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Modelling change and stability of physical and technical performance in young soccer players

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Path of love seemed easy at first *What come was many hardships*

~Hafez

DEDICATION

To my supporters,

To whom helped me get through to my life,

I am blessed to have you,

I Love you All ♥

سپاسگزارم خداوندگار را

.

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RESUMO

Esta tese investigou a relação entre mudanças no crescimento e forma do corpo, composição corporal, maturação biológica, desempenho físico, habilidades técnicas, conhecimento de jogo e historial do treino de jovens futebolistas no contexto de seus clubes. O estudo tem um delineamento longitudinal-misto; amostrou 150 futebolistas com idades compreendidas entre os 12 e 14 anos no *baseline*, oriundos de seis clubes de futebol da área metropolitana do Porto que foram selecionados do estudo *Em Busca da Excelência no Desporto - Um Estudo Longitudinal Misto em Jovens Atletas (INEX) (2016–2019)*. Os jogadores foram divididos em três coortes de idade (12, 13 e 14 anos), e seguidos consecutivamente durante 4 anos. Os dados foram coletados com protocolos padronizados, e a informação está dividida em dois domínios: Individual - biológico, aptidão física, habilidades específicas da modalidade/proficiência do jogo, psicológico, e contextual - clubes. Os procedimentos estatísticos foram realizados nos softwares *Somatotype calculation*, *SPSS*, *Timepath*, *MATLAB* e *STATA*. Os resultados mostraram que: (1) jogadores mais velhos são mais altos e pesados e têm valores de composição corporal correspondentes à maturação biológica avançada; (2) jogadores mais velhos têm melhor desempenho físico e são mais habilidosos que os seus pares mais jovens; (3) estas componentes estão relacionadas com maturidade avançada e mais tempo de treino; (4) as habilidades táticas e características psicológicas dos jogadores não diferem entre as coortes de idade; (5) os clubes oferecem uma variedade de condições para aumentar o sucesso dos jogadores na resposta ao treino e à competição; (6) o desenvolvimento da velocidade e agilidade apresentou uma tendência linear em função do tempo; (7) a puberdade é considerada um momento crucial para nutrir futuras vocações de qualidade dos jogadores de futebol dos futebolistas sobretudo no seu desempenho físico; (8) este desenvolvimento está positivamente associado com a maturidade, níveis mais elevados de força explosiva dos membros inferiores e horas acumuladas de treino; (9) velocidade de condução de bola, passe curto com tabela e o precisão de remate melhoraram com a idade, os níveis de atleticismo e horas acumuladas de treino; (10) o crescimento do corpo e a maturidade não explicaram, de forma independente, as diferenças nas trajetórias das habilidades técnicas dos jogadores; (11) o remate de precisão não está associado, significativamente, com os preditores considerados no estudo.

Espera-se que os resultados deste estudo possam contribuir para uma atitude mais esclarecida e abrangente na preparação dos jovens futebolistas em termos da sua resposta ao treino e competição ao longo da sua carreira desportiva.

PALAVRAS-CHAVE: futebol jovem; atuação; Habilidades; longitudinal; multinível; desenvolvimento; treino; maturidade.

ABSTRACT

This thesis investigates the relationship between changes in young soccer players' physical growth, body shape and composition, biological maturation, physical performance, technical skills, game knowledge and training history within the context of their clubs. A total of 150 players aged 12 to 14 years, at baseline, were selected from participants in the *In Search of Excellence in Sport – A Mixed-Longitudinal Study in Young Athletes (INEX) study (2016–2019)*. INEX was conducted in six soccer clubs of the Porto metropolitan area. They clustered into three age-cohorts (12, 13 and 14 years), were followed consecutively over 4-years using a mixed-longitudinal study design. All data were collected using standardized protocols and the information was distributed over two nested domains: individual - biological, skill/ game proficiency, psychological, and contexts - clubs. Statistical procedures were done in *Somatotype calculation, SPSS, LDA, MATLAB, and STATA*. Results showed that: (1) older players were more advanced in body physique and their body composition were in line with their advanced biological maturation; (2) older players outperformed their younger peers in all physical performance and technical skills components; (3) these components were related to both advanced maturity and increased training; (4) young soccer players' tactical skills as well as psychological characteristics did not differ across age-cohorts; (5) clubs offer a variety of conditions aiming to enhance players success in their response to training and competition; (6) young soccer players development in speed and agility showed a linear trend, i.e., they improve as time passes; (7) puberty has been found to be a crucial time for nourishing soccer players' future quality vocations in physical performance development; (8) physical performance development is positively associated with biological maturation, higher levels of explosive leg strength, and accumulated hours of soccer specific training; (9) dribbling speed, short-pass rebound and shooting accuracy linearly improved with age, levels of athleticism, and years of official soccer training had positive affect on dribbling speed development; (10) body growth and biological maturation did not independently explain differences in players' trajectories in technical skills; (11) shooting accuracy technique had no significant association with any predictors.

We hope that these results may be useful for a more comprehensive approach in young soccer players' long-term preparation in terms of their responses to training and competition.

KEYWORDS: young soccer; performance; skills; longitudinal; multilevel; development; training; maturity.

