (U9-U19). Based on previous literature, we hypothesized that differences in anthropometry exist between playing positions. On the other hand, we hypothesized that no significant differences in functional performance between playing positions are present.

Methods

Participants

Participants were 744 youth soccer players from two Belgian professional soccer clubs who participated in a longitudinal study between 2007 and 2012 (continuation Ghent Youth Soccer Project) (Vaeyens et al., 2006). All players participated in a high-level soccer development program, which consisted of four training sessions (one physical overload session, one strength session and two technical-tactical training sessions) and one game (on Saturday) per week and were assessed for anthropometrical and physical characteristics in October/November from each season. As a consequence, each participant has a maximum of six testing moments in the present study (assessed in six consecutive years). Summarized, a total of 1,806 data points from 744 unique players were recorded (214 players, 265 players, 101 players, 86 players, 53 players and 25 players had one, two, three, four, five and six testing moments, respectively). Next, players were divided into six age categories according to the players' birth year: *U9* (n=209), *U11* (n=369), *U13* (n=360), *U15* (n=358), *U17* (n=324) and *U19* (n=188). The mean (range) age of the players per age category was 8.2 ± 0.5 y (6.9-8.2 y), 9.9 ± 0.6 y (8.9-10.9 y), 11.8 ± 0.7 y (10.9-12.9 y), 13.8 ± 0.6 y (12.8-14.9 y), 15.8 ± 0.6 y (14.8-16.8 y) and 17.6 ± 0.6 y (16.8-18.8 y) for the U9, U11, U13, U15, U17 and U19 age groups, respectively.

In Belgium, youth competitions start in August and end in May, so players were measured during the first competition phase before the winter-break. All youth categories (U9 to U19) from the two involved soccer clubs played according to a certain tactical system, as suggested by the Royal Belgian Football Association (KBVB) (***Fig.1a,b,c***). According to the number of players on the field, different tactical systems or formations are used. Teams from the U9 age category play5 vs. 5 in a "*diamond*" formation with, besides the goalkeeper, 1 defender, 2 midfielders and 1 attacker on a 35m x 25m pitch (***Fig.1a***). Players from the U11 age-category play8 vs. 8 in a "*double diamond*" formation with 3 defenders, 3 midfielders and 1 attacker (***Fig.1b***). The older age-categories (from U13) play11 vs. 11 in a "*4-3-3*" formation with 4 defenders, 3 midfielders and 3 attackers as illustrated in ***Fig.1c***.

1a. ***1b.*** ***1c.***

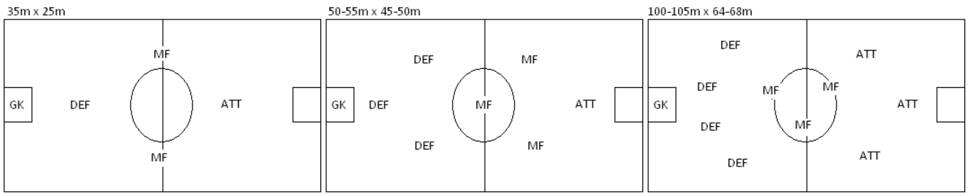

Figure 1. ***a****. U9-teams: 5 vs. 5,* ***b****. U11-teams: 8 vs. 8,* ***c****: U13-U19-teams: 11 vs. 11*

Similar to previous studies (Carling, Le Gall, & Malina, 2012; Coelho e Silva et al., 2010; Wong et al., 2008) all participants were divided into four groups according to their self-reported best position in the field: goalkeeper (GK), defender (DEF), midfielder (MF) and attacker (ATT). Switching between positions throughout the study was not controlled for, depending on the vision and the selection of the coach and players' self-reported position at each testing moment.

All players and their parents or legal representatives were fully informed about the aim and the procedures of the study before giving their written informed consent. The Ethics Committee of the Ghent University Hospital approved the present study.

Procedures

Anthropometry. Height (0.1 cm, Harpenden Portable Stadiometer, Holtain, UK), sitting height (0.1 cm, Harpenden sitting height table, Holtain, UK) and body mass (0.1 kg, total body composition analyzer, TANITA BC-420SMA, Japan) were assessed according to previously described procedures (Lohman, Roche, & Martorell, 1988) and to manufacturer guidelines. Leg length was calculated by subtracting sitting height from stature. All anthropometric measures were taken by the same investigator to ensure test accuracy and reliability. For height and sitting height, the 95% limits of agreement (Nevill & Atkinson, 1997) were -0.6 to 0.6 cm and -0.7 to 0.9 cm in 60 young soccer players between 11 and 16 years (test-retest period of one hour), respectively (unpublished observations).

Maturity status. An estimation of maturity status was calculated using equation 3 from Mirwald, Baxter-Jones, Bailey, & Beunen (2002) for boys. This non-invasive method predicts years from peak height velocity as the maturity offset (MatOffset), based on anthropometric variables (height, sitting height, body mass, leg length). Subsequently, the age at peak height velocity (APHV) is determined as the difference between the chronological age and the maturity offset. According to Mirwald et al. (2002), this equation accurately estimates the age at peak height velocity within an error of ±1.14 years in 95%

of the cases in boys, derived from 3 longitudinal studies on children who were 4 years from and 3 years after peak height velocity (i.e., 13.8 years). Accordingly, the age range from which the equation confidently can be used is between 9.8 and 16.8 years. Therefore, the equation was only applied to players in the U11 to U17 age categories, and not in the U9 and U19 age categories.

Motor coordination. First, *gross motor coordination* was investigated using a non-specific test from the "Körperkoordination Test für Kinder" (KTK) (Kiphard & Schilling, 2007). This test battery demonstrated to be reliable and valid in the age-range of the present population. Estimates of test-retest reliability can be found elsewhere (Hesar, 2011; Vandorpe et al., 2011). Only one test from the Körperkoordination Test für Kinder was used in the current study, specifically moving sideways on boxes (MS). This test consists of moving across the floor in 20 s by stepping from one plate (25 cm x 25 cm x 7.5 cm) to the next, transferring the first plate, step on it and so on. The number of relocations was counted and summed over two trials.

Physical fitness. *Flexibility* was measured using the Sit-and-Reach test (SAR), which is part of the Eurofit test battery and was conducted according to the guidelines of Council of Europe (1988) (0.5 cm). The HELENA-study (Ortega et al., 2008) reported an acceptable reliability for the sit-and-reach test in 69 male European adolescents, aged 13 years (95% limits of agreement: -7.4 to 6.8 cm).
Next, soccer-specific *endurance* was investigated using the Yo-Yo Intermittent Recovery Test level 1 (Yo-Yo IR1) (1 m). This test was conducted according to the methods of Krustrup et al. (2003). Participants were instructed to refrain from strenuous exercise for at least 48 hours before the test sessions and to consume their normal pre-training diet before the test session. The Yo-Yo IR1 has proven to be reliable by others (Ahler, Bendiksen, Krustrup & Wedderkopp, 2012; Krustrup et al., 2003; Thomas, Dawson, & Goodman, 2006).

Furthermore, *speed* performances were measured through four maximal sprints of 30 m with split times at 5 m and 30 m, with the fastest 5 m and the fastest 30 m used for analysis in order to ensure a maximal value. Between each 30 m sprint, players had 25 s to recover. The sprint performance was recorded using MicroGate RaceTime2 chronometry and Polifemo light photocells (Bolzano, Italy) (0.001 s). Others reported high levels of reliability of repeated sprint ability (Buchheit, Spencer, & Ahmaidi, 2010; Oliver, Williams, & Armstrong, 2006; Wragg, Maxwell, & Doust, 2000).

Also, to evaluate explosive leg power, two *strength* tests, standing broad jump (SBJ) and counter movement jump (CMJ) were executed. The standing broad jump is part of the Eurofit test battery and was conducted according to the guidelines of the Council of Europe (1988) (1 cm). The counter movement jump was conducted according to the methods described by Bosco, Rusko, and Hirvonen (1986) with the arms kept in the akimbo position to minimize their contribution recorded by an

OptoJump (MicroGate, Italy). The highest of three jumps was used for further analysis (0.1 cm). The reported 95% limits of agreement of the latter jump performances showed a good level of reliability in 69 male European adolescents (SBJ: -25.6 to 25 cm; CMJ: -6.7 to 6.7 cm) (Ortega et al., 2008).Furthermore, to assess combined *speed and agility*, participants performed a T-test. The athletes ran 5 m straight, turned 90° and ran 5 m towards the next turn of 180°, ran 10 m towards the third turn (180°), ran a further 5 m towards the last turn of 90°, ultimately finishing at the initial starting point. The T-test was performed in both directions with the participants turning to the left at the first attempt, and recorded using MicroGate RaceTime2 chronometry and Polifemo light photocells (Bolzano, Italy) (0.001 s). A similar modified agility T-test has shown to be reliable in 52 physical education students, aged 22 years (limits of agreement: -0.30 to 0.36 s) (Sassi et al., 2009).

At last, the UGent dribbling test was used to measure *soccer-specific motor coordination* according to previously described procedures (Vandendriessche et al., 2012). The participants performed the test twice: the first time without the ball ("*Dribble foot*" to measure agility), the second time with the ball ("*Dribble ball*" to measure dribbling skill). Players who were not able to keep control of the ball (ball crossing a border of 2 m away from the trajectory) got a second chance. A single observer measured the time (0.01 s) from start to finish with a handheld stopwatch. The UGent dribbling test was tested for its reliability in a sample of 40 adolescents. An intra-class correlation analysis (single measure) indicated moderate to high reliability values for both tasks (running without ball = 0.78, and dribbling with ball = 0.81) (Vandendriessche et al., 2012).

Testing Procedures

All test sessions were completed on an indoor tartan running track with a temperature between 15–20°C. At each testing moment, all tests of the test battery were executed in a strict order (i.e. anthropometrics and gross motor coordination, warming-up, fitness tests and followed by the Yo-Yo IR1 test after completing all other tests). All players were familiarized with the testing procedures and performed the tests with running shoes, except for moving sideways, standing broad jump and the dribbling test without ball, which was conducted on bare feet according to the guidelines. Prior to each testing moment, examiners were informed about the testing guidelines and consequently performed the test in a test sample of 40 adolescents.

Statistical Analyses

All statistical analyses were performed using SPSS for windows (version 19.0). Descriptive statistics for all positions are presented as mean ± standard deviation (SD). MANOVA was used to investigate differences between all positions with all anthropometrical characteristics, motor coordination and physical fitness parameters as dependent and position as independent variables. Chronological age was no confounding factor in the analyses since no statistical differences were found between positions (*U9*:

8.2 ± 0.5 y, F=0.634, P=0.594, df_N=3, df_D=206; *U11*: 9.9 ± 0.6 y, F=2.250, P=0.058, df_N=3, df_D=366; *U13*: 11.8 ± 0.7 y, F=0.215, P=0.886, df_N=3, df_D=357; *U15*: 13.8 ± 0.6 y, F=1.685, P=0.170, df_N=3, df_D=355; *U17*: 15.8 ± 0.6 y, F=0.752, P=0.522, df_N=3, df_D=321; *U19*: 17.6 ± 0.6 y, F=0.288; P=0.834, df_N=3, df_D=185) in all age categories. Consequently, no covariates were taken into account. Statistical significance was set at P<0.05 and the corresponding P-values are presented. Follow-up univariate analyses using Bonferroni *post hoc* test were used where appropriate.

Further, in order to estimate the magnitude of the differences in anthropometry, motor coordination and physical fitness between playing positions, the smallest worthwhile differences (SWD) were calculated according to the method outlined by Hopkins (2000) and Hopkins, Marshall, Batterham, and Hanin (2008). The smallest worthwhile difference was set at Cohen's effect size of 0.2, representing the hypothetical, smallest difference between positions according to the mean of all positions, and is equivalent to moving from the 50th to the 58th percentile. In addition, Cohen's *d* effect sizes (ES) and thresholds (0.2, 0.6, 1.2, 2.0 and 4.0 for trivial, small, moderate, large, very large and extremely large, respectively) were also used to compare the magnitude of the differences between positions (Hopkins et al., 2008).

Results

Anthropometry. Statistical differences were found for height in the age categories U11 (*P=0.012, F=3.710,* $df_N=3$*,* $df_D=366$), U15 (*P=0.030, F=3.008,* $df_N=3$*,* $df_D=355$) and U19 (*P<0.001, F=6.928,* $df_N=3$*,* $df_D=185$), where GK were taller than DEF, MF and ATT, reflected by *small* to *moderate* effect sizes (0.31-1.08) between GK and all other positions. Also, in all other age groups, GK, followed by DEF were the tallest, however there were no significant differences between positions (U9: *P=0.307, F=1.209,* $df_N=3$*,* $df_D=206$*;* U13: *P=0.067, F=2.412,* $df_N=3$*,* $df_D=357$*;* U17: *P=0.084, F=1.185,* $df_N=3$*,* $df_D=321$; *small* effect sizes (0.23-0.51)). The smallest worthwhile difference in height revealed differences from 1.1 to 1.8 cm (from 0.7 to 1.1 %) across all age groups. Significant differences for body mass (U13: *P=0.027, F=3.087,* $df_N=3$*,* $df_D=357$*;* U15: *P=0.004, F=4.471,* $df_N=3$*,* $df_D=355$*;* U19: *P=0.003, F=4.800,* $df_N=3$*,* $df_D=185$) between playing positions were found between GK and all other positions (except for the U15 age category where GK were only significant heavier than MF), with *small* to *moderate* effect sizes (0.35-0.96), and smallest worthwhile differences from 0.7 to 1.8 kg (2.2 to 3.7 %) (***Table 1***).

Maturity status. The maturity offset was not significantly different between positions, except for the U11 age group where MF were closer to APHV compared to ATT (*P=0.005, F=2.780,* $df_N=3$*,* $df_D=366$*, ES=0.43*). However, *small* effect sizes (0.33-0.51) between GK and ATT were apparent in the U13 and U17 age categories. Calculated APHV was significantly different between DEF (13.0 ± 0.4 y) and MF

(13.2 ± 0.3 y) (*P=0.041, F=2.780,* df_N*=3,* df_D*=366, ES=0.41*) in the U11 age group and between GK (13.7 ± 0.5 y) on the one hand and DEF (13.9 ± 0.6 y) and MF (14.1 ± 0.5 y) (*P=0.003, F=4.804,* df_N*=3,* df_D*=355, ES: 0.23-0.33*) on the other hand in the U15 age group. Grand mean APHV for the total sample between U11 and U17 (n=1411) was 13.7 ± 0.6 y (min = 11.7 y; max = 15.7 y), which was slightly lower compared with the mean APHV-values found in two of the three longitudinal samples the equation was derived from (Mirwald et al., 2002), although a smaller standard deviation was found in the present sample. Mean APHV-values for the U11, U13, U15 and U17 age groups were 13.1 ± 0.4 y, 13.7 ± 0.4 y, 14.0 ± 0.6 y, and 14.0 ± 0.6 y, respectively. Compared with all other positions, GK were the most advanced and ATT the most delayed in maturity status (***Table 1***).

Gross motor coordination. The smallest worthwhile differences from moving sideways varied between 1.2 and 2.2 (from 2.4 to 2.7 %) relocations resulting in *trivial* to *small* effect sizes (0.00-0.45) between positions, confirming the non-statistical differences between positions (P-values varied between 0.379 and 0.978, F-values between 0.065 and 0.156, df_N=3) across all age groups. Mean performances for the U9, U11, U13, U15, U17 and U19 age categories were 46 ± 6, 55 ± 7, 62 ± 8, 68 ± 8, 73 ± 9 and 74 ± 10 relocations, respectively (***Table 1***).

Physical fitness.

All results for flexibility, endurance, speed, strength and agility are summarized in ***Tables 1, 2*** and ***3***.

Table 1 *Means ± SD for all playing positions and per position with corresponding P-values, smallest worthwhile differences (SWD) and Effect sizes for anthropometrical and physical characteristics (U9-U13).*

AgeCat	Variable	*n*	MEAN	*n*	GOALKEEPER	*n*	DEFENDER	*n*	MIDFIELDER	*n*	ATTACKER	*P*	SWD (%)	*Effect sizes*	Positions
U9	CAge	*209*	8.2 ± 0.5	*27*	8.1 ± 0.5	*83*	8.2 ± 0.5	*31*	8.3 ± 0.5	*68*	8.2 ± 0.5	*P=0.634*	/	/	/
	Height (cm)	*209*	130.2 ± 5.5	*27*	131.3 ± 6.5	*83*	130.6 ± 4.9	*31*	130.1 ± 5.5	*68*	129.2 ± 5.5	*P=0.307*	1.1 (0.8)	*Small*	A-G/D; G-M
	Body mass (kg)	*209*	27.1 ± 3.7	*27*	27.5 ± 4.3	*83*	27.6 ± 3.7	*31*	26.9 ± 3.9	*68*	26.4 ± 3.1	*P=0.185*	0.7 (2.7)	*Small*	A-G/D
	MS (n)	*121*	46 ± 6	*16*	45 ± 7	*43*	46 ± 6	*13*	44 ± 9	*49*	47 ± 6	*P=0.439*	1.2 (2.6)	*Small*	G-A; M-D/A
	SAR (cm)	*209*	21.0 ± 4.5	*27*	20.6 ± 5.5	*83*	21.5 ± 3.9	*31*	20.3 ± 4.4	*68*	21.0 ± 4.8	*P=0.579*	0.9 (4.3)	*Small*	D-G/M
	Yo-Yo IR1 (m)	*87*	596 ± 198	*10*	516 ± 155	*40*	594 ± 195	*18*	671 ± 211	*19*	571 ± 203	*P=0.210*	40 (6.6)	*Small-**Moderate***	G-D/**M**/A; M-D/A
	Sprint5m (s)	*197*	1.32 ± 0.08	*25*	1.36 ± 0.08$_A$	*77*	1.31 ± 0.08$_B$	*30*	1.31 ± 0.07$_{A,B}$	*65*	1.30 ± 0.07$_B$	*P=0.009*	0.02 (1.2)	*Small-**Moderate***	A-D/M; G-**D/M/A**
	Sprint30m (s)	*197*	5.73 ± 0.30	*25*	5.97 ± 0.31$_A$	*77*	5.72 ± 0.28$_B$	*30*	5.70 ± 0.26$_B$	*65*	5.71 ± 0.29$_B$	*P=0.001*	0.06 (1.0)	*Moderate*	G-D/M/A
	SBJ (cm)	*208*	146 ± 13	*26*	144 ± 13	*83*	147 ± 14	*31*	146 ± 10	*68*	145 ± 13	*P=0.714*	2.6 (1.8)	*Small*	G-D
	CMJ (cm)	*182*	19.5 ± 3.3	*22*	18.5 ± 3.0	*71*	19.8 ± 3.0	*26*	20.0 ± 4.3	*63*	19.3 ± 3.4	*P=0.360*	0.7 (3.4)	*Small*	G-D/M/A
	T-test Left (s)	*121*	9.71 ± 0.42	*16*	10.02 ± 0.47	*43*	9.70 ± 0.41	*13*	9.65 ± 0.45	*49*	9.64 ± 0.36	*P=0.014*	0.08 (0.9)	*Small-**Moderate***	D-M; G-**D/M/A**
	T-test Right (s)	*121*	9.88 ± 0.46	*16*	10.17 ± 0.43	*43*	9.84 ± 0.37	*13*	9.76 ± 0.56	*49*	9.86 ± 0.50	*P=0.057*	0.09 (0.9)	*Small-**Moderate***	M-A; G-**D/M/A**
	Dribble Foot (s)	*139*	13.50 ± 0.87	*18*	13.82 ± 1.00	*51*	13.52 ± 0.87	*17*	13.54 ± 0.74	*53*	13.37 ± 0.86	*P=0.309*	0.17 (1.3)	*Small*	G-D/M/A; M-A
	Dribble Ball (s)	*139*	26.10 ± 3.17	*18*	28.78 ± 3.68$_A$	*51*	25.94 ± 2.97$_B$	*17*	25.50 ± 1.93$_B$	*53*	25.54 ± 3.10$_B$	*P=0.001*	0.63 (2.4)	*Moderate*	G-D/M/A
U11	CAge	*369*	9.6 ± 0.6	*40*	9.9 ± 0.6	*122*	9.9 ± 0.6	*86*	10.0 ± 0.5	*121*	9.7 ± 0.6	*P=0.058*	/	/	/
	MatOffset (y)	*369*	-3.2 ± 0.5	*40*	-3.1 ± 0.5$_{A,B}$	*122*	-3.2 ± 0.5$_{A,B}$	*86*	-3.1 ± 0.4$_A$	*121*	-3.3 ± 0.5$_B$	*P=0.005*	/	*Small*	D-G/M; A-G/D/M
	APHV	*369*	13.1 ± 0.4	*40*	13.0 ± 0.3$_{A,B}$	*122*	13.0 ± 0.4$_A$	*86*	13.2 ± 0.3$_B$	*121*	13.1 ± 0.4$_{A,B}$	*P=0.041*	/	*Moderate*	G-M
	Height (cm)	*369*	139.3 ± 5.6	*40*	140.5 ± 6.5$_{A,B}$	*122*	139.7 ± 5.6$_{A,B}$	*86*	140.1 ± 5.3$_A$	*121*	137.9 ± 6.2$_B$	*P=0.012*	1.1 (0.8)	*Small*	A-G/D/M
	Body mass (kg)	*369*	31.9 ± 4.3	*40*	33.3 ± 4.6$_A$	*122*	32.1 ± 4.4$_{A,B}$	*86*	32.1 ± 3.9$_{A,B}$	*121*	31.0 ± 4.2$_B$	*P=0.015*	0.9 (2.7)	*Small*	G-D/M/A; A-D/M
	MS (n)	*257*	55 ± 7	*29*	55 ± 6	*81*	55 ± 7	*56*	55 ± 7	*91*	55 ± 8	*P=0.978*	1.4 (2.5)	*Trivial*	*All positions*
	SAR (cm)	*369*	18.9 ± 7.2	*40*	19.9 ± 7.5	*122*	18.5 ± 7.3	*86*	18.7 ± 7.7	*121*	19.2 ± 6.7	*P=0.719*	1.4 (7.6)	*Trivial*	*All positions*
	Yo-Yo IR1 (m)	*85*	802 ± 259	*9*	556 ± 152$_A$	*31*	763 ± 244$_{A,B}$	*21*	912 ± 298$_B$	*24*	850 ± 208$_B$	*P=0.003*	52 (6.5)	*Small-<u>Moderate</u>-**Large***	G-<u>D</u>/**M**/**A**; D-M/A; M-A
	Sprint5m (s)	*340*	1.27 ± 0.07	*37*	1.30 ± 0.07$_A$	*112*	1.27 ± 0.08$_{A,B}$	*78*	1.26 ± 0.06$_B$	*113*	1.27 ± 0.06$_{A,B}$	*P=0.037*	0.01 (1.1)	*Small-**Moderate***	G-D/**M**/**A**

	Sprint30m (s)	*340*	5.43 ± 0.25	*37*	5.55 ± 0.31$_A$	*112*	5.42 ± 0.23$_B$	*78*	5.38 ± 0.21$_B$	*113*	5.42 ± 0.26$_B$	*P=0.004*	0.05 (0.9)	*Small-**Moderate***	G-D/**M**/A; D-M
	SBJ (cm)	*341*	159 ± 13	*37*	159 ± 15	*112*	160 ± 13	*78*	160 ± 13	*114*	157 ± 14	*P=0.474*	2.6 (1.6)	*Small*	A-D/M
	CMJ (cm)	*320*	22.0 ± 3.2	*35*	21.0 ± 3.3	*106*	22.1 ± 3.4	*71*	22.2 ± 3.1	*108*	22.1 ± 3.1	*P=0.318*	0.6 (2.9)	*Small*	G-D/M/A
	T-test Left (s)	*255*	9.45 ± 0.35	*29*	9.53 ± 0.43	*81*	9.46 ± 0.32	*56*	9.40 ± 0.31	*89*	9.46 ± 0.35	*P=0.370*	0.07 (0.7)	*Small*	G-D/M
	T-test Right (s)	*255*	9.53 ± 0.37	*29*	9.64 ± 0.40$_A$	*81*	9.55 ± 0.40$_{A,B}$	*56*	9.41 ± 0.35$_B$	*89*	9.55 ± 0.37$_{A,B}$	*P=0.031*	0.07 (0.8)	*Small-**Moderate***	G-D/**M**/A; M-D/A
	Dribble Foot (s)	*257*	12.84 ± 0.83	*29*	13.16 ± 0.85	*81*	12.91 ± 0.74	*57*	12.78 ± 0.81	*90*	12.73 ± 0.89	*P=0.073*	0.17 (1.3)	*Small*	G-D/M/A; D-A
	Dribble Ball (s)	*257*	22.53 ± 2.19	*29*	25.26 ± 2.27$_A$	*81*	22.02 ± 1.91$_{B,C}$	*57*	21.67 ± 1.83$_B$	*90*	22.65 ± 1.92$_C$	*P<0.001*	0.44 (1.9)	*Small-**Large***	G-**D**/**M**/**A**; A-D/M
U13	CAge	*360*	11.8 ± 0.7	*36*	11.8 ± 0.7	*122*	11.8 ± 0.7	*104*	11.8 ± 0.7	*98*	11.8 ± 0.6	*0.886*	/	/	/
	MatOffset (y)	*360*	-1.9 ± 0.6	*36*	-1.8 ± 0.6	*122*	-1.9 ± 0.6	*104*	-1.9 ± 0.6	*98*	-2.0 ± 0.6	*P=0.196*	/	*Small*	G-A
	APHV	*360*	13.7 ± 0.4	*36*	13.6 ± 0.3	*122*	13.7 ± 0.4	*104*	13.7 ± 0.4	*98*	13.8 ± 0.4	*P=0.166*	/	*Small*	G-D/M/A; A-D/M
	Height (cm)	*360*	149.4 ± 6.7	*36*	151.7 ± 6.5	*122*	149.8 ± 7.3	*104*	149.0 ± 6.1	*98*	148.4 ± 6.5	*P=0.067*	1.3 (0.9)	*Small*	G-D/M/A; D-A
	Body mass (kg)	*360*	38.2 ± 5.4	*36*	40.7 ± 5.2$_A$	*122*	37.8 ± 5.5$_B$	*104*	38.0 ± 5.0$_B$	*98*	37.8 ± 5.5$_B$	*P=0.027*	1.1 (2.8)	*Small*	G-D/M/A
	MS (n)	*250*	62 ± 8	*26*	61 ± 9	*82*	62 ± 8	*71*	62 ± 7	*71*	62 ± 8	*P=0.926*	1.6 (2.6)	*Trivial*	*All positions*
	SAR (cm)	*359*	19.4 ± 5.4	*36*	19.6 ± 6.6	*121*	19.6 ± 5.5	*104*	19.7 ± 4.8	*98*	18.9 ± 5.3	*P=0.675*	1.1 (5.6)	*Trivial*	*All positions*
	Yo-Yo IR1 (m)	*186*	1199 ± 358	*20*	1046 ± 430	*65*	1212 ± 342	*56*	1263 ± 339	*45*	1170 ± 358	*P=0.120*	72 (6.0)	*Small-**Moderate***	G-D/**M**/A; M-A
	Sprint5m (s)	*343*	1.21 ± 0.07	*34*	1.26 ± 0.07$_A$	*114*	1.21 ± 0.06$_B$	*101*	1.21 ± 0.07$_B$	*94*	1.19 ± 0.06$_B$	*P<0.001*	0.01 (1.2)	*Small-**Moderate***	A-D/M, G-**D**/**M**/**A**
	Sprint30m (s)	*343*	5.11 ± 0.24	*34*	5.30 ± 0.28$_A$	*114*	5.10 ± 0.20$_B$	*101*	5.12 ± 0.23$_B$	*94*	5.04 ± 0.23$_B$	*P<0.001*	0.05 (0.9)	*Small-**Moderate***	A-D/M, G-**D**/**M**/**A**
	SBJ (cm)	*345*	175 ± 14	*35*	178 ± 15	*115*	176 ± 14	*100*	174 ± 14	*95*	173 ± 16	*P=0.253*	2.8 (1.6)	*Small*	A-G/M; G-M
	CMJ (cm)	*321*	25.2 ± 3.5	*33*	25.5 ± 4.1	*103*	25.3 ± 3.3	*92*	24.7 ± 3.0	*93*	25.5 ± 3.8	*P=0.441*	0.7 (2.8)	*Small*	M-G/A
	T-test Left (s)	*243*	9.09 ± 0.37	*25*	9.34 ± 0.41$_A$	*78*	9.07 ± 0.37$_B$	*72*	9.08 ± 0.36$_B$	*68*	9.02 ± 0.35$_B$	*P=0.003*	0.07 (0.8)	*Moderate*	G-D/M/A
	T-test Right (s)	*243*	9.15 ± 0.38	*25*	9.47 ± 0.43$_A$	*78*	9.13 ± 0.32$_B$	*72*	9.11 ± 0.35$_B$	*68*	9.10 ± 0.40$_B$	*P<0.001*	0.08 (0.8)	*Moderate*	G-D/M/A
	Dribble Foot (s)	*272*	12.02 ± 0.78	*27*	12.54 ± 0.67$_A$	*90*	11.89 ± 0.77$_B$	*78*	11.96 ± 0.77$_B$	*77*	12.05 ± 0.76$_B$	*P=0.002*	0.16 (1.3)	*Small-**Moderate***	D-A; G-**D**/**M**/**A**
	Dribble Ball (s)	*272*	20.33 ± 1.59	*27*	21.99 ± 1.60$_A$	*90*	20.29 ± 1.51$_{B,C}$	*78*	19.72 ± 1.41$_B$	*77*	20.40 ± 1.44$_C$	*P<0.001*	0.32 (1.6)	*Small-Moderate-**Large***	M-D/A; G-D/A; G-**M**

Means having a different subscript are significantly different at P<0.05; CAge=chronological age, G=Goalkeeper, D=Defender, M=Midfielder, A=Attacker, MatOffset=maturity offset, MS=moving sideways, SAR=sit-and-reach, Yo-Yo IR1=yo-yo intermittent recovery test level 1, SBJ=standing broad jump, CMJ=counter movement jump, Dribble foot=dribbling test without ball, Dribble ball=dribbling test with ball

Table 2 *Means ± SD for all playing positions and per position with corresponding P-values, smallest worthwhile difference (SWD) and Effect sizes for anthropometrical and physical characteristics (U15-U19).*

	Variable	*n*	MEAN	*n*	GOALKEEPER	*n*	DEFENDER	*n*	MIDFIELDER	*n*	ATTACKER	*P*	SWD (%)	*Effect sizes*	Positions
U15	CAge	*358*	13.8 ± 0.6	*37*	13.7 ± 0.6	*123*	13.9 ± 0.6	*113*	13.8 ± 0.8	*85*	13.7 ± 0.6	*P=0.170*	/	/	/
	MatOffset (y)	*358*	-0.2 ± 0.9	*37*	0.0 ± 0.9	*123*	-0.1 ± 0.9	*113*	-0.3 ± 0.9	*85*	-0.3 ± 0.9	*P=0.089*	/	*Small*	G-M/A; D-M/A
	APHV	*358*	14.0 ± 0.6	*37*	13.7 ± 0.5_A	*123*	13.9 ± 0.6_B	*113*	14.1 ± 0.5_B	*85*	14.0 ± $0.6_{A,B}$	*P=0.003*	/	*Moderate*	G-M
	Height (cm)	*358*	162.5 ± 8.8	*37*	164.7 ± 7.7	*123*	163.8 ± 9.0	*113*	161.5 ± 8.7	*85*	161.0 ± 8.8	*P=0.030*	1.8 (1.1)	*Small*	G-M/A; D-M/A
	Body mass (kg)	*358*	49.3 ± 9.1	*37*	53.8 ± 10.0_A	*123*	49.7 ± $8.8_{A,B}$	*113*	47.6 ± 8.2_B	*85*	49.2 ± $9.6_{A,B}$	*P=0.004*	1.8 (3.7)	*Small-**Moderate***	G-D/**M**/A; D-M
	MS (n)	*244*	68 ± 8	*31*	68 ± 8	*81*	69 ± 9	*74*	68 ± 9	*58*	67 ± 7	*P=0.385*	1.6 (2.4)	*Small*	D-A
	SAR (cm)	*357*	21.3 ± 6.6	*37*	24.6 ± 6.1_A	*122*	21.6 ± $6.1_{A,B}$	*113*	20.5 ± 7.1_B	*85*	20.6 ± 6.7_B	*P=0.007*	1.3 (6.2)	*Small-**Moderate***	G-D/**M/A**
	Yo-Yo IR1 (m)	*247*	1649 ± 385	*21*	1356 ± 307_A	*87*	1618 ± 337_B	*87*	1749 ± 386_B	*52*	1651 ± 424_B	*P<0.001*	77 (4.7)	*Small-**Moderate***	G-**D**/**M**/**A**; M-D/A
	Sprint5m (s)	*333*	1.16 ± 0.07	*33*	1.18 ± 0.09	*110*	1.16 ± 0.07	*107*	1.15 ± 0.06	*83*	1.15 ± 0.07	*P=0.178*	0.01 (1.2)	*Small*	G-D/M/A
	Sprint30m (s)	*334*	4.80 ± 0.25	*33*	4.96 ± 0.31_A	*110*	4.79 ± 0.23_B	*108*	4.81 ± 0.24_B	*83*	4.74 ± 0.24_B	*P<0.001*	0.05 (1.0)	*Small-**Moderate***	G-**D**/M/**A**; A-D/M
	SBJ (cm)	*341*	194 ± 17	*35*	200 ± 22	*116*	195 ± 16	*108*	192 ± 17	*82*	195 ± 17	*P=0.078*	3.4 (1.8)	*Small*	G-D/M/A
	CMJ (cm)	*316*	28.9 ± 4.3	*35*	30.4 ± 5.8	*107*	28.8 ± 4.4	*97*	28.5 ± 4.0	*77*	29.0 ± 3.9	*P=0.164*	0.9 (3.0)	*Small*	G-D/M/A
	T-test Left (s)	*234*	8.77 ± 0.38	*28*	8.95 ± 0.34_A	*78*	8.75 ± $0.30_{A,B}$	*69*	8.79 ± $0.45_{A,B}$	*59*	8.70 ± 0.36_B	*P=0.036*	0.08 (0.9)	*Small-**Moderate***	G-**D**/M/**A**; M-A
	T-test Right (s)	*233*	8.80 ± 0.34	*28*	8.99 ± 0.34_A	*77*	8.77 ± 0.34_B	*69*	8.83 ± $0.32_{A,B}$	*59*	8.71 ± 0.34_B	*P=0.003*	0.07 (0.8)	*Small-**Moderate***	G-**D**/M/**A**; M-A
	Dribble Foot (s)	*261*	11.66 ± 0.83	*30*	11.74 ± 1.06	*86*	11.68 ± 0.87	*79*	11.63 ± 0.76	*66*	11.62 ± 0.76	*P=0.905*	0.17 (1.4)	*Trivial*	*All positions*
	Dribble Ball (s)	*261*	19.60 ± 1.71	*30*	21.26 ± 2.38_A	*86*	19.87 ± 1.52_B	*79*	19.00 ± 1.32_C	*66*	19.23 ± $1.46_{B,C}$	*P<0.001*	0.34 (1.7)	*Small-<u>Moderate</u>-**Large***	G-<u>D</u>/**M**/<u>A</u>; <u>D-M</u>; D-A
U17	CAge	*324*	15.8 ± 0.6	*25*	15.8 ± 0.7	*120*	15.8 ± 0.6	*108*	15.9 ± 0.6	*71*	15.7 ± 0.7	*P=0.522*	/	/	/
	MatOffset (y)	*324*	1.9 ± 0.8	*25*	2.1 ± 0.8	*120*	1.9 ± 0.8	*108*	1.9 ± 0.8	*71*	1.7 ± 0.7	*P=0.084*	/	*Small*	G-D/M/A; A-D/M
	APHV	*324*	14.0 ± 0.6	*25*	13.7 ± 0.5	*120*	13.9 ± 0.7	*108*	14.0 ± 0.5	*71*	14.0 ± 0.6	*P=0.052*	/	*Small*	G-D/M/A
	Height (cm)	*324*	174.4 ± 6.7	*25*	175.5 ± 5.6	*120*	175.1 ± 6.9	*108*	173.8 ± 7.1	*71*	173.6 ± 5.9	*P=0.315*	1.3 (0.8)	*Small*	G-M/A; D-A
	Body mass (kg)	*324*	62.7 ± 7.8	*25*	65.9 ± 8.8	*120*	63.1 ± 8.1	*108*	61.5 ± 7.3	*71*	62.8 ± 7.2	*P=0.064*	1.6 (2.5)	*Small*	G-D/M/A; D-M
	MS (n)	*226*	73 ± 9	*21*	73 ± 9	*78*	74 ± 10	*74*	73 ± 9	*53*	73 ± 8	*P=0.619*	1.8 (2.5)	*Trivial*	*All positions*

	SAR (cm)	*323*	24.5 ± 8.0	*25*	29.1 ± 8.9$_{A}$	*120*	23.5 ± 7.8$_{B}$	*107*	25.3 ± 7.5$_{A,B}$	*71*	23.4 ± 8.2$_{B}$	*P=0.006*	1.6 (6.5)	*Small-**Moderate***	G-**D**/**A**; M-G/D/A
	Yo-Yo IR1 (m)	*244*	2064 ± 431	*16*	1540 ± 398$_{A}$	*84*	2094 ± 415$_{B}$	*91*	2111 ± 428$_{B}$	*53*	2094 ± 372$_{B}$	*P<0.001*	86 (4.2)	*Large*	G-D/M/A
	Sprint5m (s)	*281*	1.10 ± 0.07	*23*	1.12 ± 0.08	*106*	1.10 ± 0.06	*93*	1.11 ± 0.07	*59*	1.10 ± 0.06	*P=0.309*	0.01 (1.3)	*Small*	G-A
	Sprint30m (s)	*281*	4.48 ± 0.20	*23*	4.57 ± 0.27$_{A}$	*106*	4.48 ± 0.19$_{A}$	*93*	4.51 ± 0.17$_{A}$	*59*	4.39 ± 0.18$_{B}$	*P<0.001*	0.01 (0.1)	*Small-**Moderate***	G-D/M/**A**; D-A, **M-A**
	SBJ (cm)	*296*	215 ± 18	*22*	221 ± 20	*114*	214 ± 18	*98*	214 ± 18	*62*	216 ± 17	*P=0.348*	3.6 (1.7)	*Small*	G-D/M/A
	CMJ (cm)	*279*	34.3 ± 4.4	*23*	35.5 ± 5.9$_{A,C}$	*105*	34.1 ± 4.0$_{B,C}$	*93*	33.3 ± 3.9$_{B,C}$	*58*	35.8 ± 4.6$_{A}$	*P=0.003*	0.9 (2.6)	*Small-**Moderate***	G-D/M; D-M/A; **M-A**
	T-test Left (s)	*206*	8.53 ± 0.27	*20*	8.69 ± 0.32$_{A}$	*69*	8.48 ± 0.27$_{B}$	*67*	8.56 ± 0.23$_{B}$	*50*	8.47 ± 0.26$_{B}$	*P=0.006*	0.05 (0.6)	*Small-**Moderate***	G-**D**/M/**A**; M-D/A
	T-test Right (s)	*206*	8.53 ± 0.26	*20*	8.66 ± 0.31$_{A}$	*69*	8.50 ± 0.25$_{A,B}$	*67*	8.58 ± 0.23$_{A}$	*50*	8.47 ± 0.27$_{B}$	*P=0.015*	0.05 (0.6)	*Small-**Moderate***	G-**D**/M/**A**; M-D/A
	Dribble Foot (s)	*228*	11.29 ± 0.81	*21*	11.61 ± 1.02	*79*	11.27 ± 0.81	*76*	11.25 ± 0.79	*52*	11.25 ± 0.76	*P=0.305*	0.16 (1.4)	*Small*	G-D/M/A
	Dribble Ball (s)	*227*	18.83 ± 1.45	*20*	19.88 ± 1.71$_{A}$	*79*	18.99 ± 1.19$_{A,B}$	*76*	18.38 ± 1.55$_{B}$	*52*	18.86 ± 1.30$_{B}$	*P<0.001*	0.29 (1.5)	*Small-**Moderate***	G-**D**/**M**/**A**; M-D/A
U19	CAge	*188*	17.6 ± 0.6	*20*	17.7 ± 0.6	*71*	17.6 ± 0.6	*54*	17.7 ± 0.6	*43*	17.6 ± 0.6	*P=0.834*	/	/	/
	Height (cm)	*188*	177.8 ± 6.4	*20*	182.6 ± 6.0$_{A}$	*71*	178.6 ± 6.0$_{A,B}$	*54*	176.3 ± 5.9$_{B}$	*43*	175.9 ± 6.6$_{B}$	*P<0.001*	1.3 (0.7)	*Small-**Moderate***	G-**D**/**M**/**A**; D-M/A
	Body mass (kg)	*188*	69.6 ± 7.8	*20*	75.4 ± 8.2$_{A}$	*71*	69.6 ± 8.0$_{B}$	*54*	68.1 ± 7.5$_{B}$	*43*	68.8 ± 6.8$_{B}$	*P=0.003*	1.6 (2.2)	*Moderate*	G-D/M/A
	MS (n)	*140*	74 ± 10	*16*	72 ± 9	*54*	74 ± 10	*38*	72 ± 10	*32*	76 ± 11	*P=0.379*	2.0 (2.7)	*Small*	G-A
	SAR (cm)	*188*	25.0 ± 9.5	*20*	27.4 ± 4.3	*71*	23.5 ± 9.2	*54*	25.8 ± 10.7	*43*	25.6 ± 10.1	*P=0.315*	1.9 (7.6)	*Small*	G-D/A; D-M/A
	Yo-Yo IR1 (m)	*107*	2280 ± 481	*8*	1575 ± 213$_{A}$	*43*	2353 ± 391$_{B}$	*29*	2332 ± 458$_{B}$	*27*	2316 ± 540$_{B}$	*P<0.001*	96 (4.2)	*Large-**Very large***	**G-D**/M/A
	Sprint5m (s)	*161*	1.07 ± 0.07	*20*	1.08 ± 0.05	*62*	1.07 ± 0.07	*41*	1.08 ± 0.07	*38*	1.06 ± 0.05	*P=0.226*	0.01 (1.3)	*Small*	A-G/M
	Sprint30m (s)	*161*	4.35 ± 0.16	*20*	4.44 ± 0.15$_{A}$	*62*	4.35 ± 0.16$_{A,B}$	*41*	4.38 ± 0.15$_{A,B}$	*38*	4.28 ± 0.14$_{B}$	*P=0.001*	0.03 (0.7)	*Small-**Moderate***	G-D/M; A-**G**/D/**M**
	SBJ (cm)	*168*	223 ± 19	*20*	230 ± 16	*66*	219 ± 18	*43*	219 ± 17	*39*	231 ± 19	*P=0.001*	3.8 (1.7)	*Moderate*	G-D/M; A-D/M
	CMJ (cm)	*164*	36.3 ± 4.3	*19*	38.4 ± 4.4	*64*	35.5 ± 3.7	*43*	35.6 ± 4.2	*38*	37.5 ± 5.0	*P=0.014*	0.9 (2.4)	*Small-**Moderate***	A-D/M; G-**D**/**M**
	T-test Left (s)	*128*	8.44 ± 0.24	*16*	8.52 ± 0.29	*50*	8.44 ± 0.23	*33*	8.47 ± 0.20	*29*	8.38 ± 0.25	*P=0.208*	0.05 (0.6)	*Small*	G-D/M/A; A-D/M
	T-test Right (s)	*128*	8.48 ± 0.24	*16*	8.61 ± 0.32	*50*	8.47 ± 0.22	*33*	8.51 ± 0.19	*29*	8.39 ± 0.27	*P=0.028*	0.05 (0.6)	*Small*	G-D/M; A-D/M
	Dribble Foot (s)	*147*	11.07 ± 0.77	*17*	11.33 ± 0.99	*61*	10.95 ± 0.71	*37*	11.19 ± 0.85	*32*	11.0 ± 0.65	*P=0.204*	0.15 (1.4)	*Small*	G-D/A; M-D/A
	Dribble Ball (s)	*148*	18.41 ± 1.56	*17*	20.52 ± 2.06$_{A}$	*61*	18.27 ± 1.32$_{B}$	*38*	17.77 ± 1.19$_{B}$	*32*	18.20 ± 1.13$_{B}$	*P<0.001*	0.31 (1.7)	*Small-**Large***	G-**D**/**M**/**A**; M-D/A