GLOSSARY LIST

AAHPERD	American Alliance for Health, Physical Education, Recreation and Dance
AMTI	Advanced Mechanical Technology Inc
ANOVA	Analysis of Variance
ANCOVA	Analysis of Covariance
ATS	Acceleration Testing System
BMI	Body Mass Index
C	coaching certification (level 1)
C1	Cohort 1
C2	Cohort 2
C3	Cohort 3
CEFADE	Comissão de Ética da Faculdade de Desporto da Universidade do Porto
CIFI^{2}D	Centro de Investigação Formação Inovação e Intervenção em Desporto.
cm	centimeter
CMJ	Countermovement jump
COP	Comité Olímpico de Portugal
C_g	control group
E_g	experimental group
e.g.	for example
ESHR	endurance shuttle run
FADEUP	Faculdade de Desporto da Universidade do Porto
FCT	Fundação para a Ciência e Tecnologia
FIFA	Fédération Internationale de Football Association
FPF	Portuguese Football Federation
FUT-SAT	Sistema de avaliação táctica no Futebol
g	gram
G*Power	tool to compute statistical power analyses
GPS	Global Positioning System

i.e.	That is
IBM	International Business Machines Corporation
ISAK	International Society for the Kinanthropometry
ISI	Institute for Scientific Information
ISRT	intermittent endurance
IPDJ	Portuguese Institute of Sports and Youth
INEX	In Search of Excellence - a Mixed-longitudinal Study in Young Athletes
Hz	Hertz (one cycle per second)
h	hour
$h \cdot w^{-1}$	Hour per week
Kg	kilogram
Kg^f	kilogram-force
LDA	Linear Discriminant Analysis
LSPT	Loughborough Soccer Passing
m	meter
MATLAB	matrix laboratory
Max	Maximum
MEDLINE	Medical Literature Analysis and Retrieval System Online
Min	Minimum
min	minute
mm	millimeter
$m \cdot s^{-1}$	meter per second (m/s)
MSER	multi-stage endurance run 20meter
MSGs	Medium-Sided Games
n	Sample size
nf	non-preferred foot
ns	non-significant
N_pro	Not professional
PEDro	Physiotherapy Evidence Database
PHV	Peak Height Velocity
pf	preferred foot

PMCSQ	Perceived Motivational Climate in Sport Questionnaire
Pro	
PRISMA	Preferred Reporting Items for Systematic and Meta-analyses
PRISMA-P	Preferable Reporting Items for Systematic Reviews and Meta-Analyses Protocols
PubMed	Public/Publisher Medical Literature Analysis and Retrieval System Online
Q	Question
reps	Repetitions
S	Supplementary
S10m	sprints 10 meter
S15m	sprints 15 meter
S20m	sprints 20 meter
S30m	sprints 30 meter
s	Seconds
SAFALL-FOOT	System of Assessment of Functional Asymmetry of the Lower Limbs in Football
SD	Standard deviation
SE	Standard Error
SBJ	standing broad jump
S_g	soccer group
SHR	agility shuttle run 5×10 meter
SJ	Squat jump
SLJ	Standing long jump
SPSS	Statistical Package for the Social Sciences
SR	sit and reach
RSA	repeated sprint 30 meter
TACSIS	Tactical Skills Inventory for Sports
TEOSQ	The Task and Ego Orientation in Sports Questionnaire
T-test	T-shaped pattern Test
U	Under
UEFA	Union of European Football Associations
UK	United Kingdom

USA	United States
UT	Utah
v	version
VJ	vertical jump
week^{-1}	Per week
yrs	years
year^{-1}	Per year
Yo-Yo IR1	Yo-Yo Intermittent Recovery Test - Level 1 (YYIR1)
*	Asterisk
º	Degree
β	Beta (regression coefficient)
σ^2	Variance
p	p-value
$p\eta^2$	partial eta square
γ	Gamma (tracking index)
™	trademark symbol
%	Percentage
^{2}	Quadratic Polynomial
^{3}	Cubic Polynomial
<	Lower than
≤	Lower or equal than
>	Higher than
≥	Higher or equal than
±	More or less
~	Approximately

CHAPTER I

GENERAL INTRODUCTION; PURPOSES AND FORMAL STRUCTURE OF THE THESIS

GENERAL INTRODUCTION

It is well-acknowledged that youth athletes develop within the context of their families, their peer, and their clubs. This development is multivariate and multidirectional, and hence there are many difficulties associated with assessing, evaluating and integrating all this information within a broad measurement perspective and/or performance-based theoretical model (Bergeron et al., 2015). However, from an applied and practical perspective, governing bodies and sporting organisations have been using research models to support their players' developmental processes to which they sometimes add putative talent identification programs. For example, the Long-Term Athlete Development (LTAD) model (Balyi et al., 2013) has been implemented by various national governing bodies (Badminton England 2006; Beaudoin et al., 2015; British Gymnastics, 2006) worldwide and it has been accepted , as a useful approach to develop children into elite athletes (Fédération Internationale de Football Association, 2021). Although frequently used, this model is under scrutiny because of an apparent lack of consistent scientific empirical evidence (Bailey et al., 2010; Lloyd & Oliver, 2012a; Van Hooren & De Ste Croix, 2020). For example, Ford et al. (2011) argued that future recommendations to help enhancing young players' performance during their developmental years must be based on reliable empirical evidence. Further, Williams et al. (2020) recently highlighted that there is a persistent and reiterated call for a more encompassing understanding of young athletes' pathways to success in their responses to training and competition. This is highlighted by The Great British Medallists Project (Rees et al., 2016), the International Olympic Committee statement on youth athletic development (Bergeron et al., 2015), as well as the National Strength and Conditioning Association official position (Lloyd et al., 2016). All these projects and position statements call for a better understanding of young athletes' development within the network of their families, coaches, and social environments. This is, undoubtedly, a formidable task that requires a holistic framework (Bergkamp et al., 2019; Sieghartsleitner et al., 2019). In my thesis I also hope to bring some evidence to this call using the soccer players from the

INEX project (in search of excellence in sport: a mixed-longitudinal study in young athletes) using a Bronfenbrenner bio-ecological model (Bronfenbrenner, 2005) with its person-process-context-time intertwined processes.

Indeed, soccer is, the most popular team-based sport not only for attendance and participation, but also for the audiences all over the world (Haugaasen & Jordet, 2012). In fact, the soccer charisma has expanded so much that its economic, social, cultural, and even political influences have led most countries seeking to obtain further benefits from the development of soccer in their societies (Dichter, 2020). Additionally, the large numbers of participants provide an opportunity for soccer governing bodies and stakeholders to identify and develop the next soccer generation by investing significant amounts of money in specific talent identification and development programs (Drust, 2019; Williams et al., 2020). Comprehensively, they have to devote resources and project strategies that increase the possibility of profitability, fan base growth, increase participation and enhance athletic performance (Ruta & Sala, 2018). Furthermore, clubs, as the financial heartbeat of the soccer industry (Perechuda & Pawlak 2017) are also influenced by sponsors, fans, media, and society in ensuring optimal growth and development of their players (Scafarto & Dimitropoulos, 2018). The above referred interrelations occur simultaneously and continuously over time due to their interdependence, for example, players showing superior quality in training and competitions moments, they create superior conditions to clubs have fans and financial incoming.

This large investment by the national government into sports development offers players a superior developmental environment at different levels of competition (Stambulova et al., 2020) Likewise, it is widely acknowledged that appropriate provision and training are highly required to fulfil players potential (Abbott & Collins, 2002). Therefore, practical application of suitable contemporary athlete's development models and frameworks by national governing bodies and soccer organisation is vital (Sæther & Solberg, 2015). In order to develop players holistically it is also important that developmental environments, like clubs and coaches, must consider a multidisciplinary approach. For example, the governing body for soccer in England, The English soccer/Football Association (FA) is responsible for formulating and implementing current developmental strategies for coaches' education as well as national training programmes (The FA, 2016). In particular, through using a multidisciplinary approach, the FA has adopted the 'Four Corner Model' (FCM) into their syllabus, which considers technical/tactical, physical, psychological, and social factors by dividing them into the four corners. This method of player development facilitates a 'player centred' approach which identifies specific characteristics that relate to each of the four factors. In fact, this allows coaches and/or practitioners to identify weaknesses which in turn creates individual learning objectives to assist player development, outlining a range of factors that are needed to address a young player's ability to reach their potential. Further, this agenda is based on theoretical contexts that simplify, for both clubs and coaches, the ability to apply appropriate coaching in the player's practice environment. Yet, the isolated age-specific investigation, combined research considering the whole development pathway within each of the four corners, is apparently limited (Kelly & Williams, 2020). Furthermore, the FCM isolates technical/tactical into one corner, whereas it may be argued that these two factors have relatively different meanings and outcomes. Above all, in 2012 the English Premier League clubs, in cooperation with representatives of the FA and other key soccer stakeholders, developed a long-term strategy plan - the Elite Player Performance Plan (EPPP). In fact, this plan aimed at modernization the academy system and was designed to enable the empowerment of each individual player through a player-led approach. Specially, the EPPP has three stages: Foundation (Under-9 to Under-11), Youth Development (U12 to U16) and Professional Development (U17 to U23). Accordingly, in 2015 the English FA invested £260m into a grassroots project entitled "The National Game Strategy for Participation and Development", which was, improved it in 2018 and then developed a new strategy for 2020-2024. The FA motto is 'For All' and 'age is just a number'. In these respects, it introduced the Youth Development Phase DNA content which is based on: (1) love the ball: love the game, (2) developing people: developing players, and (3) inclusive experiences for all.

The Fédération Française de Football (FFF) manages, oversees, and supervises French football through a system of decentralised delegation and administration. Ensuring the successful strategic plan, "Blue Horizon 2016" (2012-2016), the FFF has launched a new action and development plan called "Ambition 2020”. In particular, it is based on two major pillars, innovations, and performances, as applied to several major goals. For instance, at the youth level, the Ligue du Football Amateur (LFA), with the support of the 22 leagues and 91 districts, oversees grassroots football. In fact, the common objective of the FFF, LFA and decentralised bodies at regional and departmental levels is to offer the best conditions of reception and practice to the public, from the age of 5 and up. Additionally, from rural areas to large cities, they organise competitions, train coaches, participate in financing infrastructure and assisting clubs in their management via various grants or deployed measures. Also, managed by the National Technical Department, the Federal Performance Plan (PPF) works with children from the age of 13 to prepare them for the elite national level and French Teams. Therefore, since it is designed as a "double project" each young player is prepared both athletically and academically, in a way that French players are identified from the age of 11 and enter the national training centres at the age of 13. Hence, their focus is on these four areas: (1) developing and optimizing facilities, (2) updating the training programme, (3) optimising the national talent detection plan, and (4) reinforcing coaching staff.