Means having a different subscript are significantly different at P<0.05; CAge=chronological age; G=Goalkeeper, D=Defender, M=Midfielder, A=Attacker, MatOffset=maturity offset, MS=moving sideways, SAR=sit-and-reach, Yo-Yo IR1=yo-yo intermittent recovery test level 1, SBJ=standing broad jump, CMJ=counter movement jump, Dribble foot=dribbling test without ball, Dribble ball=dribbling test with ball

Table 3 *Range of effect sizes for each variable per age group.*

	MatOffset	Height	Body mass	MS	SAR	Yo-Yo IR1	Sprint 5m	Sprint 30m	SBJ	CMJ	T-test Left	T-test Right	Dribble Foot	Dribble Ball
U9	/	0.09-0.37	0.03-0.35	0.13-0.45	0.06-0.30	***0.12-0.91****	***0.00-0.83****	***0.04-0.97****	0.08-0.22	0.06-0.44	***0.03-0.99****	***0.05-0.87****	0.02-0.51	***0.01-1.14****
U11	0.00-0.43	0.07-0.42	0.00-0.54	0.00-0.15	0.03-0.19	***0.25-1.55¥***	***0.00-0.64¥***	***0.00-0.70¥***	0.00-0.22	0.00-0.38	0.00-0.37	***0.00-0.63¥***	0.06-0.47	***0.19-1.86¥***
U13	0.00-0.34	0.10-0.51	0.00-0.54	0.00-0.13	0.00-0.16	***0.12-0.60§***	***0.00-1.12§***	***0.09-1.07§***	0.07-0.32	0.00-0.24	***0.03-0.88§***	***0.03-0.98§***	***0.09-0.88§***	***0.07-1.57§***
U15	0.00-0.34	0.06-0.44	***0.06-0.72¤***	0.00-0.24	***0.01-0.62¤***	***0.09-1.10¤***	0.00-0.44	***0.09-0.85¤***	0.00-0.44	0.05-0.42	***0.11-0.71¤***	***0.18-0.83¤***	0.01-0.14	***0.17-1.36¤***
U17	0.00-0.56	0.05-0.33	0.04-0.58	0.00-0.11	***0.01-0.71I***	***0.00-1.49I***	0.00-0.31	***0.17-0.87I***	0.00-0.38	***0.06-0.60I***	***0.04-0.80I***	***0.12-0.68I***	0.00-0.43	***0.11-0.96I***
U19	/	***0.06-1.08Σ***	***0.11-0.96Σ***	0.00-0.20	0.02-0.47	***0.03-2.20Σ***	0.00-0.41	***0.19-1.13Σ***	***0.00-0.68Σ***	***0.03-0.76Σ***	0.14-0.54	0.01-0.58	0.07-0.46	***0.02-1.86Σ***

****moderate*** effect sizes for G and all other playing positions, except for the Yo-Yo IR1 (only between G-M)

¥***moderate*** effect sizes for Yo-Yo IR1 (G-D), Sprint 5 m (G-M/A), Sprint 30 m and T-test Right (G-M) to ***large*** effect sizes (for Yo-Yo IR1 (G-M/A) and Dribble Ball (G-D/M/A))

§***moderate*** effect sizes for Yo-Yo IR1 (G-M), Sprint 5 m, Sprint 30 m, T-test Left, T-test Right and Dribble Foot (G-D/M/A) and Dribble Ball (G-D/A) to ***large*** effect sizes for Dribble Ball (G-M)

¤***moderate*** effect sizes for body mass (G-M), SAR (G-M/A), Yo-Yo IR1 (G-D/M/A), Sprint 30 m, T-test Left and T-test Right (G-D/A) and Dribble Ball (G-D/A and D-M) to ***large*** effect sizes for Dribble Ball (G-M)

I***moderate*** effect sizes for SAR (G-D/A), Sprint 30 m (G-A and M-A), CMJ (M-A), T-test Left and T-test Right (G-D/A) and Dribble Ball (G-D/M/A) to ***large*** effect sizes for Yo-Yo IR1 (G-D/M/A)

Σ***moderate*** effect sizes for height and body mass (G-D/M/A), Sprint 30 m (A-G/M), SBJ (G-D/M and A-D/M) and CMJ (G-D/M) to ***large*** effect sizes for Yo-Yo IR1 (G-M/A) and Dribble Ball (G-D/M/A) to ***very large*** effect sizes for Yo-Yo IR1 (G-D)

MatOffset=maturity offset, MS=moving sideways, SAR=sit-and-reach, Yo-Yo IR1=yo-yo intermittent recovery test level 1, SBJ=standing broad jump, CMJ=counter movement jump, Dribble foot=dribbling test without ball, Dribble ball=dribbling test with ball

Discussion

The purpose of the present study was to establish anthropometrical and functional profiles of high-level youth soccer players according to their playing position. To our knowledge, this was the first study design (mixed-longitudinal) to report positional differences in such a large sample and age range, with the focus on a wide variety of assessments. The major finding of this study was that a clear difference between goalkeepers and the other field positions in almost all parameters was already manifest from the age of 8 years (youngest age group, U9). Also, between the field positions, distinctive characteristics were found from age group U17, summarizing that the defenders are the tallest amongst the field positions, midfielders have the best endurance, are the best in the dribble test with ball (from U9) and are the least explosive, and attackers are the smallest and the fastest on 30m, are the most delayed in biological maturity, and are the most explosive and agile. The present test battery was able to discriminate performances between goalkeepers and field positions from a young age (8 years) and between attackers and the other field positions after puberty (U17-U19).

The results of the present study generally support our hypothesis that differences in anthropometrical characteristics according to playing position exist. Specifically, in all age groups, goalkeepers and defenders were the tallest and heaviest players compared with midfielders and attackers who were smaller and leaner. This trend, already apparent from a young age, can be explained by the variation in maturity status, especially between 10 and 16 years. Goalkeepers and defenders seemed to enter puberty earlier since their age at peak height velocity occurred at younger age than the other positions. It has been shown that a more advanced maturity status is related to larger body dimensions (Malina, Bouchard, & Bar-Or, 2004) and higher chances to be selected at elite level (Carling et al., 2012; Coelho e Silva et al., 2010). Although, the present results show some variation among distributions of youth players by maturity status between positions, the trend towards a preference for on time and early maturing boys was consistent and in line with previous research (Carling et al., 2012; Deprez et al., 2012).

Recent studies showed that caution is warranted when using the age ate peak height velocity-method, although further research is necessary to validate this non-invasive method for the present young soccer population (Malina, Coelho e Silva, Figueiredo, Carling, & Beunen, 2012; Malina & Koziel, 2013). As a whole, it seems that talent identification and selection procedures are heavily influenced by body size dimensions and biological maturity status to at first, (de-)select players to play soccer, and second, to put players into a specific position on the short term, even from the age of 8-10 years. However, the present results did not provide information about differences in maturity status between levels, since only high-level players were assessed. As a whole, it seems that the present sample of youth soccer players is slightly advanced in maturity status (mean age at peak height velocity=13.7±0.6 y) compared with longitudinal, general population data from the Saskatchewan Growth and Development Study (SGDS) (14.0±1.0 y) and the Leuven Longitudinal Twin Study (LLTS) (14.2±0.8 y) (Mirwald et al., 2002). Furthermore, a clear distinction was found between goalkeepers and all other positions for anthropometry in the oldest age group, suggesting that body size dimension is one of the most important prerequisites to become a (professional) goalkeeper (Boone et al., 2011).

A specific physical profile for goalkeepers was already identifiable from a young age (U9). More in detail, goalkeepers were the most flexible, and this from the age of U15, suggesting that the specific nature of goalkeeping trying to defend the goal area by stretching the body to the ball could be responsible. Goalkeepers generally receive specific training within the club in order to improve their specific goalkeeping skills, which are making goalkeepers more flexible, at least more than field players. Furthermore, the lower intermittent endurance capacity for goalkeepers could be explained by the specific physical demands compared with field players. However, a good aerobic capacity is necessary in order to cope with long training sessions and matches. Therefore, the fact that the physical demand for goalkeepers is different should not be used as an excuse to pay little attention to their aerobic capacity. Goalkeepers should also be fast and agile, but they did not perform that well in the T-tests, 5 m and 30 m sprint in comparison with the field players, especially in the younger age groups (U9-U13: moderate effect sizes between goalkeepers and the field positions). Differences between goalkeepers and the other positions in 5 m and T-test disappeared when players became older (from U15), suggesting that specific training sessions for goalkeepers are focusing on starting speed and agility, which are indispensable. The 30 m sprint is probably not the most appropriate test to evaluate goalkeepers since it has been reported that their average sprinting distance in games is only between 1-12 m (Bangsbo & Michalsik, 2002).

Remarkably, dribbling skills seem to be an important characteristic at younger age (U9 to U15) for midfielders. Di Salvo and colleagues (Di Salvo et al., 2007) found in 30 professional top level games (Spanish League and Champions League) that midfielders covered a greater distance with the ball than the other positions. While these findings indicate that dribbling skills are important for midfielders at a senior level, the present results reveals that midfielders already outperformed their peers from the age of 8 years. It seems that youth coaches believe that midfielders should be creative and skilled players who act as the linking role in the team and find solutions in the crowded midfield zone of the pitch. On the other hand, one might conclude that the typical physical characteristics for different positions at senior level are not yet fully developed among young soccer players between 8 and 14 years. Because these players are very young and have not reached the top of their soccer career, their playing position will probably change during their career. When players become older (U17-U19), other functional characteristics become important, such as speed, explosive power and agility, especially to discriminate the attackers from the other field positions. This specialization due to playing position is more pronounced in the older age groups, indicating a more mature tactical understanding and a greater differentiation between the tasks of the different playing positions (Aziz, Mukherjee, Cjia, & The, 2008; Strøyer, Hansen, & Klausen, 2004). For example, attackers need to complete sprints away from defenders in order to generate space or to capitalize on goal scoring opportunities (Di Salvo et al., 2007).

Whilst no significant differences between the field positions existed for the Yo-Yo IR1, midfielders seem to have the biggest intermittent endurance capacity, especially in the younger age categories (U9-U15). When players grow older, all field positions need to have a high level of aerobic capacity to cope with the intense weekly training sessions. Additionally, midfielders have both defensive and offensive tasks including frequent movements up and down the field.

The present study has its limitations. First, other potential talent predictors, such as training history, playing minutes, psychological and sociological factors, were not included in the analysis, although these factors can affect the talent identification and selection process (Vaeyens et al., 2008). Furthermore, possible changes in tactical directives made by the coach within the investigated soccer seasons (e.g. due to injuries, players' quality,…), which could have led to the 'transformation' of players into other positions or even to the development of other functional characteristics, were not investigated. Also, players were divided into four positional roles whereas others categorized more positions (e.g. full backs, center backs, external midfielder,…) to provide more detailed information (Buchheit, Mendez-Villanueva, Simpson, & Bourdon, 2010; Lago-Peñas, Casais, Dellal, Rey, & Domíngez, 2011; Markovic & Mikulic, 2011; Mendez-Villanueva, Buchheit, Simpson, & Bourdon, 2013). For example, Lago-Peñas and colleagues (2011) found significant differences in height between central (175.0 ± 7.3 cm) and external (167.3 ± 8.4 cm) defenders, suggesting that the present results for height of the defenders are masking information. Finally, players were asked for their position at each testing moment, resulting in changes in positions for several players. This information was not recorded, although coaches and youth managers are responsible for allocating players to another position, whatever the reasons may be.

In conclusion, these results indicate two different selection procedures with the period around peak growth (age at peak height velocity, i.e. U15 in the present sample) as a decisive indicator for the further development of the different positions. On the one hand, from age group U9 to U15, the selection for a certain position is only focused on anthropometrical characteristics and soccer-specific skill to discriminate goalkeepers and midfielders from the other positions, respectively. On the other hand, after peak height velocity (U17-U19), anaerobic performance characteristics become important to distinguish attackers from all other field positions. The present test battery was able to discriminate performances between goalkeepers and field positions from a young age (8 years) and between attackers and the other field positions after puberty (U17-U19). The present data could be considered as useful benchmarks for high-level youth soccer players, serve for present and future comparisons and represent the scientific basis for developing position-specific conditioning/training protocols in youth soccer.

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PART 3

General discussion and conclusions

1. SUMMARY OF THE RESEARCH FINDINGS

The studies described in this dissertation aimed to map the talent identification, selection and development process in Flemish youth soccer. Therefore, youth players of different levels (elite, sub- and non-elite) and nationalities (Belgian and Brazilian) were assessed anthropometrical, maturational, physical fitness and motor coordination parameters, mainly on a longitudinal basis (only the elite Flemish players). The conducted research was divided into four different chapters. The first, methodological, chapter investigated test-retest reliability and validity of the intermittent endurance performance in elite, sub- and non-elite players (study 1 and 2), the short- and long-term stability of anthropometrical characteristics and intermittent endurance of pubertal soccer players (study 3), and the agreement between (invasive and non-invasive) methods to estimate maturity status in a mixed-sample of Belgian and Brazilian elite players (study 4). The second chapter focused on the influence of relative age on both aerobic (study 5) and anaerobic performance measures (study 6). The next chapter revealed the longitudinal development of intermittent endurance performance (study 7) and explosive leg power (study 8 and 9) obtained from multilevel analyses. Also, retrospective data were used to predict drop out, contract status and first-team playing time using anthropometrical, maturational, physical fitness and motor coordination characteristics (study 10). The final chapter described differences in youth soccer players' anthropometrical characteristics and general fitness level through aerobic and anaerobic tests according to the playing position on the field (study 11). To clearly overview the next section, all studies will be discussed according to the respective chapter from the '*Original research*' (part 2) they belong to.

1.1 Chapter 1: Methodological studies

Measures of reliability are extremely important in sports research (Nevill & Atkinson, 1997). A coach needs to know whether an improvement (or decrement) in performance is due to a real change or to a large amount of measurement error. Statistical procedures used to assess absolute reliability included measures of technical error (TE) and coefficient of variation (CV), and relative reliability was obtained using intra-class correlations (ICC). Furthermore, Bland and Altman plots with accompanying limits of agreement (LOA) are often applied (Bland & Altman, 1986; Nevill & Atkinson, 1997; Hopkins, 2000). However and of importance, it is not the CV of a measure that matters, but the magnitude of this 'noise' compared with (1) the usually observed changes (signal) and (2) the changes that may have a practical effect (smallest worthwhile difference) (Hopkins, 2004). A measure showing a large CV, but which responds largely to training can actually be more sensitive and useful than a measure with a low CV but poorly responsive to training. The greater the signal-to-noise ratio, the more likely the sensitivity of the measure.

Combining the results of the first two studies, the intermittent endurance capacity measured by the YYIR1 seems more reliable at elite level and in older ages compared with sub-/non-elite level and at younger ages. When compared to elite level, CV's and TE's were higher at sub- and non-elite level for YYIR1 distance. However, similar reliability measures for heart rate responses were found across levels and age groups. Though, care is warranted when comparing both studies as different study designs were used. The first study included two test sessions, whilst three test sessions were used to obtain the reliability data in the second study. Hopkins (2000) stated that reasonable precision for estimates of reliability requires approximately 50 participants and at least three trials (or test sessions), although such studies are rare in the literature and it seems that we must accept most reliability studies as pilot studies. Nonetheless, these two studies were the first to report reliability data in both elite and sub-/non-elite youth soccer players.

The data revealed that in sub- and non-elite players YYIR1 performance could, within a one-week period, differ 27%, 30% and 15% due to measurement error in the U13, U15 and U17 age groups, respectively. Given these large variance in YYIR1 performance absolute conclusions for usefulness in young players at sub- and non-elite level are difficult to make. This might reveal the limitations of the protocol used (i.e., only 2 test sessions) and a possible test or learn effect since players never ran the YYIR1 test before. In contrast, in the elite soccer population, smaller variances were reported, especially in the older age groups (i.e., U17 and U19), which could indicate that the youngest players who had the least experience with the YYIR1, could benefit the most from the possible test or learning effect during the last two sessions. Future research should consider a study design controlling for the possible test effect (e.g., test protocol with more repeated measures, excluding the first test session). Also, CV's in the older elite soccer population (i.e., 3.1-5.4% for U17 and 3.0-6.9% for U19) were similar to that of 13 adult professional soccer players (4.9%) and 18 recreational active adults (8.7%) (Krustrup *et al.*, 2003; Thomas *et al.*, 2006). Similar to the present findings, in young Italian soccer players aged 17 years, the YYIR1 also demonstrated important test characteristics such as reliability and construct validity (Fanchini *et al.*, 2014). Based on five different test occasions, the results revealed an ICC of 0.78 (0.61-0.89) and a CV of 7.3% (5.8-9.8%). Also, previous studies have reported an ICC of 0.92 for the YYIR1 in young players (Castagna *et al.*, 2010) and an ICC of 0.76 to 0.84 in different periods of the season for the heart rates at the submaximal version of the YYIR1 (after 6 minutes) (Mohr & Krustrup, 2014) and 0.90 for the submaximal YYIR1 (Ingebrigtsen *et al.*, 2014). Overall, our results support previous studies (for a review, see Bangsbo *et al.*, 2008), which suggested that both the maximal as well as the submaximal versions of the YYIR1 have a good and similar level of reliability. Additionally, due to its submaximal intensity, its inverse relationship with the maximal YYIR1 distance and short duration, the submaximal version of the YYIR1 (until level 14.8 or 6 min and 22 sec) could be useful for the physical assessment during rehabilitation or regular assessment of a player's fitness during the competition season (Krustrup *et al.*, 2003). However, a recent study showed that the submaximal version appears to have poorer sensitivity for detecting the training-induced effects compared to the maximal version of the YYIR1 (Fanchini *et al.*, 2014).

Generally, the level of both elite and sub-/non-elite youth soccer players form the present dissertation seems similar and even superior compared with high-level players from other countries. ***Table 1*** provides an overview of the YYIR1 performance of the present Belgian (Flemish) soccer population compared with players from other countries.

Table 1 *YYIR1 performances (m) in Flemish soccer players compared to other studies.*

Study	Nationality	Level	*n*	U13	*n*	U15	*n*	U17	*n*	U19
Study 1	Belgium	E	*44*	1270 ± 440	*57*	1818 ± 430	*49*	2151 ± 373		
		SE	*31*	965 ± 378	*16*	1425 ± 366	*11*	1640 ± 475		
Study 2	Belgium	E			*22*	2024 ± 470	*10*	2404 ± 347	*4*	2547 ± 337
Markovic & Mikulic (2011)	Croatia	E	*17*	933 ± 241	*21*	1184 ± 345	*20*	1581 ± 390	*15*	2128 ± 326
Castagna *et al.* (2009)	San Marino	E			*14*	842 ± 352				
Castagna *et al.* (2010)	San Marino	E			*18*	760 ± 283				
Buchheit & Rabbani (2014)	Iran	E					*14*	1392 ± 257		
Carvalho *et al.* (2014)	Spain	E	*33*	1314 ± 299	*33*	2099 ± 384				
Rebelo *et al.* (2014)	Portugal	E					*30*	1462 ± 356		
Benounis *et al.* (2013)	Tunisia	E			*42*	2648 ± 633				
Lopez-Segovia *et al.* (2014)	Spain	SE							*21*	1760 ± 329
Hammouda *et al.* (2013)	Tunisia	E					*15*	1764 ± 482		

E=Elite; SE=Sub-elite

The third study demonstrated that anthropometrical and maturational characteristics (i.e., stature, body mass and maturity offset) and YYIR1 performance in pubertal (11-16 years) soccer players showed a high stability over a two-year period, and a moderate stability over a four-year period. This suggests the longer the follow-up period, the more difficult to predict a player's potential in intermittent running performance. Adolescent players who possess the required characteristics to make the elite adult level may not necessarily retain these attributes through growth and maturation (Vaeyens *et al.*, 2008). Indeed, our results demonstrated that players performing the worst in YYIR1 performance at the age of 12 years are able to reduce the gap with the better performing players due to growth and maturation, however they still performed the worst, at least until the age of 16 years. A study by Buchheit and Mendez-

Villanueva (2013) also showed that the relative ranking of each players within a team can vary considerably, so that the changes in anthropometric and physical performance measures are unlikely to be predictable throughout adolescence. For example, the latter researchers revealed that the level of stability was measure-dependent and was ranked moderate (ICC's between 0.66 and 0.71) for performance measures (i.e., 10-m sprint, CMJ and maximal sprint) and very high (ICC's between 0.91 and 0.96) for stature, body mass and APHV over four years. In contrast, data from the present thesis demonstrated moderate stability for stature (ICC=0.57), body mass (ICC=0.75), maturity offset (ICC=0.66) and YYIR1 performance (ICC=0.59). It is however worth noting that within the limited number of players (i.e., n=10) in the Buchheit and Mendez-Villanueva (2013) study, small changes in ranking are responsible for large changes in ICC. This has implications for identification and selection procedures already at a young age. Players might be false positively retained in or false negatively de-selected from a high-level development program based on their current aerobic endurance capacities at younger ages, whereas our results showed that the worst performers at a young age may eventually catch up their better performing counterparts at older ages. Moreover, it should be noted that even the players with the lowest YYIR1 performance were already highly selected into a talent development programme and possesses already a high level of aerobic endurance compared to others (Castagna *et al.*, 2009; 2010; Buchheit & Rabbani, 2014; Rebelo *et al.*, 2014). The fact that some players in the present thesis were able to extremely improve their YYIR1 performance (e.g., one player went from 1.280m to 2.360m over two years), lends support to individual interventions to develop high-intensity intermittent running performance. Also, several studies indicated that developing proper aerobic endurance capacity is only important in late puberty (i.e., 15-16 years) to distinguish between future successful and less successful players (Philippaerts *et al.*, 2006; Vaeyens *et al.*, 2006; Gonaus & Müller, 2012).

Remarkably, in study 3, players performing the best in YYIR1 performance were the smallest and leanest, and the furthest from peak height velocity. Therefore, anthropometrical characteristics and maturational status cannot explain these baseline differences, although several studies showed that soccer players with increased body size dimensions and biological maturity performed better in speed, power and strength, especially during the pubertal years (Malina *et al.*, 2004a; Vaeyens *et al.*, 2006; Carling *et al.*, 2009). Similar to the present findings, Figueiredo and colleagues (2009a) found that late maturing soccer players had better aerobic performances compared with their early maturing peers between 11 and 14 years, although the latter authors assessed the yo-yo intermittent endurance test (level 1).

The final methodological study showed that concurrent equations to estimate mature stature tend to agree in adolescent soccer players and the correlation between the invasive (TW2 and TW3 skeletal age) and non-invasive protocols (APHV) was very large to nearly perfect (ranged 0.70 to 0.95). However, caution is needed in the transformation of estimated APHV into somatic maturity categories. Current studies confirmed that this approach tend to over-estimate the percentage of players who are on time, although the literature consistently suggests adolescent soccer players to be more likely to be advanced according to the discrepancy between skeletal age and chronological age (Figueiredo *et al.*, 2009a; Malina, 2011) (***Table 2***). Also, it emerged from the results that the mean skeletal age (i.e., SA) (TW2 SA: 14.59 ± 1.55 y; TW3 SA: 13.50 ±1.61 y) was in advance of chronological age (13.43 ± 1.33 y) in the mixed-sample of Brazilian and Belgium elite youth soccer players between 11 and 16 years. Other samples of youth soccer players of similar chronological age showed comparable results, although different methods estimating SA were used and should be considered in the interpretation (Fels vs. TW2 vs. TW3) (***Table 2***).

Table 2 *Means and standard deviations for chronological (CA) and skeletal (SA) ages, and frequencies by skeletal maturity status.*

Study	Method	n	CA (y)	SA (y)	Skeletal maturity status			
					late	on time	early	mature
Deprez et al. (study 4), Belgium elite								
	TW2	148	13.43 ± 1.33	14.59 ± 1.55	0	75	72	0
	TW3	148	13.43 ± 1.33	13.50 ± 1.61	0	92	56	0
Malina et al. (2007), Spanish elite								
	Fels	40	13.50 ± 0.45	14.27 ± 0.87	0	14	24	2
	TW3	40	13.50 ± 0.45	13.70 ± 1.19	1	19	9	11
Malina et al. (2010), Portuguese elite and sub-elite, Spanish elite								
	Fels	111	13.55 ± 0.30	14.16 ± 0.98	9	63	39	0
Hirose (2009), Japanese elite								
	TW2	47	13.7 ± 0.3	14.2 ± 0.9	1	30	15	1
Coelho-e-Silva et al. (2010), Portuguese elite[1] and local[2]								
	Fels[1]	45	13.7 ± 0.3	15.0 ± 0.9	0	21	24	0
	Fels[2]	69	13.6 ± 0.3	14.1 ± 1.0	7	40	22	0
Valente-dos-Santos et al. (2012b), Portuguese elite								
	Fels	83	13.7 ± 0.3	14.0 ± 1.1	11	48	24	0

TW = Tanner-Whitehouse

Key points

- The YYIR1 is a reliable and valid field test to measure a player's intermittent endurance capacity in a high-level youth soccer population between 13 and 18 years.
- The submaximal version of the YYIR1 (with heart rate registration) could be useful to measure the player's fitness during the season at both elite and sub-/non-elite level.
- The non-linear development of intermittent endurance capacity offers support to an individual guidance through adolescence.
- Large inter-individual differences in growth and maturation in pubertal children exist, despite the homogeneity in anthropometry and maturational status in elite youth soccer players around peak height velocity.
- From the age of 11 years, soccer excludes late maturing players based on SA minus CA difference.
- Estimates of mature stature obtained from the maturity offset protocol tend to overestimate mature stature when compared with estimates derived from skeletal age.
- The maturity offset protocol generally overestimates young adolescent soccer players as 'on time', whilst the literature suggests soccer players are more likely be advanced in maturity status based SA minus CA.

1.2 Chapter 2: Relative age effect and performance

Studies 5 and 6 revealed that relative age did not confound aerobic or anaerobic performance in young soccer players between 10 and 18 years of age, despite a clear overrepresentation of soccer players who were born in the first semester of the selection year (Helsen *et al.*, 2005; Carling *et al.*, 2009; Cobley *et al.*, 2009; Hirose, 2009). Compared to others (Helsen *et al.*, 2005; Carling *et al.*, 2009; Hirose, 2009; Fragoso *et al.*, 2014; Gil *et al.*, 2014), the relative proportions of players born in the first and last quarter of each selection year in studies 5 and 6 (i.e., first quarter: 37.6 - 42.3%, fourth quarter: 13.1 - 13.8%) are similar to those previously reported in international players from Europe, elite Portuguese, French, Japanese players, and non-elite Spanish youth soccer players (i.e., first quarter: 35.2 - 49.4%, fourth quarter: 6.0 - 17.0%) (***Figure 1***). As a consequence and despite several proposals to reduce or eliminate the RAE (e.g., rotating cut-off date) and the raising awareness of it in youth soccer since two decades, the overrepresentation of players born in the first quarter of the selection year is also noticeable at senior level (Vaeyens *et al.*, 2005; Helsen *et al.*, 2012).

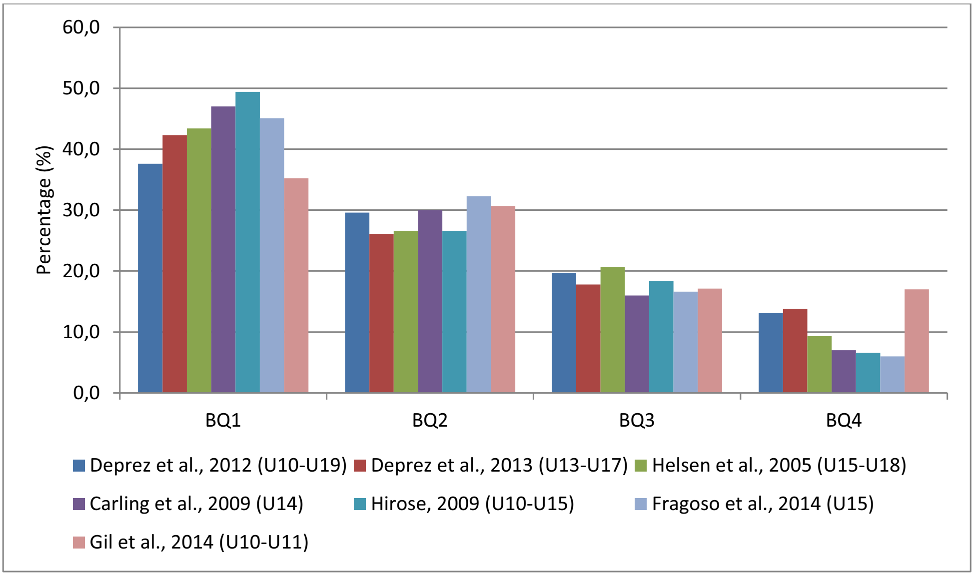

Figure 1 *Birth date distributions (%) per birth quarter of young and adult soccer players.*

Primarily, physical differences (i.e., greater chronological age and likelihood of more advanced physical characteristics) are responsible for large RAE's where attributes of greater height, body mass, strength, speed and endurance do provide performance advantages in youth soccer (Cobley e al., 2009). Indeed, a recent study investigating the relationship between birth quarter and anthropometrical and physical performance measures in 88 Spanish young soccer players, aged 9-10 years found significant higher values for stature, leg length, fat-free mass, speed and agility in players born in the first birth quarter compared to players born in the fourth birth quarter (Gil *et al.*, 2014). Complementary, those players early born in the selection year benefit from these physical advantages, receive early recognition from coaches and talent scouts and are more selected into higher levels of competition, training and coaching. However, in contrast, our results (studies 5 and 6) showed no differences in anthropometric and physiological characteristics between players across all birth quarters in each category. These observations agree with previous studies that also reported no differences across the four birth quarters in anthropometrical characteristics and functional capacities in 160 French elite U14 soccer players (Carling *et al.*, 2009) and 69 Portuguese 13-15 years old youth soccer players (Malina *et al.*, 2007). Nonetheless, there was a trend with players born in the first quarter being taller and heavier than players born in the fourth quarter. This might be explained by the fact that (1) the formation of homogenous players in terms of aerobic (i.e., YYIR1) and anaerobic performances (i.e., CMJ, SBJ, 5m and 30m sprint times) was already manifest before the age of 10 years, and (2) players of the same chronological age vary in maturational status (Malina *et al.*, 2007). In order to cope with the physical advantage of their peers born in the first months of the selection years and thus to avoid de-selection, players born later in the selection year benefit from entering maturity more early. Hirose (2009) reported similar findings in a study with 332 Japanese elite youth soccer players, aged 9−15 years, where the few players born late(r) in the selection year that were selected into the elite teams also showed advanced biological and physical characteristics. If late born (and late maturing) players avoid early de-selection and remain in their sport until late adolescence/early adulthood (when the physical disadvantages disappear), they often outperform their early born or early mature counterparts. For instance, Carling *et al.*(2009) reported that once players were selected into an elite youth academy (from the age of 13 years), their date of birth did not influence the opportunity to turn professional. Moreover, Vaeyens *et al.* (2005) demonstrated no differences in the likelihood of being selected and playing minutes between early and late born adult Belgian semi-professional soccer players.

Remarkably and of importance, in study 5, since APHV was not a confounding factor for the performance in the YYIR1, the relative advantages of maturation were likely to have a relatively small influence on the YYIR1 results. In contrast, the outcomes for anaerobic performances in study 6 were affected by biological maturation and demonstrated possible advantages for players born in birth quarter one compared with players born in quarter four suggesting that caution is warranted in the evaluation of players and that biological maturation should be taken into account. Due to statistical techniques (i.e., covariates, effect size, smallest worthwhile differences), we were able to evaluate all players on the same chronological age- and maturation-level, an impossible analysis for the coach on the field.

Key points

- Players born in the first part of the selection year are overrepresented compared with players born in the last part of the selection year.
- Selection procedures focus on the formation of homogenous groups of soccer players in terms of anthropometrical and physiological characteristics.
- Players who are born late in the selection year are more likely to mature early in order to cope with the chronological and physiological disadvantages compared with their early born peers.
- The effect of biological maturation was more pronounced in anaerobic performance measures compared with aerobic endurance performance.

1.3 Chapter 3: Longitudinal research

Other researchers highlighted the importance of including motor coordination parameters in the search for gifted young athletes (Mirkov *et al.*, 2010; Vandendriessche *et al.*, 2012; Vandorpe *et al.*, 2012). It seems that developing basic motor abilities during the first decade of life, is fundamental for future athletic career success. A longitudinal study showed that both children with relatively high and low motor competence increased their physical fitness over time (between 6 and 10 years), although children with high motor competence still outperformed their less skilled peers (Fransen *et al.*, 2014). Moreover, a five-year follow-up study demonstrated that differences between high and low motor competence groups at baseline (5-6 years), increased over five years for the endurance shuttle run, and supports the importance of introducing motor skills into talent development programs from a young age (Hands, 2008).

In the present dissertation, the development of aerobic (study 7) and anaerobic characteristics (studies 8 and 9) in young soccer players, and the prediction of future successful and less successful soccer players (study 10) are positively related to non-specific subtests from the '*Körperkoordination test für Kinder'* (KTK) (Kiphard & Schilling, 2007). More specific, the subtest 'moving sideways' is most positively related to the development physiological parameters and most discriminative between future successful and drop-out players. This tests consists of moving across the floor in 20 sec by stepping from one plate (25 cm x 25 cm x 5.7 cm) to the next, transferring the first plate, stepping on it, and so on (***Figure 2***). The number of relocations was counted and over two trials.

Figure 2 *Moving sideways (Kiphard & Schilling, 2007).*

Several studies reported values for moving sideways in different populations in Belgium (Flanders). A brief overview is shown in ***Table 3***. Generally, similar outcomes for moving sideways were found in different Belgium elite soccer populations (Vandendriessche *et al.*, 2012; Pion *et al.*, 2014), and compared to the general population, elite soccer players between 7 and 11 years of age, outperform their peers who are not specifically involved in soccer (Vandorpe *et al.*, 2011). The latter finding was also supported by a longitudinal research in a group of elite soccer players and controls, demonstrating that better agility and coordination parameters typically characterize the soccer group (Mirkov *et al.*, 2010). Recently, a study investigating discriminant parameters to distinguish elite athletes involved in nine different sports, showed that the soccer players were ranked somewhere in the middle of the sport spectrum for motor coordination (score of 67 ± 9) (Pion *et al.*, 2014). Table tennis players showed the best performance (77 ± 12), whereas basketball players performed the worst (64 ± 13).

Table 3 *Values for 'moving sideways' (n) (KTK-subtest; Kiphard & Schilling, 2007) in different populations in Belgium.*

Study	Nationality	Population	Age	n	Moving sideways
Study 7	Belgium (Flanders)	Elite soccer	11 y	28	60 ± 7
Study 8	Belgium (Flanders)	Elite soccer	11 y	123	59 ± 7
Study 9	Belgium (Flanders)	Elite soccer	7 y	70	39 ± 5
			8 y	81	42 ± 5
			11 y	123	59 ± 7
			12 y	30	58 ± 8
			16 y	108	72 ± 9
			17 y	11	65 ± 7
Study 10	Belgium (Flanders)	Elite soccer	15 y	68	75 ± 9
			16 y	51	74 ± 9
Vandorpe *et al.* (2011)	Belgium (Flanders)	Normal population	7 y	191	34 ± 5
			8 y	238	37 ± 6
			11 y	156	44 ± 7
Vandendriessche *et al.* (2012)	Belgium (Flanders)	International soccer	U16	18	69 ± 7
			U16 F*	19	66 ± 8
			U17	21	70 ± 6
			UI7 F*	15	67 ± 6
Pion *et al.* (2014)[£]	Belgium (Flanders)	Elite soccer	16 y	20	67 ± 9

**late maturing U16 and U17 international soccer players; [£]this study reported values for moving sideways in nine different sports.*

Additionally, moving sideways seems to predict countermovement performance, whereas jumping sideways is related to standing broad jump outcome. This might be explained by similarities in the specific protocol for countermovement jump and moving sideways on the one hand, and standing broad jump and jumping sideways on the other hand. Indeed, countermovement requires a high degree of multi-joint movements, similar to moving sideways performance and jumping sideways requires a high degree of lower limb work rate and stability, which is also needed in executing a standing broad jump. Remarkably, backward balancing seems to predict soccer-specific endurance wich could be related to the fast turns after 20m where balance is important in the Yo-Yo IR1 protocol, Therefore, the inclusion of specific programs focusing on general motor coordination is recommended as it benefits all players to improve their soccer-specific endurance and explosive leg power, even from a young age. Furthermore, motor coordination tasks are independent of maturational status and provide more insight in the future potential of young athletes.

Besides, the development of aerobic and anaerobic characteristics is positively influenced by growth in body size dimensions (i.e., stature, leg length, fat-free mass) and negatively by fat-mass. Recently, a four-year longitudinal study in elite Spanish soccer players (between 11 and 15 years) also examined physical growth and the development of YYIR1 (Carvalho *et al.*, 2014). The authors found that the development of the YYIR1 was positively influenced by chronological age and systematic training exposure over the season. The inter-individual variation in somatic maturity status (expressed as percentage of predicted mature stature) and body size were not significant explanatory variables on the development of the YYIR1. Other longitudinal observations and correlation studies found that chronological age (Figueiredo *et al.*, 2009a; Roescher *et al.*, 2010; Valente-dos-Santos *et al.*, 2012a), height (Wong *et al.*, 2009), maturity indicators (i.e., testicular volume, serum testosterone levels, skeletal age, stage of pubic hair) (Hansen & Klausen, 2004; Malina *et al.*, 2004a; Valente-dos-Santos *et al.*, 2012a) and training volume (Malina *et al.*, 2004a; Figueiredo *et al.*, 2010; Valente-dos-Santos *et al.*, 2012a) positively, and sum of skinfolds (Figueiredo *et al.*, 2010) negatively contributed to the aerobic fitness in young soccer players. Also, in young male soccer players, strength-related motor performances (such as vertical and standing long jump) improve with increasing body size dimensions (i.e., stature and body size) and sexual maturity (Malina *et al.*, 2004a; Baldari *et al.*, 2009). Of particular interest in the talent development process, the present findings demonstrated that the YYIR1 and the broad jump (SBJ) have been recommended as these outcomes of aerobic endurance and explosive leg power are not confounded by the maturational status of the players. However, we already demonstrated that the use of the maturity offset protocol in young soccer players is questionable (study 4).

Finally, retrospective data revealed that players signing a professional soccer contract possessed more explosive leg power from the age of 16 years compared to players not signing a professional contract. Similarly, a longitudinal study used physiological data to predict future career progress in elite Austrian youth soccer players between 14 and 17 years (Gonaus & Müller, 2012). The results demonstrated superior physiological performances of players who had been drafted to play in a national youth team compared with players who had never been drafted to play for a national youth team. For example, at the age of 16 years, drafted players performed the 5m sprint significantly faster (1.01±0.06s) than non-drafted players (1.04±0.07s; F=18.547; P<0.001), corresponding to some extent with the present differences between contracted and non-contracted players (*contract*=1.05±0.06s; *no contract*=1.09±0.07s; F=4.371; P=0.041). Also, at adult level, it has been reported that muscle strength and short-distance speed is favorable in French professional compared with amateur soccer players (Commetti *et al.*, 2001). Altogether, it appears that measuring physical and physiological characteristics (e.g., explosive leg power) in young soccer players can provide helpful information in terms of predicting future career progression (Reilly *et al.*, 2000; Le Gall *et al.*, 2010; Gonaus & Müller, 2012). Moreover, the present thesis demonstrated also that being more explosive increased the opportunity to receive more first-team playing time.

Key points

- Non-specific motor coordination is a potential predictor of future success in youth soccer and, together with changes in body size dimensions (i.e., stature, body mass, fat-free mass, fat mass), contribute to the development of aerobic and anaerobic characteristics.
- The contribution of biological maturation in the development of aerobic endurance and explosive leg power is irrelevant in a group of highly-selected young soccer players.
- Explosive leg power is likely to be a key physical factor that predicts future career status (receiving a professional soccer contract) and playing minutes in young soccer players.

1.4 Chapter 4: Positional differences in performance

The last study of this dissertation investigated differences in anthropometry, maturity status, motor coordination, functional capacities and soccer-specific skill by playing position in elite soccer players between eight and 18 years of age. The results revealed that inherent anthropometrical and physical capacities (i.e., speed, power, agility) might select players in or reject players from certain positions. For example, a major finding of this study was that coaches are more likely to select the tallest (and heaviest) players into goalkeeping and defending positions. Moreover, as players grow older and position-specific training becomes more relevant, more distinct differences appeared between goalkeepers and the outfield positions in anthropometrical and physical characteristics. Therefore, it is important to recognize that in order to properly characterize performance characteristics of goalkeepers, position-specific tests measures should be developed (Rebelo *et al.*, 2014). For example, the 30 m sprint is probably not the most appropriate test to evaluate goalkeepers since it has been reported that their average sprinting distance in games is only between 1-12 m (Bangsbo & Michalsik, 2002).

Table 4 provides an overview of the anthropometrical and maturational characteristics of young soccer players according to their playing position. For a clear overview of the latter characteristics in this thesis, I would like to refer the reader to tables I and II of study 11. The Brazilian study revelaed that goalkeepers and defenders are much taller compared with the Belgium players in this thesis (Fidelix *et al.*, 2014), whilst others reported similar findings (Coelho-e-Silva *et al.*, 2010; Carling *et al.*, 2012; Lago-Peñas *et al.*, 2014). Also, skeletal age of all players is advance of chronological age, except for the midfielders in the French study (Carling *et al.*, 2009; Coelho-e-Silva *et al.*, 2010). The present thesis did not investigate skeletal age, however we estimated both goalkeepers and defenders an earlier growth spurt compared to midfielders and attackers, although the differences between estimated time at peak height velocity between positions was rather small. We already reported the homogeneity in anthropometry and maturity in young soccer players (studies 5 and 6).

Table 4 *Anthropometrical and maturational characteristics of elite young soccer players by playing position.*

Study	Population	Variable	n	GK	n	DF	n	MF	n	FW
Coelho-e-Silva *et al.* (2010)	Portugal	Age			48	13.7 ± 0.3	37	13.6 ± 0.2	29	13.7 ± 0.3
		SA			48	14.6 ± 1.2	37	14.2 ± 0.9	29	14.6 ± 0.9
		Stature			48	162.7 ± 8.4	37	160.3 ± 9.0	29	162.8 ± 9.1
		Body mass			48	52.7 ± 9.4	37	50.1 ± 9.0	29	52.4 ± 7.1
Carling *et al.* (2012)	France	Age	23	13.4 ± 0.3	31	13.6 ± 0.3	60	13.5 ± 0.5	44	13.5 ± 0.4
		SA	23	14.0 ± 0.9	31	14.2 ± 1.4	60	13.3 ± 1.2	44	13.9 ± 1.5
		Stature	23	168.0 ± 8.1	31	168.3 ± 9.3	60	160.2 ± 8.7	44	161.9 ± 8.2
		Body mass	23	57.3 ± 9.5	31	56.8 ± 8.8	60	48.5 ± 8.8	44	50.6 ± 8.3
Fidelix *et al.* (2014)	Brazil	Age	7	16.3 ± 0.8	22	16.1 ± 0.8	20	16.4 ± 0.7	18	16.2 ± 0.8
		Stature	7	188.0 ± 2.6	22	177.6 ± 6.5	20	175.9 ± 5.8	18	175.8 ± 6.9
		Body mass	7	80.5 ± 4.3	22	69.9 ± 7.9	20	68.6 ± 7.0	18	70.2 ± 9.2
Lago-Peñas *et al.* (2014)*	Spain	Age	16	14.2 ± 2.3	55	14.4 ± 1.4 - 15.7 ± 2.3	62	14.9 ± 2.1 - 15.1 ± 1.7	23	15.2 ± 2.2
		Stature	16	169.9 ± 12.1	55	164.2 ± 9.8 - 173.3 ± 10.4	62	161.9 ± 10.8 - 164.1 ± 10.0	23	166.6 ± 10.3
		Body mass	16	64.3 ± 10.2	55	55.8 ± 10.9 - 68.2 ± 10.9	62	54.4 ± 12.4 - 54.5 ± 10.9	23	61.5 ± 12.1

*GK=goalkeepers; DF=defenders; MF=midfielders; FW=forwards; SA=skeletal age; *mean values for DF include external and central DF, mean values for MF include wide and central midfielders.*

Also, the time around peak height velocity seems to be crucial in this selection process. For example, before APHV (i.e., U9 to U15) players with excellent dribbling skills and larger body size dimensions are more likely to be selected to play as midfielder. However, the typical characteristics for different playing positions at senior age are yet not fully developed among young soccer players between eight and 14 years, although the typical anthropometrical characteristics of goalkeepers (i.e., taller and heavier) were, in agreement with other studies (Coelho-e-Silva *et al.*, 2010; Carling *et al.*, 2012), already manifest at young age. Also, previous studies investigating positional differences are limited and the results have been inconsistent (Malina *et al.*, 2000; Gil *et al.*, 2007). For example, Coelho e Silva *et al.* (2010) reported no positional differences in 128 Portuguese young soccer players (13-14 y) for anthropometrical and physical characteristics, whereas Gil *et al.* (2007) found in 241 soccer players (14-21 y), that goalkeepers were the tallest and heaviest, defenders had a lower quantity of fat, midfielders were characterized by the best endurance, while forwards were the most explosive players, which is in accordance with a study by Lago-Peñas *et al.* (2011).