On the other hand, sole members of the governing body of football in Germany, the Deutscher Fußball-Bund (DFB) which, are Deutsche Fußball Liga (DFL), organise the professional Bundesliga and the 2 Bundesliga along with five regional and 21 state associations while organising the semi-professional and amateur levels as well. In particular, the 2002 DFB started a new plan: the “Talent Development Programme” that focusing on football at a new level, increasing investment in young players' development plan, creating a nationwide talent network, reforming technical systems of levelling talents of trainers and talent scouts, changing the philosophy of the game, recruiting more full-time trainers, and modernizing educational facilities. At first, 366 local bases were implemented in order to support the 14,000 most talented eleven to sixteen-year-old players while German professional clubs were obliged to extend their youth academic 2nd Bundesliga. Then in 2006, they introduced Foot Pass, which has provided a quality management system, evaluates clubs, youth academies, centres of excellence, and elite football schools, and monitors their performance. Also, in 2007, the programme made its next step - they launched elite school for soccer to give talented players the chance to concentrate on soccer and school side by side. Additionally in 2007 they presented U17-Bundesliga along with optimized talent development programme and certification of youth academies. In fact, DFB, which intends to support DFL, regional associations, as well as football organizations, is constituting DFBnet. Therefore, after the implementation of DFB talent and elite development program and reforming the system of licensing professional clubs by DFB and DFL, Double Pass evaluates the youth academic 2nd Bundesliga every three years based on eight criteria. To illustrate, these criteria are strategy and finance, organization and system, football education and assessment, support and education, personnel, communication and cooperation, infrastructure and facilities, effectiveness, and permeability. Besides, the development of coaching standards at different levels, from grassroots to elite levels, is another critical DFB priority for implementing a DFB talent and elite development program. Most important, the German government is one of the essential pillars of German's football talent management program. The German government, using legal advantage by interfering in the distribution of income between all football clubs, plays a vital role in progressing this program. So, to implement the DFB talent and elite development program, yearly DFB invested around 10 million euros for constructing centres of football, soccer ground, and player and coach education centres. Furthermore, clubs have invested in youth academies and centres of excellence construction. In fact, DFB, winner of U21 UEFA European Cup 2021, defined long-term goals and objectives for the youth development. Three interactive goals were outlined: (i) motivation to play and move; (ii) fascinating football; and (iii) top ranking in international football, that are included over four steps and seven stages programme: Step 1 – Basic Training: a) Moving (3-6 yrs.) and b) Playing (7-10 yrs.); Step 2 – Talent Development: c) Learning (11-

14 yrs.) and d) Stabilisation (15-18 yrs.); Step 3 – Elite promotion: e) Preparing for peak performance (17-20 yrs.); and Step 4 – Top-level football: e) Perfection of peak performance (21-29 yrs.) and f) Stabilising peak performance (> 30 yrs.).

In all above football federations, enormous investments in recruiting staff and constructing facilities for young players were made. Having qualified and experienced staff is understood as the most critical success factor to players' reach elite levels (European Club Association, 2012), in regards of the player largescale development and the definition of the transition strategy from youth to senior.

Age-specific needs refer to the explicit requirements of players at various age groups across the development process (Höner & Votteler, 2016; Lesinski et al., 2020; Slimani & Nikolaidis, 2019) or as Suppiah et al. (2015) describe it; 'different strokes for different folks'. For example, using the LTAD model as a physical developmental guide to support the training programme of age-related differences in physical capacities, such as agility and sprint ability (Mendez-Villanueva et al., 2011). Through the implementation of the organisational structure of competitive frames, the Federação Portuguesa de Futebol (FPF) divided their player pathways from U5 to U19 age groups into two distinct phases: (1) escalão etário that included: Petizes (U5-U7), Traquinas (U8-U9), Benjamins (U10-U11), Infantis (U12-U13), and (2) Níveis de Desempenho that included (1) Juniores C (U14-U15), (2) Juniores B (U16-U17), and (3) Juniores A (U18-U19). FPF segregated them into different age category and game system for competition (fig.1).

Fig 1. FPF youth competition system (Federação Portuguesa de Futebol, June 2018)

One of the main challenges in young soccer players' development is to link innovative research with governing bodies and soccer organisation strategies for soccer development, and coaches' practises to help these youngsters to maximize their potential. Soccer is a multiplex and intensive team-sport, requiring during a competitive match adequate combinations of motor abilities together with technical-tactical actions which are executed in an intermittent fashion over a 90-minute game (Dolci et al., 2020). It has thus been reiterated that to succeed in this multifaceted performance related sport high levels of tactical, technical, and athleticism are required (Wallace & Norton, 2014) and these are not exclusively dependent on one standard set of skills. Nor on a single performance profile that all players should comply with (Williams et al., 2020). Further, it has "long" been suggested by the "compensation phenomenon" (Bartmus et al., 1987) that deficiencies in one area of performance might be compensated for by strengthening others. This is also related to expected performance during training and competition (Vaeyens et al., 2008). Hence, the repeated call to identify factors that influence or associate young soccer players' performance unfolding and this enterprise needs to be grounded on evidence-based developmental pathways to smooth the development of the next soccer generation (Williams et al., 2020).

Change and stability of young soccer players' physical performance and motor specific skills during puberty show remarkable inter-individual variation that are governed by a plethora of factors (Malina, 2003). To better comprehend and tweeze out the interdependence of players' physical growth and the various ways with which they express their motor performance requires a longitudinal study, however the vast array of studies to date with young soccer players have been cross-sectional in nature (Sarmento et al., 2018). Although relevant, their data do not provided a clear distinction between the effects of the dynamics of physical growth, biological maturation and training on young players' multivariate ways of expressing their motor performance (Kelly & Williams, 2020). On the other hand, available longitudinal data on motor (abilities and skills) performance of young soccer players in mainly from European countries. These studies vary in scope, design, methods of data analysis and practical implications of their results. For example, the Ghent youth soccer project used a mixed-longitudinal study design with 160 players aged 10-13 years at baseline, and followed them for five years assessing their physical growth, biological maturation, motor performance, and technical skills (Vaeyens et al., 2006). Also, Huijgen et al. (2010) investigated 267 Talented Dutch youth soccer players from two talent development programmes of premier league soccer clubs aged 12-19 years old at baseline that were followed during 5 years and assessed them on their physical growth, playing position, soccer training stimuli and speed and dribbling ability. Finally, the prospective longitudinal cohort study with 14,178 under 12 (U12) German players, of a nationwide Talent Identification Program starting in 2004 (baseline). Three-year longitudinal resulted in four measurement points field tests (sprint, agility, dribbling, ball control, shooting) and eight-year prospective study in their adult level in the 2014-15 soccer season (Leyhr et al., 2018).