Key points

- Goalkeepers and defenders were the tallest and heaviest compared with midfielders and attackers in all age groups (U9-U19).
- At younger ages (U9-U15), no distinct differences in physical capacities were found, except for midfielders who had the best dribbling skills.
- At older ages (U17-U19), attackers are the most explosive, the fastest and more agile compared with the other positions.
- The timing around peak height velocity seems decisive for players to selected in or rejected from certain positions: goalkeepers (tallest) and midfielders (dribbling skills) before, and attackers (explosive, fast and agile) after peak height velocity.

1.5 What this thesis adds

- The use/validity of a field test to estimate the maturity status
- Study of the reliability and validity of field tests measuring physical fitness in youth soccer players
- The relationship between the relative age effect and physical performance
- The use of multilevel analyses to investigate the longitudinal development of aerobic and anaerobic performance characteristics on such a large scale
- The demonstrated importance of non-sport specific, motor coordination in talent identification and development programs in youth soccer

2. PRACTICAL IMPLICATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

2.1 The role of maturation and relative age

The present research in soccer talent identification demonstrates a systematic bias in selection towards players born early in the selection year (i.e., relative age effect) (study 1; study 5; study 6), and players who are early and average in maturation (study 4) (Helsen *et al.*, 2005; Malina *et al.*, 2007; 2012; Cobley *et al.*, 2009; Figueiredo *et al.*, 2009a; Ostojic *et al.*, 2014). For example, in study 1, chronological ages for elite players in the U13, U15 and U17 age groups were relatively older (12.8 ± 0.6 y, 14.8 ± 0.6 y and 16.6 ± 0.6 y, respectively) when compared with their sub/non-elite peers (12.4 ± 0.6 y, 14.1 ± 0.4 y and 16.2 ± 0.6 y, respectively). In practice, misconceptions in the evaluation of gifted players still exist as many coaches confuse the terms 'relative age effect' and 'maturation'. Players who are born early in the selection year are not necessarily early to mature and vice versa. It has been suggested in the present dissertation (study 5) that only a small number of players born in the last part of the selection year but with advanced biological maturation might be successful at elite teams (Hirose, 2009). This would imply that players who are born later in the selection year and are later to mature are not represented at elite level, although these players might be as gifted as their early born and early maturing counterparts. Indeed, Figueiredo *et al.* (2009a) found that the latter players are more likely to drop out of the sport, which was confirmed in a study by Philippaerts *et al.* (2004) who found that the majority of elite youth soccer players (> 62%) had a skeletal age in advance of chronological age (***Figure 3***). Moreover, after the age of 13.8 years (i.e., mean estimated time at peak height velocity; Philippaerts *et al.*, 2006), late maturing players (SA < CA) were less present at elite level (***Figure 3***).

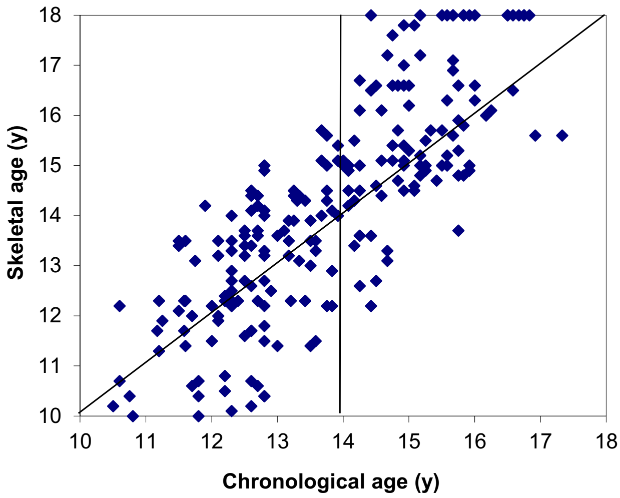

Figure 3 *Relationship between chronological and skeletal ages in elite Flemish soccer players (Philippaerts et al., 2004).*

Apparently, talent identification processes are focused on the formation of homogenous groups of players in terms of anthropometrical and maturational characteristics (Carling *et al.*, 2009; Hirose, 2009), and therefore relatively older and younger players of the same age group show similar functional capacities and skills (study 5; study 6; Malina *et al.*, 2007). Several solutions are presented to reduce the RAE in youth soccer, such as a rotating cut-off date, the creation of smaller age groups and changing the mentality and philosophy of coaches (Helsen *et al.*, 2000; 2005; Vaeyens *et al.*, 2005). However to date, the present thesis still showed large overrepresentations of players born in the first part of the selection year, and this selection bias may already exist before the age of nine years.

Coaches should pay more attention to technical and tactical skills when selecting players as opposed to an over-reliance on anthropometrical characteristics such as stature (Helsen *et al.*, 2005). It has been argued that we need to move away from early selection policies and from an emphasis on winning at young ages, partly because it is so difficult to predict the ultimate level that someone can reach (Martindale *et al.*, 2005). Therefore, soccer federations, clubs and coaches should explicitly provide opportunities to as many youngsters as possible, and they might restructure the training and competition process at younger ages (i.e., 7 to 11 years) according to the relative age of the players to reduce the advantages of growth and maturation of early born players.

The present dissertation examined no differences in biological maturation between different age groups of levels of performance as we only investigated young, elite soccer players. However in the first study, we revealed that the elite players reached the estimated APHV earlier (smaller maturity offset) compared with their sub-elite counterparts, although the results were not significant. Also, study 4 was the only study incorporating skeletal age, considered as the golden standard in assessing maturity status (Malina, 2011). It was not surprisingly that the trend for an overrepresentation of players more advanced in biological maturation emerged from the results. Generally, the mixed-sample of Belgian and Brazilian players showed, on average, a skeletal age (SA; TW2: 14.6 ± 1.6 y; TW3: 13.5 ± 1.6 y) in advance of the chronological age (CA; 13.4 ± 1.3 y). Also, in study 11, the mean estimated APHV of the players (10-16 y) was 13.7 ± 0.6 y, which was slightly earlier compared with other Flemish (13.8 ± 0.8 y; Philippaerts *et al.*, 2006), or Welsh (Bell, 1993) and Danish soccer players (i.e., 14.2 ± 039 y; Froberg *et al.*, 1991), and compared with non-athletic European boys (ranged 13.8 – 14.2 y; Malina *et al.*, 2004b). Remarkably, maturity status was not able to distinguish future club and drop out players in study 11, which suggests that selection procedures are highly focusing on the formation of tall, heavy and more mature soccer players, already from the age of 9 years. Longitudinal data (study 3) showed that anthropometry and maturation are highly stable on the short-term (i.e., 2 year follow-up), although on the long-term (i.e., 4 year follow-up) players later in maturation and with smaller body size dimensions might (partially) catch up their more mature, taller and heavier counterparts between 10 and 16 years as every play eventually will reach the mature status (Buchheit & Mendez-Villanueva, 2013). This reflects the large inter-individual variation in growth and maturation between pubertal youth soccer players, and suggests that talent identification and development programmes should account for individual maturation. A recent study in Serbian youth soccer players showed that players with an advanced biological age were overrepresented (Ostoijic *et al.*, 2014). Interestingly, at follow-up eight years later, elite soccer competence seems to be achieved more often by the boys who were late maturers at the age of 14 years, while early maturing boys less frequently reached top-level soccer.

However, care is warranted when using the Mirwald *et al.* (2002) protocol for the estimation of maturity status (study 4). Poor agreement was found between classifications of maturity status (i.e., advanced, on time and late) based on the relationship between invasive (i.e., skeletal age) and other non-invasive indicators (i.e., estimated APHV and percentage of estimated mature stature). However, the use of the maturity offset-protocol has extensively been used in large samples of young athletes (Vandendriessche *et al.*, 2012; Matthys *et al.*, 2013; Moreira *et al.*, 2013). Recently, a study examined differences between predicted and actual age at PHV in 193 Polish boys (Malina & Koziel, 2014). Predicted years from PHV and APHV derived from the longitudinal sample followed from 8 to 18 years were dependent on CA at prediction and actual APHV; predicted APHV also had a reduced range of variation compared to actual APHV (Malina & Kozieł, 2014). Similarly, across all presented studies involved with estimated APHV measures, the values varied between 12.8 y and 14.2 y between chronological ages of 9 and 18 years of age (study 1; 3; 4; 5; 6; 7; 8; 10; 11). Indeed, within the younger chronological age groups, APHV-values were remarkably lower when compared with the values in older chronological age groups. For example, in study 5, estimated APHV for the U11 age group ranged between 12.8 and 13.0 years, compared with the U17 age group, where APHV ranged between 13.8 and 14.1 years across all birth quarters. Nevertheless, predicted APHV appears to have validity for boys who are on time (average) in the timing of actual APHV and during the age interval that spans the growth spurt, approximately 12.0 to 14.99 years (Malina & Kozieł, 2014). Further studies really need to validate the equations for predicting APHV in independent longitudinal samples. Measures of stature and body mass on a regular basis (e.g., once every two or three months) could provide more reliable data concerning the timing of peak growth (Malina & Koziel, 2014).

Cross-sectional data revealed that estimated APHV did not confound possible differences in YYIR1 performance across birth quarters (study 5), although in contrast, an estimation of biological maturity could significantly contribute to differences in anaerobic performances between birth quarters (study 6). However, in both studies, the statistics used were practical irrelevant for the coach on the field. Therefore, longitudinal designs (i.e., multilevel models) incorporating growth and maturation could provide more precise information on their contribution among other to several performance measures (study 7, study 8, study 9). For example, the model predicting aerobic performance between 11 and 16 years (study 7) did not permit the inclusion of biological maturation, although contrasting results in the literature were presented with the later maturing boys having the better aerobic endurance (Coelho-e-Silva *et al.*, 2008; Figueiredo *et al.*, 2009b; 2010). Also, it was reported that running economy did not differ between early and late maturing elite soccer players (Segers *et al.*, 2008). Remarkably, the variability in maturity status seems to benefit later maturing soccer players when assessing the countermovement jump (CMJ) but not the standing broad jump (SBJ), which development is independent of maturity status (study 8). These findings suggest that different jumping protocols (vertical vs. long jump) highlight the need for special attention in evaluating jump performances. In addition, study 10 revealed that anthropometry and estimated biological maturation did not discriminate between future *club* and *drop out* players. These longitudinal findings suggest, again, the early formation of players who tend to be advanced or average in maturity status, although comparisons with other studies might be difficult as different protocols were used to estimate maturity status (Figueiredo *et al.*, 2010). At the onset of puberty, later maturing players, who are possibly gifted, might not get the chance to develop their abilities at the highest youth soccer level and therefore, they are not able to reach their potential. These players in particular needs to be protected by the sport on different levels.

Finally, one of the aims of study 11 was to examine differences in biological maturation between four different playing positions. On average, goalkeepers and defenders seem to be the tallest, heaviest and most advanced in maturity status, whereas attackers were the smallest, leanest and most delayed in maturity status. These findings are in accordance with other research (Wong *et al.*, 2009; Lago-Peñas *et al.*, 2011; Sporis *et al.*, 2011; Gil *et al.*, 2014). Furthermore, the estimated age around peak spurt (i.e., U15 in study 11) is a decisive indicator for the further development of the different positions. On the one hand, from age group U9 to U15, the selection for a certain position is strongly focused on anthropometrical characteristics and soccer-specific skills to discriminate goalkeepers and midfielders from the other positions, respectively. On the other hand, after peak height velocity (U17–U19), anaerobic performance characteristics become important to distinguish attackers from all other field positions. Talent identification models should thus be dynamic and provide opportunities for changing parameters in a long-term developmental context (Vaeyens *et al.*, 2006). However, transitions between positions in youth soccer are still possible (due to possible changes in maturational status and physical characteristics) and should be recommended for further longitudinal research in specific studies.

2.2 Test battery

The test battery administered in the present dissertation includes measures of anthropometry, biological maturation, motor coordination parameters, flexibility, explosive leg power, agility, speed, soccer-specific endurance and soccer-specific motor coordination, which all were found to be reliable and valid (study 1; study 2; Ortega *et al.*, 2008; Sassi *et al.*, 2009; Buchheit *et al.*, 2010; Hesar, 2011; Vandorpe *et al.*, 2011; Vandendriessche *et al.*, 2012). Atkinson and Nevill (1998) outlined the importance of using valid and reliable physical performance tests for research and athlete support. For consistency and comparability it would be useful if the same testing procedures could be used throughout the age range of players found in the youth academy (U9–U19), but no research has investigated if there are any differences in the reliability of a field-test, or battery of field tests, when completed by soccer players drawn from different age groups (Hulse *et al.*, 2013). Despite high ecological validity, it is important to remember that no field test will determine performance during soccer match-play, as it is difficult to isolate the importance of individual physical parameters when the overall demands of the sport are so complex. Also, it has been considered whether multiple small-sided games could act as a talent identification tool in elite youth soccer as the results demonstrated that there was a moderate agreement between the more technically gifted soccer players and success during multiple small-sided games (Unnithan *et al.*, 2012).

Although many other field and laboratory tests exist to measure aerobic endurance, special emphasis was given to the YYIR1 through this dissertation. The YYIR1 test is a soccer-specific field test as it includes interval moments and short turns compared to other (continuous) endurance tests (e.g., endurance shuttle run, treadmill tests,…). Moreover, our results showed that maturation has no impact on (the development of) YYIR1 performance, thus early maturing players with larger body size dimensions do not necessarily run further compared with lesser maturing counterparts (study 1; 3; 5; 7). Players playing at higher soccer levels are already highly selected in terms of anthropometrical and maturational characteristics, and classifications based on maturity offset should be examined critically

(Malina & Koziel, 2014). In this thesis, we investigated the reliability, validity, stability and discriminative ability of the YYIR1 between future successful and less successful players, and between playing positions, and we studied the development through puberty with influences of growth, maturation and motor coordination. Based on our findings, we conclude that the YYIR1 is recommended as a valuable tool in the talent identification and development process, especially at elite level (study 2), as it was found reliable and discriminative between different levels of performance (elite vs. sub-elite; elite vs. drop-out) and positions on the field (goalkeepers vs. outfield players) (study 1; study 2; study 10; study 11). However, despite the fact that the YYIR1 performance is reliable and seems stable on the short term, one shot long-term predictions are unreliable as poor performers are able to catch up the better performers (study 3). The use of immature key variables for long-term talent prediction is problematic because of the dynamic nature of sport performance and its underlying determinants (Vaeyens *et al.*, 2008). Inter-individual differences in growth, development and training cause an unstable non-linear development of performance characteristics (Vaeyens *et al.*, 2008). Therefore, we suggest an individual, longitudinal follow-up accounting for growth and maturation. Furthermore, a good aerobic capacity is necessary in order to cope with long training sessions and matches, and a basic level of aerobic capacity is required. Benchmark values could assist in the (individual) soccer training programme. For example, ***Table 1*** revealed YYIR1 distances between 1800 m and 2000 m for elite Belgian U15 players (study 1; study 2), with goalkeepers requiring a minimum of about 1500 m and midfielders about 2100 m, which is related to the specific (aerobic) game demands of each position (study 11). Furthermore, studies 1 and 2 revealed that the submaximal heart rate (after completing level 14.8 or after 6’22”) during the YYIR1 test was inversely correlated with the YYIR1 distance (Krustrup *et al.*, 2003), suggesting that the test is appropriate to measure changes in physical fitness without using the test to maximal exhaustion. Moreover, the assessment of the YYIR1 requires a minimum of test equipment.

The significant role of non-specific motor coordination parameters in the present longitudinal studies was highlighted. It has already been reported that both non-specific (i.e. three components of the KTK-test battery) as well as soccer-specific motor coordination skills (i.e., UGent dribbling test) did not distinguish between early and late maturing Belgian international soccer players, and that such tests are not related to biological maturation or experience in soccer (Malina *et al.*, 2005; Coelho-e-Silva *et al.*, 2010; Vandendriessche *et al.*, 2012). Moreover, possessing higher levels of motor coordination is beneficial on the long term for aerobic (study 7) and anaerobic performances (study 8). In the present sample of soccer players, it seems that non-specific motor coordination is essential in discriminating players from a high-level training program and drop out players, even from the age of 9 years until late puberty (study 10). Including motor coordination into talent identification programs could prevent the drop out of promising (late maturing) players. Therefore, as suggested by Vandendriessche and colleagues (2012), motor coordination skills should be part of a selection strategy in high-level talent development programs. These non-specific motor coordination tests may provide more insight in the future potential of a young athlete when compared with fitness tests, which mainly highlight the current performance. Therefore, clubs and coaches should think about incorporating specific motor coordination sessions into the regular training scheme of young soccer players, already from a young age. In this reasoning, investing in a more specialized coaching staff (e.g., graduated masters in the physical education) seems necessary to design specific training programmes throughout the season.

During a soccer match, energy delivery is dominated by the aerobic metabolism. However, explosive actions (i.e., short sprints, tackles, jumps and duel play) are covered by means of the anaerobic metabolism, and are often considered crucial for match outcome (Bangsbo, 1994; Wragg *et al.*, 2000; Stølen *et al.*, 2005), but also for future career success in youth and adult soccer (study 10; Vaeyens *et al.*, 2006; Le Gall *et al.*, 2010; Waldron & Murphy, 2013). Whilst speed performances distinguished future successful and less successful soccer players throughout the high-level development program (U10-U17), measures of explosive leg power favour future successful players from the age of 13 years (study 10).

In conclusion, an appropriate test battery to identify and evaluate elite youth soccer players' physical and physiological characteristics should certainly require measures of anthropometry and biological maturation (see previous section), motor coordination, explosive leg power and aerobic endurance. Coaches should be able to administer efficient, valid, reliable fitness tests, which are specific to soccer, with a minimal amount of equipment (Walker & Turner, 2009). For example, the organization of the test sessions in the present dissertation permitted us to assess between 350 and 400 players in one week. ***Table 5*** provides an overview of the organization for a test session assessing about 30 players, conducted on an indoor tartan underground.

Table 5 *Overview of the test battery used in the present dissertation.*

Test	Equipment	n testers	Time
	PART 1		
1. Stature	Stadiometer	2$	45min§
2. Sitting height	Sitting height table		
3. Body mass and body fat*	TANITA-scale	1	
4. KTK$^{\Sigma}$	Wooden boxes and slats	6	
Standardized warming-up			15min
	PART 2¶		
5. CMJ	Optojump	1	45-60min
6. T-test (agility)	Timing gates, cones	1	
7. RSA (4x30m sprint)	Timing gates, chronometer	2	
8. UGent dribbling test	Dribbling mat, cones, chronometer	2	
9. SAR and HGR	SAR-table and dynamometer	1	
10. KTK$^{\Sigma}$ and SBJ	Mat with slat, SBJ-mat, chronometer	2	
	PART 3		
11. YYIR1	Radio, CD with protocol, cones	2-3	30min
TOTAL		*9*	*max 2h30min*

**body fat was measured via bio-electrical impedance; $^{\Sigma}$two components of the KTK-test battery were assessed in part 1: moving boxes and backwards balancing, and one item was conducted in part 2: jumping sideways; $same investigator was used to assess stature and sitting height, the second tester was necessary to write the data down; §players were randomly assigned to a test in part 1, than followed a strict order (from 1 to 4); ¶for an extensive description of the tests in part 2, see the original research section*

2.3 Practical implications and recommendations for the various stakeholders

Based on our findings, in the next section, action points will be suggested for the different actors involved in the talent development process in youth soccer so that every player receives equal opportunities, even if they are relatively younger and/or late to mature. Furthermore, we recommend some interventions 'on the field' for (physical) coaches and scouts based on the development of the physical and physiological characteristics highlighted in this thesis.

2.3.1 Authorities

1. Set up campaigns for the promotion of the general physical development and offer playing and sporting opportunities for every young child. For example, the implementation in elementary schools (6-12 y) of the Flemish Sports Compass, consisting of anthropometrical, physical performance and motor coordination parameters, could give direction to young children which sport they will best suited in (Pion *et al.*, 2014). Also, physical education sessions should provide as many 'movement time' for all children, and offer a large spectrum of different sports.

2. Release budget for smaller, less easily accessible communities to provide proper facilities and accommodations to practice sports, and ensure qualitative follow-up by means of a sports functionary.

2.3.2 Soccer federations

3. Youth academies from professional soccer clubs are expected to develop future elite adult players, already from the age of 6 or 7 years. Due to its large popularity, a massive amount of new entrants (mainly between 6 and 8 years of age) are introduced to the sport of soccer each season. As a consequence, all these new youngsters are not able to benefit from the high standard of the soccer development programme at elite level, thus being disadvantaged at the start of their early soccer career. Therefore, we suggest that it is primarily the task of the soccer federation to develop the youngest players up till the age of 9-10 years, and not the responsibility of the elite clubs. Investments in better development programmes with more qualified coaches at local and regional level are suggested. Also, an overall cooperation with other sports federations would provide chances for a broader athlete development with more chances to appropriate transfers between sports.
4. To reduce the RAE and provide opportunities for all children involved in soccer, we suggest restructuring the competition in its present form for players between 6 and 12 years of age. In practice, competition per se reinforces the RAE as coaches of young soccer teams are still focusing on winning games and therefore select the taller and stronger players within their group. We suggest striving for a more homogenous, regional-based "mini-competition" in two different phases (before and after the Winter break). A club is assigned to a regional group stage with a total of 6 to 8 teams, so that each club plays between 10 and 14 games (total of home and away games). Also, more soccer tournaments and mutual games should be organized so that all players gather playing time, focusing on fun and enjoyment rather than the competition aspect. After the Winter break, each group stage (dependent on the amount of clubs in a particular region) is re-divided so that teams ending in the top three or four of each group stage will play against each other. The same procedure is valid for the last three or four teams of each group stage. The biggest advantage of this organization will be noticeable after the Winter break and will lead to more homogenous group stages, which in turn will increase their perception of success, enjoyment, intrinsic motivation and team spirit. Moreover, regional-based group stage will reduce the travel costs and time.
5. In almost all Belgian national division clubs, the youth teams ranging from U8 to U12 enter into competition with two competitive teams (i.e., A- and B-team). To cope with relative age differences and provide opportunities for all, the A-team could play with players born in the first half of the selection year (i.e., players born from January 1st to June 30th), and the B-team

with players born between July 1st and December 31st. Therefore, clubs should have no other choices to select players equally distributed along the selection year (provided that the birth date distribution of the normal population is equally distributed, which is the case for Belgium).

6. Organize training programs to develop more and better qualified trainers. The federations should provide appropriate education for specialized functions such as scouts and physical coaches, and each club should at least employ one qualified physical coach and several qualified scouts (depending on the level) for the youth academy. Both team and physical coaches, and scouts should be aware of the confounding influence of the RAE during the early stages of childhood in youth sport. A change in mentality imposes itself so that coaches are really aware of this phenomenon.

2.3.3 Clubs

7. Clubs from which the philosophy is to pursue talent development should invest in specialized youth staff members (e.g. physical coaches) who could implement what is known from the literature into practice (e.g., test battery, appropriate interpretation regarding relative age and maturation,…).
8. Given the crucial period from pre- and post- to late adolescence in the physical development of gifted young soccer players, it seems extremely important that both clubs and federation align their players' physical supervision (workload, training content,…), and a good communication is essential.
9. Clubs should formalize a long-term vision for the physical, physiological, psychological and sociological development (Williams & Reilly, 2000) with respect to the players' individual development within the team. This individual approach seems logical and applied at adult level, however in youth, there is much room for improvement, even at elite level. For example, what are the guidelines for the physical preparation during the first competition phase for an U14 youth team? And how does the club deal in the training process with players who are late and early to mature within that particular team? Clear directives for team coaches should be clear.
10. Create a follow-up database with players' information (i.e., "physical passport": anthropometrical characteristics, test outcomes, players history, injuries,…), so that a holistic player s' evaluation is provided.

2.3.4 Coach / physical coach / scout

11. To cope with the constraints of the estimation of APHV, the physical coach should assess anthropometrical parameters on a regular basis (e.g., 6x/year) in players between 11 and 16 years. For example, the difference in stature relative to the previous assessment could be

graphically presented for each player. Increasing differences indicate that the players approach peak height velocity. On the contrary, decreasing differences indicate that players already reached their peak growth. The training process could be aligned according to this valuable information (cf. LTAD; Balyi & Hamilton, 2004). Obviously, charting the individual growth curves is one of the tasks of a qualified physical coach.

12. Implementation of an appropriate test battery with reliable and valid tests is recommended to map the strengths and weaknesses of each player. Furthermore, appropriate benchmarks are required to evaluate a player in terms of his relative age and maturity status.
13. Provide opportunities (playing time, enjoyment) for every player, not only the tallest and strongest as the benefits for the latter players are just temporary. Eventually, each player will reach the mature status. Instead, focus on tactical and technical characteristics (team coaches and scouts). Do not systematically exclude the late born and late maturing players.
14. Do not select players into a specific positional role already from an early age (e.g., 9 years of age). Keep rotating until late puberty and implement from then on specialized positional training. Our results showed that from the age groups U15-U17 (i.e., after peak height velocity), it is still possible to select or reject players into specific positions, as players are able to fully develop their physical and physiological potential. Moreover, explosive leg power is one of the physiological parameters necessary to develop a successful future professional soccer career.
15. Non-specific motor coordination has proven its significant contribution in the development of aerobic and anaerobic characteristics, and high discriminative ability to distinguish between future elite and drop-out players form the age of 9 years on. Therefore, we suggest the implementation of specific motor coordination training sessions (e.g., as a training session on its own, or implemented in each soccer warming-up) even before the age of 9 years so a high level of motor coordination can be reached. Also, practicing other sports (e.g., during Summer and Winter break, or several sessions during season) is recommended as part of a total athlete development, which will be beneficial for the total stability and prevention of injuries.

2.3.5 Player evaluation

During the research years of the present dissertation, we developed a useful tool to map the strengths and weaknesses for each player at each test session which provides the coach to evaluate, interpret and monitor the progress of his anthropometrical, maturational, motor coordination, aerobic and anaerobic performance parameters. This scoresheet (see below, ***Figure 5***) was based on test scores (for each test and chronological age) and benchmarks (percentiles) are provided by means of six colours (***Figure 4***).

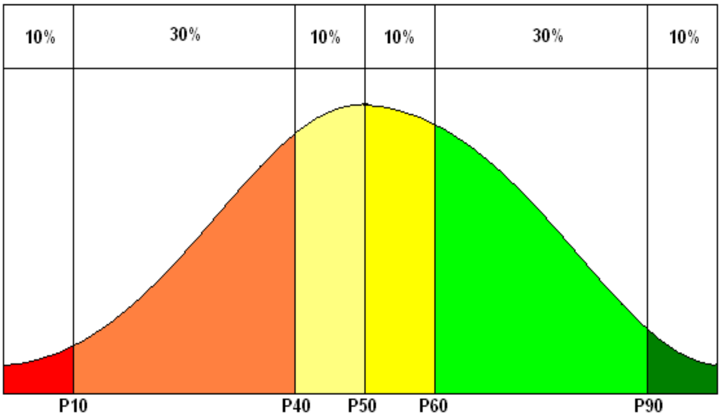

Figure 4 *Benchmark colours according to percentile scores*

Obviously, red tinted colours are scores between percentile (P) 1 and P40, green tinted scores are better and between P60 and P100. Yellow tinted scores are labelled as average. A score for a test marked dark green belongs to the top 10%-score for this particular test.

In the next section, the usefulness of the scoresheet will be explained according to the testresults of an U16 player:

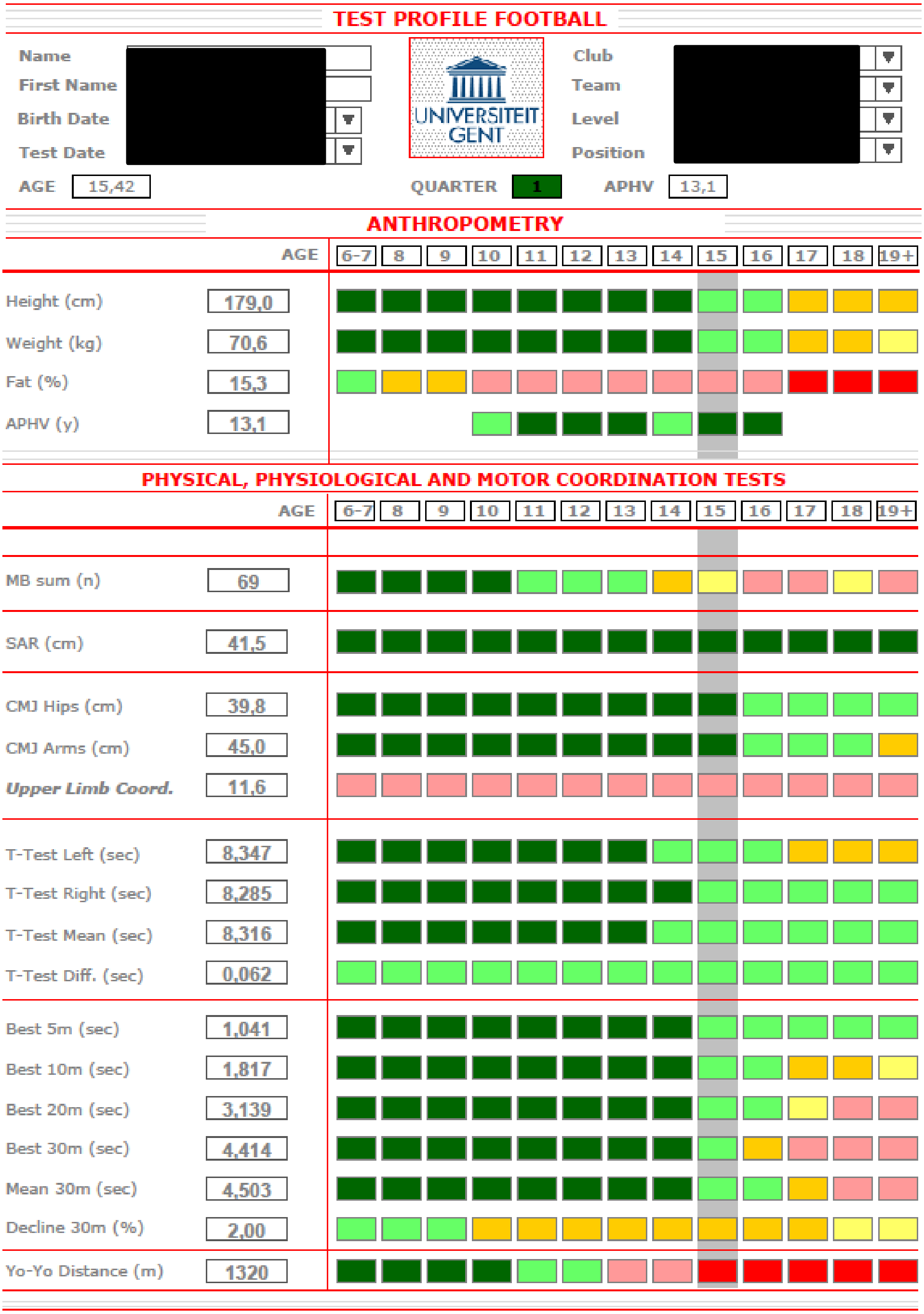

Figure 5 *Score sheet of an individual player*

Explanation:

- Heading: personal characteristics like name, date of birth…
- The grey coloured, vertical band represents the chronological age band the player belongs to. The colours in all other age bands represents the player's score (for a particular test) in comparison with chronologically younger or older players. For example, the player's score on the YYIR1 (i.e., 1320m) is coloured dark red in comparison with his age-matched peers, and is coloured light green when compared with a 12-year-old (see next point).
- Quarter and APHV: the birth quarter (i.e., 1 to 4) the player is born in, and the estimation of the age at peak height velocity (i.e., APHV via Mirwald), respectively. APHV is coloured (in the section 'anthropometry') to label the player as earlier (shades of green), average (shades of yellow) or later mature (shades of red). For example, a player born in the fourth birth quarter who is late to mature should not be evaluated with his chronological age-matched peers, but perhaps with peers who are one or two years younger. That is the reason to put all chronological age categories into the scoresheet.
- Obviously, green tinted scores are strengths, red tinted scored are weaknesses, and form the basis of the development of an individual working plan (besides the collective team training). The scoresheet of the next test session could be evaluated in terms of progress and longitudinal follow-up. For example, this particular player needs to work on his aerobic endurance and general motor coordination in the period before the next test session. The physical coach of the club could design this player's individual program and work with him before, during or after collective training session, depending on the training contents.

2.3.6 Practical training guidelines

In the literature, there is no evidence that strictly following certain guidelines in youth soccer providing number of weeks of training, sessions a week, hours a week, hours a year… eventually will lead to success in adult soccer. For example, if we take the 10.000 hours-rule (or 1000 hours a year for 10 years) of Ericsson et al. (1993) into account, none of the elite clubs in Belgium does meet this criterion. Other development models, like the LTAD from Balyi and Hamilton (2004) have never been evidenced. Moreover, The LTAD-model (Balyi & Hamilton, 2004) was recently criticized by McNarry *et al*. (2014), who stated that aerobic fitness, speed and strength are trainable throughout maturation and that many studies, which have purportedly observed a maturational threshold (or trigger point), may imply have used an insufficient training dose (duration and/or intensity) in the younger participants, thereby supporting an artificial influence of maturation. More pronounced adaptations during puberty may be related to a greater overall training dose (i.e., longer duration of training and/or higher baseline fitness/physical activity levels) rather than to physiological changes associated with puberty *per se*. The principle of the 'windows of opportunity' was also disproved by Ford *et al.* (2011) who support a more individualized approach with certain periods of 'training emphasis', along the training process to advance all fitness components during childhood and adolescence. For example, the present thesis has proven that the training of motor coordination significantly influences aerobic and anaerobic parameters from late childhood to late adolescence, and not only during the 'window of accelerated adaptation for motor coordination' between 9 and 12 years (Balyi & Hamilton, 2004). Also, estimated velocities for fitness tests (i.e., aerobic fitness, strength and speed) tend to reach their peak around the time of maximal growth of height (i.e., APHV) (Philippaerts *et al*., 2006). In the context of talent identification and development, coaches should be aware of the characteristics of the growth spurt and recognize that changes in growth and performance at this time are highly individualized. Does this mean that soccer-specific training should be implemented at particular maturational stages or 'sensitive periods'? Likely not, although training stimuli with respect to appropriate training volume and intensity should be taken into account. For example, in the growth spurt, a player's imbalance between the development of his long bones (e.g., tibia and fibula) on the one hand and muscles and tendons on the other, implies a reduction in training stimuli in both volume and intensity for a relatively short period. But, as mentioned before, this requires the knowledge of the individual growth curve.

Despite these obstacles, clubs and coaches could benefit from general developmental guidelines from childhood to late adolescence that emerged from the present disseratation and experience on the field. ***Table 6*** provides an overview of the basic physiological characteristics from which chronological age they can/may be trained at.

Table 6 Trainable basic physiological parameters according to chronological age.

Parameter	7	8	9	10	11	12	13	14	15	16	17
Motor coordination	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Aerobic fitness											
Endurance	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Interval											
Extensive							✔	✔	✔	✔	✔
Intensive									✔	✔	✔
Speed											
Maximal/reaction	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Endurance/repeated									✔	✔	✔
Strength											
Endurance					✔	✔	✔	✔	✔	✔	✔
Maximal							✔	✔	✔	✔	✔
Explosive/power									✔	✔	✔
Flexibility	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

3. LIMITATIONS

Although the present thesis is multidimensional as we assessed physical and physiological predictors of talent, the psychological (i.e., tactical, perceptual-cognitive parameters, personality, task-ego orientation,…) and sociological (i.e., role of the parents/coaches, training experience,…) predictors of talent in soccer as described by the model of Williams and Reilly (2000) were not explicitly studied in this thesis. The contribution of these factors in the road to expertise has been described by many others (for reviews see Helsen *et al.*, 2000; Morris, 2000; Williams, 2000; Abbott & Collins, 2004; Mann *et al.*, 2007). For example, Abbott & Collins (2004) stated that a greater emphasis on psychological factors would appear to be required within talent identification and development processes as opposed to relying on physical and anthropometrical indicators of talent. However, as some belief that it takes ten years of dedicated practice to achieve excellence (Ericsson *et al.*, 1993), not only does an athlete require the capacity to perform, but also both the capacity and the motivation to acquire and refine skills, and to develop within a specific sporting setting with its inherent psychosocial complexity.

The fourth study in this dissertation already confirmed the poor agreement between maturity categories based on invasive and non-invasive methods (Malina & Koziel, 2014). The equation developed by Mirwald *et al.* (2002) provides an accurate estimation of APHV for boys, average in maturity status, who are around peak height velocity (13-15 years). The use of the maturity-offset protocol has extensively been used in youth soccer populations (Buchheit *et al.*, 2010; Mendez-Villanueva *et al.* 2010; 2011; Vandendriessche *et al.*, 2012; Moreira *et al.*, 2013). Also, in the present soccer population, maturation does not affect aerobic endurance and some measures of explosive leg power, and does not distinguish between future successful and less successful players. This demonstrates again the extreme homogeneity in biological maturation in the present soccer players. Further studies need to consider the assessment of skeletal age as the 'golden standard' of maturity status, although the assessment has associated expenses, requires trained observers and implies a low dose of radiation exposure.

4. CONCLUSIONS

Most sporting organizations begin talent identification programmes between the onset and completion of puberty. However, these players already passed a first latent selection mechanism, called the relative age effect. Many 'gifted' players with the potential to become elite athletes may have already dropped out of the sport or experienced lower levels of training and competition only because they are born later in the selection year. To provide equal changes for any youngster, a talent identification model emerged from the present thesis based on physical and physiological predictors of soccer talent (Williams & Reilly, 2000), and the talent identification models of Balyi & Hamilton (2004), Gagné (2004) and Coté and colleagues (2007) (***Figure 4***).

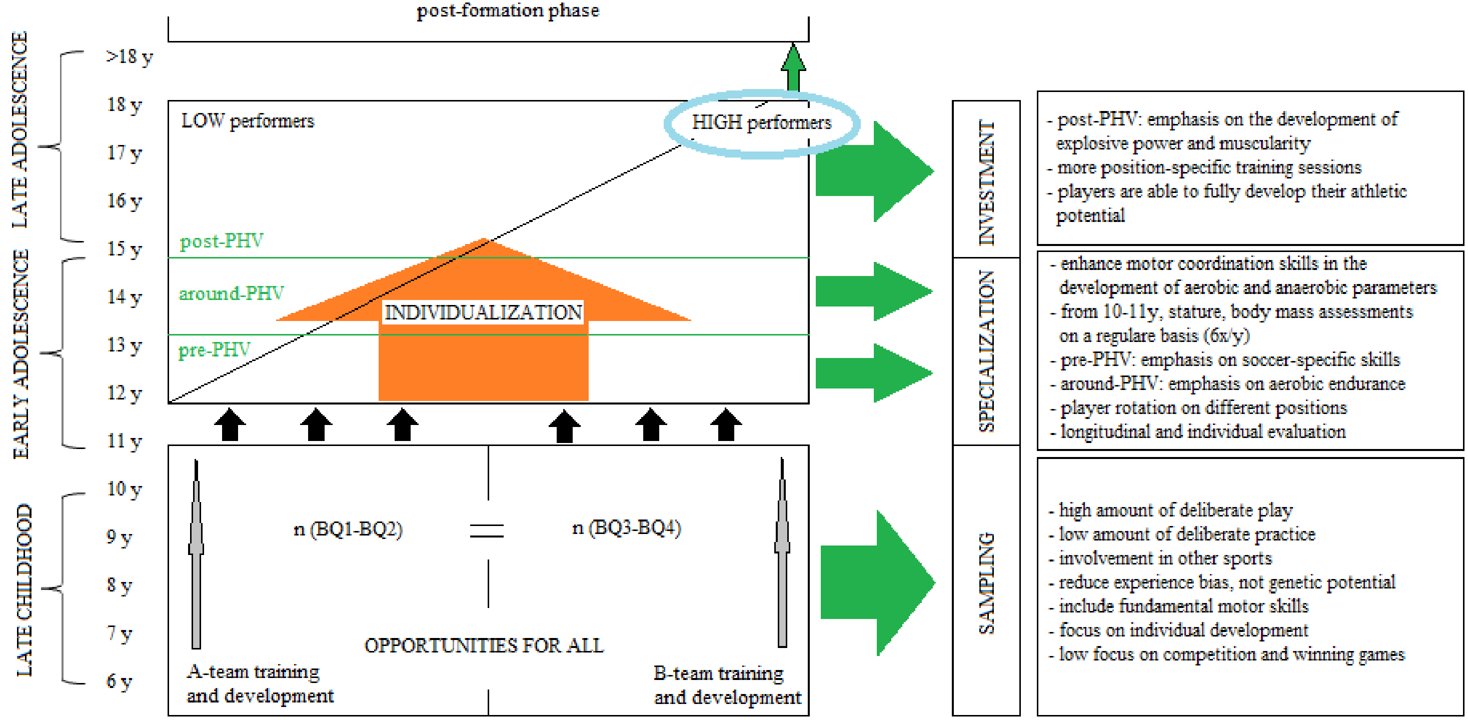

Figure 6 *Long-term model for physical and physiological development (“LPDM”).*

Long-term physical and physiological development model (LPDM)

As mentioned above, the presented LPDM is obviously related to other talent development models described in the literature and should be seen as a 'work in progress' (Balyi & Hamilton, 2004; Gagné, 2004; Coté *et al.*, 2007) (see the 'general introduction' section for a brief review). In this model we adopted the framework of Coté *et al.* (2007) and followed the early diversification pathway to reach expertise. Although, a review recently showed that elite youth soccer players and later professionals participate in other sports only to a small degree (Haugaasen & Joret, 2012). However, there may be some advantages to general or diverse practice that need to be taken into account, such as injury prevention, general physical and psychological development and its suggested effect on motivation and burn-out (Wiersma, 2000). Also, with respect to the model of Balyi and Hamilton (2004), athletic development from childhood into adulthood is characterized by certain sensitive periods of accelerated adaptation ('*windows of opportunity'*) to speed, motor competence, strength, endurance and suppleness, associated with growth and maturation (LTAD). However, the LTAD model was recently criticized given the lack of empirical evidence for the LTAD model due to the large number of physiological factors that influence performance (Ford *et al.*, 2011). Therefore, the authors support a more individualized approach with certain periods of '*training emphasis*' (see ***Figure 4***), along the training process to advance all fitness components during childhood and adolescence. Finally, Gagné (2004) showed in his DMGT-model that a certain degree (top 10 percent → see blue circle in Figure 4) of 'natural abilities' is critical to end up as being 'talented', which indicates a large influence of heritability in the developmental progress in young children.