In general, previous longitudinal studies on soccer players showed that physical and technical performance improved with age but at different rates and varied tempos. For example Forsman et al. (2016) showed straight speed, agility, passing and dribbling ability lasted relatively high and stable over the period of 1 year in 12-14 years old Finish players. Philippaerts et al. (2006), in 5 years mixed-longitudinal study in Belgium 11-13 years old at baseline, found after aligning changes by age-at-peak height velocity (APHV), that the majority of physical performance peak spurts coincided with APHV, and straight speed and lower limb explosive strength plateaued after APHV. In a 6 years mixed-longitudinal study in Spanish players (Carvalho et al., 2017) it was found that agility reached a stable rate around 3-4 years after APHV, however sprint maximum velocity occurred around 2 years after APHV. A six-year longitudinal case study in U10 age category English players (Moran et al., 2020) showed that straight speed and lower limb explosive strength trajectories are asymmetrical and erratic.

Soccer has been exposed to significant changes in game speed, structure and play patterns. Barreira et al. (2015) investigated the variables influencing the evolution of tactical and technical elite soccer behaviours between 1982 and 2010 and found that soccer dynamics have changed towards more teamwork and less individual work. In specific, between 2002 and 2010 players performed more passing than dribbling and 1x1 probably due to the tactical numerical disadvantage of the attacking team in the area of play. This probably required soccer become more physically demanding, which has leads to taller and heavier players being observed in age groupings (Malina et al., 2017) as well as having higher speed and resistance (Haugen et al., 2013; Tønnessen et al., 2013). These characteristics may be considered as related factors in the success of professional footballers (Nevill et al., 2019). It has been reported that sports performance is directly related to athletes' body composition (Thomas et al., 2016), and how it (i.e., body fat) can influence and impact on soccer performance (Mills et al., 2017). For example, longitudinal studies showed a positive link between lean body mass and dribbling and speed (Huijgen et al., 2010). Negative associations were also observed on developing overall skill and fat mass (Valente-dos-Santos et al., 2012b); further, lean body mass, stature have been shown to relate with minutes of match play (Clemente et al., 2021).

As described by the Fédération Internationale de Football Association (2021) ; 'The modern soccer player needs pace and the ability to change gears'. A higher level of athleticism is a key factor to approach the level of soccer performance (Dolci et al., 2020). Players are required to endure large volumes and varieties of stress during match play, especially as it is critical to goal scoring opportunities (Schulze et al., 2021). For example, Faude et al. (2012) highlighted that straight speed and ability to change of direction and body control were dominant physical actions during goal scoring. Furthermore, it has been noted that teams finishing higher within league tables show enhanced physical qualities, especially larger aerobic capacity and greater strength (Wisløff et al., 1998). Therefore, it is important to continue to work on essential soccer elements, *viz*, agility, explosiveness, speed and power. Further, training methods must take this into account from a young age, for the purpose of diminishing the number of technical or even tactical errors caused by tiredness, and thus to improve individual performance as well as the collective performance of the team (Fédération Internationale de Football Association, 2021).

Although increased physical attributes are linked to higher performance levels, it is important to remember that technical skills such as passing, dribbling, shooting, are also vital to soccer success. Schulze et al. (2021) highlighted that the best substitutions time is when players reduced their physical output. Previous studies have demonstrated a reduction in short-passing accuracy of 41% in first and 60% in second halves in young soccer players (Rampinini et al., 2009), possibly due to fatigue. Earlier, a longitudinal study in Portuguese young soccer players revealed that lower limb explosive strength, as well as aerobic capacity, have been related to developing dribbling skills (Valente-dos-Santos et al., 2014). However, moderate relationships were found between dribbling and passing ability with agility and speed (Forsman et al., 2016). There seems to be limited research on the influence of level of athleticism on skills (Wing et al., 2020). Moreover, available longitudinal reports on the tactical declarative skills are uncommon. A 1-year study showed that tactical declarative skills is relatively stable in total of 288 male soccer players ranging from 12 to 14 years from 16 Finish soccer clubs (Forsman et al., 2016). Also, high level Dutch soccer players within the age range of 16-18 years tend to have better scores and improve their game knowledge when compared to their peers (Kannekens et al., 2011).