The novelty in the present model compared to the other described above, is the exclusion of the relative age effect by providing opportunities for all young children. This particular procedure was already explained in abovementioned sections. Although, we are aware that this will entail the re-education of coaches to shift their focus from early success and selection to appropriate development as current performance is different from adult potential.

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APPENDIX 1

Appendix 1 *Overview of anthropometrical characteristics (i.e., stature and weight) of youth soccer players according to age and level.*

Study	**Nationality**	**Level**	**Age**	**Position***	***n***	**Stature (cm)**	**Weight (kg)**
Malina *et al*. [2000]	Portugal	Regional	11-12 y	--	*63*	1.51 ± 0.08 (range 1.37 to1.76)	43.1 ± 7.0 (range30.5 to 64.5)
			13-14 y	--	*29*	1.63 ± 0.08 (range 1.51 to 1.77)	52.5 ± 8.7 (range 40.6 to 77.9)
			15-16 y	--	*36*	1.74 ± 0.06 (range 1.61 to 1.88)	64.1 ± 5.3 (range 53.5 to 81.1)
Malina *et al*. [2004]	Portugal	Elite	14 y	DF	*29*	169.2 ± 7.5	57.3 ± 7.8
				MF	*30*	165.4 ± 9.0	54.5 ± 9.8
				FW	*10*	170.8 ± 9.9	61.4 ± 9.2
Vaeyens *et al.* [2006]	Belgium	Elite	U13	--	*48*	151.8 ± 6.6	40.3 ± 6.1
			U14	--	*32*	157.7 ± 8.4	44.3 ± 6.5
			U15	--	*37*	167.5 ± 8.8	53.4 ± 9.6
			U16	--	*35*	171.7 ± 7.4	57.9 ± 8.2
		Sub-Elite	U13	--	*25*	151.5 ± 5.8	40.8 ± 4.8
			U14	--	*38*	161.3 ± 7.7	48.0 ± 7.8
			U15	--	*25*	167.9 ± 7.5	52.9 ± 8.5
			U16	--	*13*	174.0 ± 8.3	60.6 ± 9.8
		Non-Elite	U13	--	*29*	153.5 ± 7.6	42.3 ± 8.7
			U14	--	*41*	160.5 ± 8.4	46.7 ± 8.8
			U15	--	*33*	168.4 ± 9.2	54.5 ± 10.6
			U16	--	*18*	175.1 ± 7.9	60.5 ± 9.4
Gil *et al.* [2007a]	Spain	Regional	17 y	GK	*29*	179.5 ± 5.9	74.0 ± 7.9
				DF	*77*	175.5 ± 7.6	68.9 ± 9.1
				MF	*79*	174.7 ± 7.6	68.5 ± 9.7
				FW	*56*	174.8 ± 6.8	68.4 ± 9.1
Figueiredo *et al*. [2009a]	Portugal	Regional	11 y	--	*87*	144.6 ± 6.7	38.1 ± 6.2
			14 y	--	*72*	163.5 ± 9.3	54.1 ± 10.1
Figueiredo *et al*. [2009b]	Portugal	Drop-out	12 y	--	*21*	143.6 ± 6.1	39.5 ± 6.4
		Club	12 y	--	*54*	143.7 ± 5.9	36.5 ± 5.0
		Elite	12 y	--	*12*	150.8 ± 8.3	42.4 ± 8.3
Hirose [2009]	Japan	Elite	U10	--	*34*	135.6 ± 4.5	30.2 ± 2.9

			U11	--	*52*	141.1 ± 5.5	33.7 ± 3.8
			U12	--	*66*	147.9 ± 6.5	37.8 ± 4.8
			U13	--	*92*	158.5 ± 7.9	47.1 ± 8.1
			U14	--	*47*	164.4 ± 7.4	51.9 ± 7.5
			U15	--	*41*	167.9 ± 6.7	59.0 ± 7.5
Wong *et al*. [2009a]	China	Elite	U14	GK	*10*	1.69 ± 0.06	54.6 ± 7.3
				DF	*20*	1.67 ± 0.07	56.2 ± 6.2
				MF	*25*	1.65 ± 0.08	52.2 ± 9.6
				FW	*15*	1.56 ± 0.11	43.9 ± 9.5
Coelho-e-Silva *et al*. [2010]	Portugal	Local	U14	--	*69*	158.6 ± 8.2	48.6 ± 8.9
		Elite	U14	--	*45*	167.1 ± 6.9	56.7 ± 5.7
Le Gall *et al*. [2010]	France	International	U14	--	*16*	162.6 ± 10.5	52.5 ± 9.9
			U15	--	*16*	171.5 ± 9.4	59.3 ± 10.3
			U16	--	*16*	176.1 ± 7.5	65.3 ± 8.8
		Professional	U14	--	*56*	165.0 ± 8.8	53.8 ± 9.5
			U15	--	*54*	170.8 ± 8.0	60.3 ± 9.2
			U16	--	*57*	175.3 ± 8.2	66.0 ± 8.2
		Amateur	U14	--	*89*	162.1 ± 9.0	50.8 ± 9.2
			U15	--	*76*	169.1 ± 8.2	58.8 ± 9.2
			U16	--	*70*	169.1 ± 8.2	58.8 ± 9.2
Vandendriessche *et al.* [2012]	Belgium	International	U16	--	*18*	175.4 ± 8.5	64.0 ± 6.8
		Futures$^{\Sigma}$		--	*19*	167.9 ± 6.3	54.4 ± 6.4
		International	U17	--	*21*	176.8 ± 5.9	67.9 ± 6.7
		Futures$^{\Sigma}$		--	*15*	167.8 ± 4.8	53.2 ± 5.1
Rebelo *et al.* [2013]	Portugal	Elite	U19	GK	*9*	178.1 ± 4.6	78.7 ± 8.1
				CD	*13*	183.3 ± 3.6	78.0 ± 6.6
				FB	*14*	174.7 ± 5.7	69.3 ± 6.5
				MF	*38*	174.8 ± 7.1	71.6 ± 7.1
				FW	*21*	175.1 ± 6.8	71.7 ± 7.4
		Non-Elite	U19	GK	*9*	174.5 ± 3.7	70.4 ± 7.6
				CD	*13*	178.1 ± 6.6	73.1 ± 7.8
				FB	*13*	171.2 ± 6.6	68.4 ± 7.0

				MF	*30*	173.7 ± 5.8	66.6 ± 8.5
				FW	*20*	173.1 ± 6.5	68.3 ± 6.5
Fidelix *et al*. [2014]	Brazil	Elite	16 y	GK	*7*	188.0 ± 2.6	80.5 ± 4.3
				DF	*22*	177.6 ± 6.5	69.9 ± 7.9
				MF	*20*	175.9 ± 5.8	68.6 ± 7.0
				FW	*18*	175.8 ± 6.9	70.2 ± 9.2
Lago-Penas *et al*. [2014]	Spain	Regional	15 y	GK	*16*	169.9 ± 12.1	64.3 ± 10.2
				FB	*29*	164.2 ± 9.8	55.8 ± 10.9
				CDF	*26*	173.3 ± 10.4	68.2 ± 10.9
				EMF	*28*	164.1 ± 10.0	54.5 ± 10.9
				CMF	*34*	161.9 ± 10.8	54.4 ± 12.4
				FW	*23*	166.6 ± 10.3	61.5 ± 12.1

**GK: goalkeeper, DF: defender, CD: central defender, FB: full-back, MF: midfielder, CMF: central midfielder, EMF: external midfielder, FW: forward;* $^{\Sigma}$*these players are international level, although late maturing (based on maturity offset; Mirwald et al., 2002)*

APPENDIX 2

Appendix 2 *Percentage of youth soccer players classified as advanced, average, late or mature in maturity status based on skeletal age (SA).*

Study	**Nationality**	**Level**	**Protocol**	**Age**	***n***	**Maturity status***			
						Late	**Average**	**Advanced**	**Mature**
Malina *et al*. [2000]	Portugal	Regional	Fels	11-12 y	*63*	20.6	58.7	20.7	0
				13-14 y	*29*	6.9	55.2	37.9	0
				15-16 y	*43*	2.3	32.6	48.8	16.3
Malina *et al*. [2007]	Spain	Elite	Fels	12-16 y	*40*	0	35	60	5
			Tanner-Whitehouse 3	12-16 y	*40*	2.5	47.5	22.5	27.5
Figueiredo *et al*. [2009b]	Portugal	Regional	Fels	11-12 y	*87*	19.5	51.7	28.8	0
				13-14 y	*72*	6	63	31	0
Hirose [2009]	Japan	Elite	Tanner-Whitehouse 2#	U10	*34*	41.2	44.1	14.7	0
				U11	*52*	19.2	63.5	17.3	0
				U12	*66*	10.6	63.6	25.8	0
				U13	*92*	9.8	58.7	30.4	1.1
				U14	*47*	2.1	63.9	31.9	2.1
				U15	*41*	9.8	53.6	4.9	31.7
Coelho-e-Silva *et al*. [2010]	Portugal	Local	Fels	U14	*69*	10.1	58	31.9	0
		Elite		U14	*45*	0	46.7	53.3	0
Malina *et al*. [2010]	Portugal-Spain	Elite-Regional	Fels	11 y	*82*	20	52	28	0
				12 y	*84*	20	55	25	0
				13 y	*111*	8	57	35	0
				14 y	*92*	9	58	34	0
				15 y	*126*	6	36	50	8
				16 y	*74*	9	45	23	23
				17 y	*23*	0	61	0	39
Carling *et al*. [2012]	France	Regional	Greulich-Pyle	U14	*158*	16	62	22	0
Hirose & Hirano [2012]	Japan	Elite	Tanner-Whitehouse 2#	U10	*17*	35.3	52.9	11.8	0
				U11	*28*	10.7	75	14.3	0
				U12	*44*	9.1	70.5	20.5	0
				U13	*31*	6.5	35.5	58.1	0
				U14	*28*	7.1	71.4	17.9	3.6
				U15	*26*	11.5	76.9	0	11.5
				U16	*7*	0	28.6	0	71.4

			Tanner-Whitehouse 3	U10	*17*	52.9	47.1	0	0
				U11	*28*	28.6	64.3	7.1	0
				U12	*44*	36.4	52.3	11.4	0
				U13	*31*	9.7	25.8	64.5	0
				U14	*28*	14.3	46.4	35.7	3.6
				U15	*26*	3.8	61.5	23.1	11.5
				U16	*7*	0	28.6	0	71.4
Malina *et al*. [2012]	Portugal	Regional	Fels	11-12 y	*87*	19.5	51.7	28.8	0
				13-14 y	*93*	4.3	59.1	36.6	0
Valente-dos-Santos *et al*. [2012a; 2012b; 2012d]	Portugal	Regional	Fels	11 y	*40*	15	57.5	27.5	0
				12 y	*57*	15.8	57.9	26.3	0
				13 y	*83*	13.3	57.8	28.9	0
				14 y	*80*	13.8	56.3	29.9	0
				15 y	*66*	10.6	57.6	31.8	0
				16 y	*30*	13.3	53.3	33.4	0
				17 y	*10*	0	60	40	0

**Based on the difference between chronological (CA) and skeletal age (SA): advanced (SA minus CA > 1.0 y), average (SA within ±1.0 y of CA) and late (SA minus CA < 1.0 y). SA at the mature status differs according to the method used: Fels (SA ≥ 18.0 y; Roche et al., 1988), TW2 (SA ≥ 18.1 y; Tanner et al., 1983), TW3 (SA ≥ 16.5 y; Tanner et al., 2001), GP (SA ≥ 19.0 y Greulich & Pyle, 1959)*

#To convert radius-ulna-short bone (RUS) score of TW2 into SA, standardized conversion tables for the Japanese population ascribed by Murata et al. (1993) were used. Mature status was reached as SA ≥16.0 y.

APPENDIX 3

Appendix 3 *Overview of aerobic fitness characteristics of youth soccer players according to age and level.*

Study	Nationality	Level	Measure	Age	Position*	*n*	Score
Baxter-Jones *et al*. [1993]	England	Elite	VO_2max	13.1 ± 0.7 y	--	*13*	55.7 ± 3.7 $ml.min^{-1}.kg^{-1}$
				13.7 ± 0.9 y	--	*27*	55.7 ± 4.0 $ml.min^{-1}.kg^{-1}$
				15.9 ± 1.4 y	--	*77*	61.5 ± 4.9 $ml.min^{-1}.kg^{-1}$
Bunc & Psotta [2001]	Czech Republic	Elite	VO_2max	8 y	--	*22*	56.7 ± 4.9 $ml.min^{-1}.kg^{-1}$
Hansen *et al.* [2004]	Denmark	Elite	VO_2max	12 y	--	*21*	58.2 ± 6.7 $ml.min^{-1}.kg^{-1}$
				14 y	--	*21*	62.6 ± 6.5 $ml.min^{-1}.kg^{-1}$
		Non-Elite		12 y	--	*28*	55.3 ± 6.7 $ml.min^{-1}.kg^{-1}$
				14 y	--	*28*	55.9 ± 6.6 $ml.min^{-1}.kg^{-1}$
Vaeyens *et al.* [2006]	Belgium	Elite	$EHSR^{\Sigma}$	U13	--	*41*	8.5 ± 1.5 min
				U14	--	*32*	9.5 ± 1.4 min
				U15	--	*37*	10.8 ± 1.2 min
				U16	--	*33*	11.2 ± 1.6 min
		Sub-Elite		U13	--	*24*	8.2 ± 1.6 min
				U14	--	*38*	9.2 ± 0.9 min
				U15	--	*25*	9.4 ± 1.4 min
				U16	--	*12*	9.8 ± 1.0 min
		Non-Elite		U13	--	*31*	7.6 ± 1.4 min
				U14	--	*41*	8.2 ± 1.4 min
				U15	--	*32*	8.7 ± 1.7 min
				U16	--	*15*	9.3 ± 1.6 min
Visscher *et al*. [2006]	Netherlands	Elite	$ISRT^{\infty}$	12-15 y	--	*18*	86.1 ± 16.4 runs
				16-18 y	--	*28*	90.2 ± 23.7 runs
		Sub-Elite		12-15 y	--	*88*	75.6 ± 20.3 runs
				16-18 y	--	*79*	87.8 ± 19.0 runs
Gil *et al*. [2007a]	Spain	Regional	VO_2max	17 y	GK	*29*	48.4 ± 11.1 $ml.min^{-1}.kg^{-1}$
					DF	*77*	58.6 ± 9.5 $ml.min^{-1}.kg^{-1}$
					MF	*79*	57.7 ± 9.9 $ml.min^{-1}.kg^{-1}$

					FW	*56*	62.4 ± 10.8 $ml.min^{-1}.kg^{-1}$
Gil *et al*. [2007b]	Spain	Selected	VO_2max	14 y	--	*29*	56 ± 2 $ml.min^{-1}.kg^{-1}$
				15 y	--	*36*	58 ± 2 $ml.min^{-1}.kg^{-1}$
				16 y	--	*29*	53 ± 3 $ml.min^{-1}.kg^{-1}$
				17 y	--	*32*	62 ± 5 $ml.min^{-1}.kg^{-1}$
		Non-Selected		14 y	--	*19*	48 ± 3 $ml.min^{-1}.kg^{-1}$
				15 y	--	*17*	57 ± 3 $ml.min^{-1}.kg^{-1}$
				16 y	--	*12*	57 ± 5 $ml.min^{-1}.kg^{-1}$
				17 y	--	*20*	57 ± 3 $ml.min^{-1}.kg^{-1}$
Gravina *et al*. [2008]	Spain	Elite first team	VO_2max	10-14 y	--	*44*	Range 56.10 to 57.74 $ml.min^{-1}.kg^{-1}$
		Elite reserve			--	*22*	Range 56.58 to 58.85 $ml.min^{-1}.kg^{-1}$
Carling *et al*. [2009]	France	Elite	VO_2max	13 y	--	*160*	Range 56.8 to 58.5 $ml.min^{-1}.kg^{-1}$
Wong & Wong [2009]	China	Elite	VO_2max	16 y	--	*16*	60.5 ± 5.4 $ml.min^{-1}.kg^{-1}$
Coelho-e-Silva *et al*. [2010]	Portugal	Local	YYIE1[¥]	13 y	--	*69*	2272 ± 762 m
		Elite			--	*45*	2338 ± 792 m
		Local-Elite		13 y	DF	*48*	2441 ± 803 m
					MF	*37*	2218 ± 810 m
					FW	*29*	2163 ± 641 m
Le Gall *et al*. [2010]	France	International	VO_2max	U14	--	*16*	59.2 ± 3.2 $ml.min^{-1}.kg^{-1}$
				U15	--	*16*	61.5 ± 3.9 $ml.min^{-1}.kg^{-1}$
				U16	--	*16*	62.4 ± 2.7 $ml.min^{-1}.kg^{-1}$
		Professional		U14	--	*56*	58.2 ± 2.7 $ml.min^{-1}.kg^{-1}$
				U15	--	*54*	59.9 ± 2.7 $ml.min^{-1}.kg^{-1}$
				U16	--	*57*	62.2 ± 3.2 $ml.min^{-1}.kg^{-1}$
		Amateur		U14	--	*89*	57.8 ± 2.8 $ml.min^{-1}.kg^{-1}$
				U15	--	*76*	60.1 ± 3.6 $ml.min^{-1}.kg^{-1}$
				U16	--	*70*	61.7 ± 3.7 $ml.min^{-1}.kg^{-1}$
Roescher *et al*. [2010]	Netherlands	Professional	ISRT[∞]	14 y	--	*11*	67.6 ± 15.6 runs
				15 y	--	*22*	81.6 ± 15.8 runs
				16 y	--	*17*	90.5 ± 23.4 runs
				17 y	--	*27*	99.3 ± 21.1 runs

				18 y	--	*27*	108.6 ± 18.8 runs
		Non-Professional		14 y	--	*15*	72.5 ± 18.2 runs
				15 y	--	*28*	83.5 ± 18.7 runs
				16 y	--	*28*	85.4 ± 19.3 runs
				17 y	--	*28*	88.3 ± 18.7 runs
				18 y	--	*26*	92.7 ± 22.0 runs
Markovic & Mikulic [2011]	Croatia	Elite	YYIR1[£]	U13	--	*17*	933 ± 241 m
				U14	--	*16*	1000 ± 202 m
				U15	--	*21*	1184 ± 345 m
				U16	--	*14*	1538 ± 428 m
				U17	--	*20*	1581 ± 390 m
				U18	--	*14*	1800 ± 415 m
				U19	--	*15*	2128 ± 326 m
Valente-dos-Santos *et al*. [2012a]	Portugal	Elite	EHSR[Σ]	11 y	--	*40*	680 ± 360 m
				12 y	--	*57*	960 ± 360 m
				13 y	--	*83*	1140 ± 320 m
				14 y	--	*80*	1320 ± 380 m
				15 y	--	*66*	1520 ± 320 m
				16 y	--	*30*	1620 ± 220 m
				17 y	--	*10*	1720 ± 120 m
Moreira *et al*. [2013]	Brazil	Elite	YYIE1[¥]	U12	--	*23*	1626 ± 382 m
				U13	--	*22*	1747 ± 302 m

**GK: goalkeeper, DF: defender, MF: midfielder, FW: forward; [Σ]ESHR: endurance shuttle run (Council of Europe, 1988); [∞]ISRT: interval shuttle run test (Stolen et al., 2005); [¥]YYIE1: yo-yo intermittend endurance test level 1 (Bangsbo, 1994); [£]YYIR1: yo-yo intermittent recovery test level 1 (Krustrup et al., 2003)*

APPENDIX 4

Appendix 4 *Overview of anaerobic performances (jump performances, muscle strength and sprint performances) across different levels and countries.*

Study	Nationality	Level	Protocol	Age	*n*	Performance
			JUMP PERFORMANCES			
Moreira *et al*. [2013]	Brazil	Elite	CMJ hips*	U12-U13	*45*	from 34.8 ± 5.2 cm to 35.9 ± 5.3 cm[#]
Carling *et al*. [2009]	France	Elite	CMJ arms[Σ]	U14	*160*	from 41.9 ± 5.9 cm to 44.1 ± 6.9 cm[¥]
Figueiredo *et al*. [2010a; b]	Portugal	Elite	CMJ hips*	11-12 y	*75*	26.0 ± 4.0 cm
				13-14 y	*68*	32.0 ± 4.9 cm
Coelho-e-Silva *et al*. [2010]	Portugal	Elite	Squat jump	U14	*45*	31.2 ± 5.1 cm
		Local			*69*	27.1 ± 4.4 cm
Malina *et al*. [2004]	Portugal	Elite	CMJ hips*	13-15 y	*69*	29.3 ± 4.6 cm
Deprez *et al*. [2013]	Belgium	Elite	CMJ hips*	U13	*146*	from 23.3 ± 3.6 cm to 24.6 ± 2.6 cm[¥]
				U15	*162*	from 26.7 ± 4.5 cm to 29.2 ± 3.8 cm[¥]
				U17	*247*	from 32.9 ± 4.3 cm to 34.5 ± 4.5 cm[¥]
			SBJ[√]	U13	*146*	from 173 ± 10 cm to 177 ± 14 cm[¥]
				U15	*162*	from 190 ± 16 cm to 196 ± 18 cm[¥]
				U17	*247*	from 214 ± 17 cm to 221 ± 18 cm[¥]
Fernandez-Gonzalo *et al*. [2010]	Spain	Regional	CMJ hips*	U10	*15*	26.5 ± 6.2 cm
				U12	*15*	43.2 ± 11.7 cm
			CMJ arms[Σ]	U10	*15*	30.0 ± 6.8 cm
				U12	*15*	44.4 ± 9.7 cm
			Squat jump	U10	*15*	21.7 ± 5.3 cm
				U12	*15*	40.1 ± 10.4 cm
			Drop jump	U10	*15*	24.4 ± 4.1 cm
				U12	*15*	26.3 ± 5.4 cm
Vandendriessche *et al*. [2012]	Belgium	National	CMJ hips*	U16	*18*	35.4 ± 3.5 cm
				U16 F[$]	*19*	30.9 ± 4.6 cm
				U17	*21*	36.3 ± 3.8 cm
				U17 F[$]	*15*	31.8 ± 4.4 cm
			SBJ[√]	U16	*18*	223.6 ± 11.0 cm
				U16 F[$]	*19*	205.1 ± 13.2 cm
				U17	*21*	230.0 ± 15.7 cm
				U17 F[$]	*15*	211.1 ± 12.1 cm
Valente-dos-Santos *et al*. [2012c]	Portugal	Elite	CMJ hips*	11 y	*40*	25.6 ± 4.2 cm
				12 y	*57*	27.8 ± 5.0 cm
				13 y	*83*	30.6 ± 5.3 cm
				14 y	*80*	32.9 ± 5.0 cm
				15 y	*66*	35.3 ± 4.7 cm
				16 y	*30*	37.3 ± 5.6 cm
				17 y	*10*	35.9 ± 2.6 cm
Vänttinen *et al*. [2010]	Finland	Regional	CMJ hips*	10 y	*12*	27.8 ± 4.2 cm