It is clear that while age can be used as a proxy for general developmental changes, maturation has unique and additive influences on structural neurodevelopmental trajectories (Tamnes et al., 2017). Puberty is an important period of development with a complex set of neuroendocrine processes that occurs between childhood and adulthood to produce internal and external physical changes (Tanner, 1962). A growth spurt co-occurs with increase in circulating growth hormone, estradiol, and testosterone (Albin & Norjavaara, 2013; Russell & Grossmann, 2019) during puberty. Biological maturation can be described as the status, timing, and tempo of progress to achieving a mature state; these timing and tempo of growth are highly individual and asynchronous with decimal age across adolescence (Baxter-Jones et al., 2020). Also, it is well-acknowledged that body size (e.g., stature and weight) is affected by advancing chronological age and biological maturation which in turn affects physical performance characteristics (e.g., speed, strength) (Baxter-Jones, 2017). Physical and hormonal markers of puberty are associated with advanced brain structure and neurodevelopment patterns (Herting & Sowell, 2017). Neuromuscular adaptive responses are improved by regular physical training, contributing to improved sport-specific skills and performance. Factors, including individual differences in physical and psychosocial development and the rate of pubertal development, may also contribute to the way in which adolescents experience sports activities (Brown et al., 2017). For example, a previous longitudinal study highlighted agility (Valente-dos-Santos et al., 2014) and repeated sprint ability (Valente-dos-Santos et al., 2012a) aerobic capacity and explosive strength (Deprez et al., 2015) development to be related to maturity status. In contrast, Carvalho et al. (2014) suggested that aerobic capacity was not related to maturity status. Also, Bidaurrazaga-Letona et al. (2015) showed that the interaction of chronological age with maturity status was not significantly associated with agility development. Furthermore, Malina et al. (2005) observed that biological maturation may impact technical skills, and a longitudinal study with Portuguese soccer players showed maturity status to be interrelated to inter-individual variability in dribbling speed field test (Valente-dos-Santos et al., 2014). However, this trend was not observed in dribbling performance of English players during match-play (Saward et al., 2019). Additionally, Clemente et al. (2021) highlighted that maturation is not necessarily a determining factor in the participation of matches.

According to Giblin et al. (2014), involvement in structured physical skill development facilitates the unfolding of psychological factors and movement skills to support lifelong physical activity. However, this concept known as ‘deliberate preparation’ only offers a subjective explanatory viewpoint (Giblin et al., 2014). Deliberate preparation is supported by subject leading researchers and should not be disregarded (MacNamara & Collins, 2015). Consequently, the educated practice approach of the deliberate preparation theory (Anders Ericsson, 2008) may be supported by early specialisation (Ford & Williams, 2017) through participating in greater coach-led hours during childhood. Arguably, athletes who have completed more deliberate practice will have more time to develop essential psychological characteristics and fundamental movement skills, consequently leading to greater performance (Williams & Ford, 2008). Players with these characteristics have been shown to possess superior tactical intelligence (Memmert & Roth, 2007; Roca et al., 2012; Williams et al., 2012). Despite the investment of football governing bodies (Premier League, 2021) in the development of research-informed long-term athlete development frameworks that account for influence of biological maturation (Cumming et al., 2018), there is limited empirical evidence to suggest that adolescent soccer players experience windows of opportunity for training adaptation during puberty. The Youth Physical Development model states that most components of physical performance are trainable across the development range (Lloyd & Oliver, 2012b). Additionally, Ford et al. (2012) highlighted the alleged impacts of adequate training stimuli on the development of young players soccer performance. For example, in two mixed-longitudinal studies dribbling improvement was also driven by training stimuli (Huijgen et al., 2010; Valente-dos-Santos et al., 2014) and aerobic capacity development was related to training (Carvalho et al., 2014). In contrast, a study showed that repeated-sprint ability development was not linked to training stimuli (Valente-dos-Santos et al., 2012a). Furthermore, two different longitudinal investigations in young Italian players showed that although soccer training improved the rate of physical performance, no links were identified between physical performance rates and change with biological maturation (Di Giminiani & Visca, 2017). Further, it has also been revealed that seasonal improvement of skills and physical performance were independent of training exposure in under 14 age categories (Francioni et al., 2018). However, evidence exists to suggest that specific training among male youth athletes during ages associated with puberty may elicit an enhanced training response due to greater concentrations of anabolic hormones (Rogol, 2016). A lack of clarity is still present regarding the biological maturation, performance development and how they may influence training loads that optimize training adaptation and maximizing performance potential (Kelly & Williams, 2020).

Modelling performance within a longitudinal framework is a complex and challenging quest. This is more evident in young players, namely in soccer, given coaches' expectations in terms of their responses to training and competition. Multilevel modelling encompasses a set of methods and statistical procedures that allows scientists to effectively analyse cluster data. Additionally, this procedure is exceptionally flexible as it allows researchers to embed in the same equation (at the player level) putative covariates (i.e., predictors). Multifaceted longitudinal models can provide valuable insights by tracking young players' developmental dynamics in their growth, maturation, and performance. There is an apparent scarcity of available data using the multilevel framework to track young players' multidimensional changes. Hence, this thesis aims to investigate the complex relationship between changes in growth in size and shape, body composition, biological maturation, physical performance, technical skills, and youngsters training information within the context of their clubs. Bronfenbrenner ecological systems approach linked to the multilevel statistical model will be the joint templates for this project. Using a mixed-longitudinal design, around 150 soccer players aged 12-14 years old at baseline recruited from 6 clubs in the Oporto Soccer Association were be followed during 4 consecutive years.

OUTLINE OF THE THESIS

The current thesis was conceived and methodologically designed to pursuing the following main aim: *to investigate change and stability of physical and technical performance in young Portuguese soccer players*. It is hoped that it will provided a comprehensive insight into young soccer players' development since it was based on the following pillars: (1) the ecological systems model where person, process, context and time are simultaneous considered (Bronfenbrenner, 2005), i.e., the dynamic and multifaceted ways of physical performance and technical skills expressed themselves within the uniqueness of each player; (2) its mixed-longitudinal design; (3) the multilevel statistical model structure [repeated observations (level-1) nested within individual players (level-2), and (4) the relationship dynamics of changes among a broad set of variables that were collected and organized around five domains: four were within the players' orbit (biological, skill/game proficiency, psychological) and the final domain was context related, i.e., their clubs.

Given the entanglement of the issues addressed by this thesis, a set of specific aims were formulated: (1) present the main ideas, the general design and methodological domain of the INEX study; (2) to model soccer players´ physical performance changes, and to investigate the importance of its correlates; (3) to examine players´ physical performance stability in time; (4) to understand how young players´ technical skills develop across the time.

FORMAL STRUCTURE OF THE THESIS

This thesis consists of several peer-reviewed publications and manuscripts submitted for publication. Chapter I comprises the general introduction, the aims and the outline of the thesis. Chapter II refers to the general methodology of the INEX study, which consists of the methodological published paper with the baseline results. Chapter III presents a systematic review paper of longitudinal studies on young soccer players' motor performance. Chapter IV deals with the modelling of motor performance trends. Chapter V presents a general discussion, conclusions, and limitations of the thesis together with indications for future research. At the end of each chapter there is a reference to the bibliography according to the rules of the journal to which each article was submitted or which is in the submission process. The general chapters of the thesis [I, II (with the exception of article I) and V] present the bibliographic references in accordance with the rules of the Faculty of Sport of the University of Porto (FADEUP).

Table 1. Thesis formal outline

Chapter I	**General introduction, aims and formal structure of the thesis**
Chapter II	**General Methodology** **Overview of *INEX study* (soccer portion) methodology** **<u>Article I</u>** **Body Physique, Body Composition, Physical Performance, Technical and Tactical Skills, Psychological Development, and Club Characteristics of Young Male Portuguese Soccer Players: The INEX Study** Aims: to describe age-associated differences in body physique, body composition, physical performance, technical and tactical skills psychological and club characteristics in male soccer players, aged 12–14 years of age.

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Authors: Maryam Abarghoueinejad, Daniel Barreira, Cláudia Dias, Eduardo Guimarães, Adam D. G. Baxter Jones, D, and José Maia

Chapter III **Literature review**

review

Article II

Motor performance in male youth soccer players. A systematic review of longitudinal studies.

Aims: to provide a summary of existing longitudinal data dealing with male soccer players' motor performance changes during adolescence which is a very important time-window for the nurturing of soccer players' careers.

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Chapter IV **Modelling performance**

Article III

Change and stability in straight speed and agility in young male Portuguese soccer players. The INEX study

Aims: (1) to model mean changes in 20 and 30 m straight speed and agility, (2) to investigate the putative influences of maturity offset, explosive strength, and weekly training, and (3) to describe the tracking of soccer players' performance in straight speed and agility.

Under submission

Authors: Maryam Abarghoueinejad, Adam D. G. Baxter-Jones, Daniel Barreira, Filipa Sousa and José Maia

	Article IV **Modelling trajectories of young soccer players' technical skills: The INEX study** Aims: (1) to model youth soccer players' technical skills' developmental trajectories, and (2) to investigate the effects of independent time dependant predictors on trajectories development, namely height, body fat, biological maturation, physical performance, and training. *Under submission* Authors: Maryam Abarghoueinejad, Adam D. G. Baxter-Jones, Daniel Barreira, and José Maia
Chapter V	**General discussion**
Chapter VI	**General conclusions and limitations of the thesis as well as future research.**

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CHAPTER II

GENERAL METHODOLOGY

GENERAL METHODOLOGY

In Search of Excellence – a Mixed-longitudinal Study in Young Athletes (INEX) study overview

The present thesis was imbibed in larger research project particularly funded by the Portuguese Sports Institute and Olympic Committee titled: *In Search of Excellence—A Mixed-longitudinal Study in Young Athletes* (INEX) study (2016–2019): https://inex-cifi2d.pt/. The INEX study was designed, organized, and implemented by the Centre of Re-search, Education, Innovation, and Intervention in Sport (CIFI^{2}D), located in the Faculty of Sport at the University of Porto (FADEUP), Portugal. The INEX study used a multilevel ecological systems template (Bronfenbrenner, 1979) study randomly recruited ~1000 young athletes male adolescent athletes from five team sports: basketball, handball, soccer, volleyball, and water polo (~200 participants per sport) and followed them consecutively for 4 years with mixed-longitudinal design with five age-cohort (11, 12, 13, 14, and 15 years) which had a 3-year overlap between age-cohorts, generating 7-years of data on developmental trajectories (11 to 17 years).

Aims

- To develop multivariate profiles of male youth athletes from 5 sports (soccer, basketball, handball, volleyball, and water-polo).
- To model developmental trajectories, both within and between individuals, and to investigate predictors of success.
- To investigate the impact of competitive demands, with increasing age, on young athletes' path to excellence.

Main expectation

(i) at the player level, data will provide new, extensive, and integrated information to each young athlete regarding his development, as well as windows of opportunity to reach expertise in his preferred sport namely in excelling in response to training and competition.

(ii) at the parental level, substantive data will be available to help, encourage and support their sons towards the road of superior achievement.

(iii) at the coach/club level, data will provide new material and evidence in order to increase the efficiency in training methodology and youth long-term preparation in their sporting carriers.

(iv) in economic and cultural terms, as youth excel in sport the great will be the incentive to attend their competitions by a large public.

(v) at a more global front, local and national, this unique data set will enhance sports authorities as well as political authorities in designing a new agenda towards an integrated and more efficient program to sports development during youth which is missing in Portugal.