				12 y	*12*	29.5 ± 3.4 cm
				14 y	*12*	35.8 ± 4.2 cm
Figueiredo *et al*. [2009a]	Portugal	Elite	CMJ hips*	11-12 y	*12*	29.0 ± 4.4 cm
		Club			*54*	25.8 ± 4.1 cm
		Drop-out			*21*	25.5 ± 5.3 cm
		Elite	Squat jump	13-14 y	*21*	27.0 ± 3.9 cm
		Club			*36*	23.4 ± 4.0 cm
		Drop-out			*15*	22.8 ± 4.6 cm
Le Gall *et al*. [2010]	France	International	CMJ arms$^{\Sigma}$	U14	*16*	43.7 ± 7.3 cm
		Professional			*56*	42.6 ± 5.8 cm
		Amateur			*89*	42.8 ± 5.5 cm
		International		U15	*16*	47.9 ± 6.1 cm
		Professional			*54*	46.3 ± 5.5 cm
		Amateur			*76*	45.1 ± 5.3 cm
		International		U16	*16*	50.6 ± 6.4 cm
		Professional			*57*	49.4 ± 5.7 cm
		Amateur			*70*	47.8 ± 4.9 cm
Vaeyens *et al*. [2006]	Belgium	Elite	CMJ hips*	U13	*47*	33.7 ± 4.7 cm
		Sub-elite			*28*	32.6 ± 5.2 cm
		Non-elite			*31*	30.8 ± 4.4 cm
		Elite		U14	*34*	37.1 ± 5.4 cm
		Sub-elite			*41*	37.0 ± 4.4 cm
		Non-elite			*45*	34.4 ± 5.5 cm
		Elite		U15	*37*	40.1 ± 4.5 cm
		Sub-elite			*27*	40.3 ± 4.9 cm
		Non-elite			*32*	35.6 ± 5.9 cm
		Elite		U16	*35*	44.7 ± 5.0 cm
		Sub-elite			*12*	45.0 ± 5.8 cm
		Non-elite			*15*	41.1 ± 6.4 cm
		Elite	SBJ$^{\surd}$	U13	*47*	170.1 ± 14.5 cm
		Sub-elite			*28*	169.5 ± 14.8 cm
		Non-elite			*31*	161.7 ± 16.1 cm
		Elite		U14	*34*	182.3 ± 17.7 cm
		Sub-elite			*41*	180.1 ± 17.4 cm
		Non-elite			*45*	171.7 ± 19.3 cm
		Elite		U15	*37*	193.4 ± 13.4 cm
		Sub-elite			*27*	191.1 ± 22.1 cm
		Non-elite			*32*	179.8 ± 20.7 cm
		Elite		U16	*35*	201.5 ± 13.6 cm
		Sub-elite			*12*	200.8 ± 20.0 cm

		Non-elite			*15*	194.4 ± 23.7 cm
Gil *et al*. [2007]	Spain	Selected	CMJ hips*	U15	*29*	38.0 ± 0.9 cm
		Non-selected			*19*	37.3 ± 1.4 cm
		Selected		U16	*36*	40.5 ± 0.9 cm
		Non-selected			*17*	43.3 ± 1.4 cm
		Selected		U17	*29*	42.3 ± 1.2 cm
		Non-selected			*12*	40.0 ± 1.4 cm
		Selected		U18	*32*	44.0 ± 0.9 cm
		Non-selected			*20*	44.6 ± 0.8 cm
		Selected	Squat jump	U15	*29*	35.8 ± 0.7 cm
		Non-selected			*19*	36.7 ± 1.3 cm
		Selected		U16	*36*	39.6 ± 1.0 cm
		Non-selected			*17*	39.8 ± 0.9 cm
		Selected		U17	*29*	40.9 ± 1.2 cm
		Non-selected			*12*	39.2 ± 0.8 cm
		Selected		U18	*32*	42.6 ± 1.1 cm
		Non-selected			*20*	42.7 ± 0.8 cm
Gonaus and Müller [2012]	Austria	Drafted	CMJ arms$^{\Sigma}$	U15	*205*	35.8 ± 5.5 cm
		Non-drafted			*1160*	34.1 ± 5.5 cm
		Drafted		U16	*252*	38.8 ± 5.4 cm
		Non-drafted			*1089*	36.5 ± 5.6 cm
		Drafted		U17	*228*	39.3 ± 5.7 cm
		Non-drafted			*995*	37.7 ± 5.7 cm
		Drafted		U18	*136*	40.2 ± 5.5 cm
		Non-drafted			*668*	39.0 ± 5.7 cm
Wong and Wong [2009]	China	National	CMJ hips*	U17	*16*	39.33 ± 4.82 cm
Wong *et al*. [2009]	China	Elite	CMJ arms$^{\Sigma}$	U14	*70*	from 52.5 ± 5.7 cm to 54.3 ± 7.7 cm^{ǂ}
Nedeljkovic *et al*. [2007]	Serbia and Montenegro	National	CMJ hips*	U13	*82*	25.5 ± 3.4 cm
				U14	*86*	28.1 ± 3.6 cm
				U15	*81*	31.0 ± 4.0 cm
				U16	*88*	33.5 ± 5.2 cm
				U17	*75*	34.6 ± 4.4 cm
				U18	*66*	37.7 ± 3.9 cm
			SBJ$^{\surd}$	U13	*82*	178 ± 14 cm
				U14	*86*	192 ± 15 cm
				U15	*81*	209 ± 15 cm
				U16	*88*	222 ± 18 cm
				U17	*75*	230 ± 15 cm
				U18	*66*	241 ± 11 cm

			MUSCLE STRENGTH			
Carling *et al*. [2009]	France	Elite	PTQ dom$^{\infty}$ 1.05rad/s	U14	*160*	from 138.6 ± 37.2 Nm to 163.0 ± 37.7 Nm
			PTQ dom$^{\infty}$ 4.19 rad/s			from 83.0 ± 23.4 Nm to 96.1 ± 23.3 Nm
			PTQ non-dom$^{£}$ 1.05 rad/s			from 135.9 ± 30.9 Nm to 166.6 ± 32.9 Nm
			PTQ non-dom$^{£}$ 4.19 rad/s			from 56.8 ± 2.7 Nm to 58.5 ± 2.9 Nm
Fernandez-Gonzalo *et al*. [2010]	Spain	Regional	MVIC (leg press)$^{¤}$	U10	*15*	919.2 ± 302.8 N
				U12	*15*	1414.1 ± 651.7 N
			Peak power (leg press)	U10	*15*	234.4 ± 92.5 N
				U12	*15*	428 ± 156.8 N
Forbes *et al*. [2009b]	England	Elite	PTQ dom$^{\infty}$ 1.05rad/s	U12	*24*	80.3 ± 22.1 Nm
				U13	*25*	94.3 ± 23.9 Nm
				U14	*27*	107.8 ± 29.2 Nm
				U15	*21*	148.3 ± 39.2 Nm
				U16	*26*	151.1 ± 31.5 Nm
				U18	*29*	181.8 ± 24.4 Nm
Le Gall *et al*. [2010]	France	International	PTQ dom$^{\infty}$ 1.05rad/s	U14	*16*	3.5 ± 0.6 $Nm.kg^{-1}$
		Professional			*56*	3.5 ± 0.6 $Nm.kg^{-1}$
		Amateur			*89*	3.5 ± 0.6 $Nm.kg^{-1}$
		International		U15	*16*	3.5 ± 0.4 $Nm.kg^{-1}$
		Professional			*54*	3.6 ± 0.7 $Nm.kg^{-1}$
		Amateur			*76*	3.6 ± 0.4 $Nm.kg^{-1}$
		International		U16	*16*	3.5 ± 0.5 $Nm.kg^{-1}$
		Professional			*57*	3.6 ± 0.5 $Nm.kg^{-1}$
		Amateur			*70*	3.7 ± 0.4 $Nm.kg^{-1}$
Wong and Wong [2009]	China	National	Weighted squat 1 RM[¶]	U17	*16*	116.3 ± 25.5 kg
Nedeljkovic *et al*. [2007]	Serbia and Montenegro	National	Knee extension strength	U13	*82*	201 ± 42 N
				U14	*86*	250 ± 55 N
				U15	*81*	315 ± 72 N
				U16	*88*	394 ± 101 N
				U17	*75*	412 ± 82 N
				U18	*66*	482 ± 121 N
			Hip flexion strength	U13	*82*	181 ± 42 N
				U14	*86*	189 ± 49 N
				U15	*81*	212 ± 61 N
				U16	*88*	248 ± 57 N
				U17	*75*	287 ± 79 N
				U18	*66*	308 ± 66 N
			SPRINT PERFORMANCES			
Gibson *et al*. [2013]	Scotland	Elite	15 m sprint	U17-U19	*32*	2.43 ± 0.08 sec
			40 m sprint			7.11 ± 0.25 sec

			RSA[§]: sum of 6 x 40 m			44.40 ± 1.62 sec
Carling *et al*. [2009]	France	Elite	10 m sprint	U14	*160*	from 1.98 ± 0.07 sec to 1.94 ± 0.08 sec[¥]
			40 m sprint			from 6.03 ± 0.31 sec to 5.86 ± 0.29 sec[¥]
Figueiredo *et al*. [2010a; b]	Portugal	Elite	35 m sprint	11-12 y	*75*	8.3 ± 0.5 sec
				13-14 y	*68*	7.8 0 ± 0.4 sec
			10 x 5 m	11-12 y	*75*	20.4 ± 1.2 sec
				13-14 y	*68*	18.7 ± 0.9 sec
Coelho-e-Silva *et al*. [2010]	Portugal	Elite	10 x 5 m	U14	*45*	19.34 ± 1.13 sec
		Local			*69*	19.08 ± 1.04 sec
		Elite	Best of 7 sprints[χ]	U14	*45*	7.60 ± 0.30 sec
		Local			*69*	7.93 ± 0.44 sec
		Elite	RSA[§]: sum of 7 sprints[χ]	U14	*45*	55.00 ± 2.17 sec
		Local			*69*	57.54 ± 3.32 sec
Malina *et al*. [2004]	Portugal	Elite	30 m sprint	13-15 y	*69*	4.88 ± 0.30 sec
Deprez *et al*. [2013]	Belgium	Elite	5 m sprint	U13	*146*	from 1.26 ± 0.05 sec to 1.22 ± 0.07 sec[¥]
				U15	*162*	from 1.21 ± 0.07 sec to 1.17 ± 0.07 sec[¥]
				U17	*247*	from 1.12 ± 0.07 sec to 1.09 ± 0.07 sec[¥]
			30 m sprint	U13	*146*	from 5.27 ± 0.17 sec to 5.17 ± 0.21 sec[¥]
				U15	*162*	from 4.96 ± 0.28 sec to 4.80 ± 0.22 sec[¥]
				U17	*247*	from 4.52 ± 0.20 sec to 4.43 ± 0.18 sec[¥]
Mendez-Villanueva *et al*. [2011]	Qatar	Elite	10 m sprint	U14	*14*	1.93 ± 0.11 sec
				U16	*22*	1.80 ± 0.06 sec
				U18	*25*	1.73 ± 0.06 sec
			20 m sprint	U14	*14*	2.85 ± 0.23 sec
				U16	*22*	2.53 ± 0.11 sec
				U18	*25*	2.34 ± 0.08 sec
			RSA[§]: mean of 10 x 30 m	U14	*14*	5.04 ± 0.28 sec
				U16	*22*	4.62 ± 0.17 sec
				U18	*25*	4.39 ± 0.12 sec
Vandendriessche *et al*. [2012]	Belgium	National	T-test Left	U16	*18*	8.289 ± 0.200 sec
				U16 F[$]	*19*	8.443 ± 0.200 sec
				U17	*21*	8.147 ± 0.179 sec
				U17 F[$]	*15*	8.237 ± 0.207 sec
			T-test Right	U16	*18*	8.306 ± 0.243 sec
				U16 F[$]	*19*	8.503 ± 0.224 sec
				U17	*21*	8.204 ± 0.222 sec
				U17 F[$]	*15*	8.327 ± 0.234 sec
			5 m sprint	U16	*18*	1.072 ± 0.047 sec
				U16 F[$]	*19*	1.096 ± 0.057 sec
				U17	*21*	1.074 ± 0.075 sec

				U17 F[$]	*15*	1.077 ± 0.039 sec
			10 m sprint	U16	*18*	1.817 ± 0.059 sec
				U16 F[$]	*19*	1.905 ± 0.079 sec
				U17	*21*	1.818 ± 0.083 sec
				U17 F[$]	*15*	1.878 ± 0.057 sec
			20 m sprint	U16	*18*	3.133 ± 0.102 sec
				U16 F[$]	*19*	3.288 ± 0.127 sec
				U17	*21*	3.120 ± 0.120 sec
				U17 F[$]	*15*	3.238 ± 0.109 sec
			30 m sprint	U16	*18*	4.380 ± 0.155 sec
				U16 F[$]	*19*	4.630 ± 0.172 sec
				U17	*21*	4.332 ± 0.163 sec
				U17 F[$]	*15*	4.554 ± 0.163 sec
Valente-dos-Santos *et al*. [2012a; c]	Portugal	Elite	RSA[§]: sum of 7 sprints[χ]	11 y	*40*	62.11 ± 3.41 sec
				12 y	*57*	59.18 ± 3.13 sec
				13 y	*83*	57.63 ± 3.12 sec
				14 y	*80*	55.11 ± 2.32 sec
				15 y	*66*	53.74 ± 2.19 sec
				16 y	*30*	52.02 ± 2.44 sec
				17 y	*10*	51.41 ± 2.19 sec
Vänttinen *et al*. [2010]	Finland	Regional	10 m sprint	10 y	*12*	2.08 ± 0.07 sec
				12 y	*12*	2.02 ± 0.05 sec
				14 y	*12*	1.90 ± 0.09 sec
Figueiredo *et al*. [2009a]	Portugal	Elite	Best of 7 sprints[χ]	11-12 y	*12*	8.05 ± 0.30 sec
		Club			*54*	8.38 ± 0.49 sec
		Drop-out			*21*	8.55 ± 0.55 sec
		Elite	RSA[§]: mean of 7 sprints[χ]	13-14 y	*21*	8.32 ± 0.31 sec
		Club			*36*	8.80 ± 0.54 sec
		Drop-out			*15*	9.06 ± 0.71 sec
Le Gall *et al*. [2010]	France	International	10 m sprint	U14	*16*	1.96 ± 0.10 sec
		Professional			*56*	1.95 ± 0.09 sec
		Amateur			*89*	1.96 ± 0.08 sec
		International		U15	*16*	1.87 ± 0.08 sec
		Professional			*54*	1.89 ± 0.08 sec
		Amateur			*76*	1.89 ± 0.07 sec
		International		U16	*16*	1.82 ± 0.10 sec
		Professional			*57*	1.85 ± 0.08 sec
		Amateur			*70*	1.85 ± 0.07 sec
		International	20 m sprint	U14	*16*	3.34 ± 0.14 sec
		Professional			*56*	3.32 ± 0.14 sec

		Amateur			*89*	3.33 ± 0.14 sec
		International		U15	*16*	3.17 ± 0.13 sec
		Professional			*54*	3.20 ± 0.14 sec
		Amateur			*76*	3.22 ± 0.11 sec
		International		U16	*16*	3.06 ± 0.16 sec
		Professional			*57*	3.12 ± 0.12 sec
		Amateur			*70*	3.11 ± 0.24 sec
		International	40 m sprint	U14	*16*	5.88 ± 0.29 sec
		Professional			*56*	5.91 ± 0.29 sec
		Amateur			*89*	5.91 ± 0.28 sec
		International		U15	*16*	5.52 ± 0.40 sec
		Professional			*54*	5.63 ± 0.26 sec
		Amateur			*76*	5.69 ± 0.23 sec
		International		U16	*16*	5.40 ± 0.29 sec
		Professional			*57*	5.47 ± 0.22 sec
		Amateur			*70*	5.52 ± 0.18 sec
Vaeyens *et al*. [2006]	Belgium	Elite	30 m sprint	U13	*42*	4.4 ± 0.2 sec
		Sub-elite			*24*	4.5 ± 0.2 sec
		Non-elite			*31*	4.7 ± 0.2 sec
		Elite		U14	*32*	4.3 ± 0.2 sec
		Sub-elite			*38*	4.3 ± 0.2 sec
		Non-elite			*42*	4.5 ± 0.3 sec
		Elite		U15	*37*	4.1 ± 0.2 sec
		Sub-elite			*25*	4.2 ± 0.2 sec
		Non-elite			*33*	4.4 ± 0.3 sec
		Elite		U16	*31*	3.9 ± 0.2 sec
		Sub-elite			*12*	4.0 ± 0.2 sec
		Non-elite			*15*	4.0 ± 0.2 sec
		Elite	10 x 5 m	U13	*42*	20.6 ± 1.4 sec
		Sub-elite			*24*	21.2 ± 1.6 sec
		Non-elite			*31*	21.4 ± 1.2 sec
		Elite		U14	*32*	20.1 ± 1.5 sec
		Sub-elite			*38*	20.2 ± 1.2 sec
		Non-elite			*42*	20.8 ± 1.5 sec
		Elite		U15	*37*	19.8 ± 1.3 sec
		Sub-elite			*25*	20.1 ± 1.4 sec
		Non-elite			*33*	20.4 ± 1.2 sec
		Elite		U16	*31*	19.4 ± 1.3 sec
		Sub-elite			*12*	19.0 ± 1.0 sec
		Non-elite			*15*	19.9 ± 1.1 sec

Gil *et al*. [2007]	Spain	Selected	30 m sprint	U15	*29*	3.95 ± 0.05 sec
		Non-selected			*19*	4.20 ± 0.07 sec
		Selected		U16	*36*	3.73 ± 0.03 sec
		Non-selected			*17*	3.74 ± 0.04 sec
		Selected		U17	*29*	3.68 ± 0.04 sec
		Non-selected			*12*	3.70 ± 0.04 sec
		Selected		U18	*32*	3.60 ± 0.04 sec
		Non-selected			*20*	3.62 ± 0.06 sec
Gonaus and Müller [2012]	Austria	Drafted	20 m sprint	U15	*205*	3.16 ± 0.13 sec
		Non-drafted			*1160*	3.21 ± 0.15 sec
		Drafted		U16	*252*	3.07 ± 0.11 sec
		Non-drafted			*1089*	3.12 ± 0.12 sec
		Drafted		U17	*228*	3.02 ± 0.11 sec
		Non-drafted			*995*	3.07 ± 0.11 sec
		Drafted		U18	*136*	2.99 ± 0.10 sec
		Non-drafted			*668*	3.03 ± 0.11 sec
		Drafted	5 x 10 m	U15	*205*	11.53 ± 0.43 sec
		Non-drafted			*1160*	11.80 ± 0.46 sec
		Drafted		U16	*252*	11.27 ± 0.41 sec
		Non-drafted			*1089*	11.51 ± 0.41 sec
		Drafted		U17	*228*	11.14 ± 0.36 sec
		Non-drafted			*995*	11.35 ± 0.40 sec
		Drafted		U18	*136*	11.07 ± 0.35 sec
		Non-drafted			*668*	11.28 ± 0.40 sec
Wong and Wong [2009]	China	National	5 m sprint	U17	*16*	1.07 ± 0.05 sec
			10 m sprint			1.81 ± 0.05 sec
			15 m sprint			2.50 ± 0.07 sec
			20 m sprint			3.10 ± 0.09 sec
			30 m sprint			4.32 ± 0.13 sec
Wong *et al*. [2009]	China	Elite	10 m sprint	U14	*70*	from 2.09 ± 0.23 sec to 2.05 ± 0.14 sec‡
			30 m sprint			from 4.96 ± 0.40 sec to 4.81 ± 0.36 sec‡
Nedeljkovic *et al*. [2007]	Serbia and Montenegro	National	10 x 5 m	U13	*82*	19.3 ± 0.7 sec
				U14	*86*	18.9 ± 1.0 sec
				U15	*81*	18.4 ± 0.7 sec
				U16	*88*	18.1 ± 0.8 sec
				U17	*75*	17.5 ± 0.6 sec
				U18	*66*	17.1 ± 0.7 sec

******CMJhips=counter movement jump performed with hands placed on the hips; #performances were measured over one soccer season; ΣCMJ arms=counter movement jump performed with arm-swing; ¥performances were measured across birth quarters; ∝PTQ dom=peak torque quadriceps of the dominant leg; £PTQ non-dom=peak torque quadriceps of the non-dominant leg; χseven-sprint protocol by Bangsbo [1994]; √SBJ=standing broad jump; ¤MVIC=maximum voluntary isometric contraction;*

§RSA=repeated sprint ability; [$]U16 F=U16 Futures: youth soccer players playing for the national team who are late to mature; [¶]1RM=one repetition maximum; ǂperformances were measured across four positional roles (goalkeepers, defenders, midfielders and forwards)

LIST OF PUBLICATIONS AND PRESENTATIONS

A1

Deprez D, Vaeyens R, Coutts AJ, Lenoir M, Philippaerts RM. Relative age effect and YoYo IR1 in youth soccer. Int J Sports Med 2012; 13: 987-993.

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A3

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C1-C3

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