Procedures

The procedures described below correspond to all measurements made in the INEX study. However, not all available information were used in the present thesis. All procedures followed the original protocols defined by the members of the INEX study research team. The protocols included a wide range of variables covering four fundamental domains: (1) biological [anthropometry, body composition, biological maturation and physical performance]; (2) skill/game proficiency [technical skills, tactical performance, tactical skills and perceptual-cognitive skills]; (3) psychological [motivational climate, stress and emotions, coping and emotional regulation and grit]; and (4) contextual [family support and family structure, coach knowledge and competence and club information].

Assessment protocol

Players were assessed during two test sessions occurring over one day. The first test session was held between 8h till 12h. During this time, the following were assessed: (1) anthropometric and body composition measurements at collected Kinesiology laboratory; (2) a series of psychological questionnaires collected at Psychological laboratory (3) technical performance and (4) Match games happened at FADEUP soccer campus. Lunch served 12h till 14h at FADEUP canteen. The second test session was between 14h till 17h. During the second session, the following were assessed: (1) the second series of psychological questionnaires and (2) tactical skills questionnaire collected at psychological laboratory;(3) physical performance test assessed at FADEUP´ sports hall.

Statistical analysis

Descriptive statistics are presented as means, standard deviations (±SD) and frequencies. ANOVA was used to compare means across the three age-cohorts and the Bonferroni's test for post-hoc multiple comparisons; partial eta square ($p\eta^2$) was used as a measure of effect size. ANCOVA was used to compare adjusted means accounting for weekly formal soccer training (combined from weekly number and minutes of for-mal soccer training) and biological maturation. All statistical analyses were performed using the IBM SPSS Statistics v.25 software and the significance level was set at 5%. While the statistical parametric mapping analysis for the countermovement jump (CMJ) was done in MATLAB, the force plate data were post-processed using a custom Matlab2019a routine (MATLAB, MathWorks Inc., Natick, MA, USA). The CMJ phases were identified as advised (Linthorne, 2001), as were the jump height calculation methods.

Given the nested structure of the data we relied on the hierarchical multilevel linear model to predict physical performance and technical skills developmental trends (Hedeker and Gibbons, 2006). Two-level hierarchical structure was defined with repeated measures (level 1) nested within soccer players (level 2). Given cohorts' sequential waves of data collection, we followed Hedeker and Gibbons (2006) advice and anchored the time metric at the beginning of the study in cohort 1. Since we have missing-by-design, and the sample size is not large, we relied on the Kenward and Roger (1997; 2009) methodology to inferences in fixed effects, as well as its restricted maximum likelihood parameter estimates as implemented in STATA 16 software.

Finally, to describe unfolding stability, or tracking, we relied on Foulkes and Davis (1981) γ statistic which computes the probability that two growth curves do not intersect (cross) over time, i.e., pairs of growth curves tend to maintain their relative position over the time frame of the study. The γ statistic only takes positive values, ranging from 0 to 1. According to their developers, if $\gamma \leq 0.50$ there is no tracking; if $0.50 < \gamma < 1.00$ tracking is present, and if $\gamma = 1.00$, tracking is said to be perfect. In this analysis we used the LDA software (Schneiderman and Kowalski, 1993). Finally, in all analysis alpha was set to 5%.

Ethical Issues

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the Faculty of Porto, University of Porto (CEFADE 13.2017, 25 July 2017). The project does not involve the collection and processing of sensitive personal data and genetic information, but it does require monitoring and observation of the participants. The anonymity and confidentiality of the data will be assured when sharing the results with the scientific community.

Research consent

Written informed consent was obtained from parents or legal guardians as well as individual assent from each soccer player. The Ethics Committee of the lead institution approved the study (CEFADE 13.2017), and the Porto Football Association gave formal permission for data collection.

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METHODOLOGICAL ARTICLE

PAPER I

Body physique, Body composition, Physical performance, Technical and Tactical Skills, Psychological Development, and Club Characteristics of Young Male Portuguese Soccer Players: The INEX study

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ABSTRACT

Abstract: Youth soccer performance is multifaceted, includes physical growth, biological maturation, and physical fitness, and is linked to the sporting environment to which the players are exposed. We aim to describe age-related associations in body physique, body composition, physical performance technical and tactical skills, psychological and club characteristics of male soccer players aged 12 to 14 years. A total of 157 male soccer players clustered into three age-cohorts (12, 13 and 14 years) were recruited from six soccer clubs. Anthropometric, body composition and body physique, biological maturation, physical performance, skill/game proficiency data, psychological characteristics, and clubs' characteristics were collected. Group means were compared using analysis of variance and covariance. Fourteen years old players were significantly taller, heavier, leaner, faster, stronger, and technically more skilled than their younger peers ($p < 0.05$). Differences in physical performance and technical skills ($p < 0.05$) were found between age groups when adjusting for confounders of soccer training and biological maturation. No significant differences ($p > 0.05$) between age groups were found in psychological domains. Our findings suggest that age, biological maturation, and training volume are key factors influencing young soccer players' performance and development. Further, clubs' conditions provide players with ample resources for their success in training and competition.

Keywords: youth soccer; body physique and composition; performance; skills; motivation

INTRODUCTION

Youth soccer performance is multifaceted and is linked to physical growth, biological maturation, physical fitness, motor skills and psychological development, all entwined with the family and sporting environments. Interest in adolescent growth, biological maturation, and development, termed auxology, has a long history [1–4] and the young athlete, a specialized sub-group, has been extensively studied [5,6]. The Bronfenbrenner's ecological systems theory indicates that a child's development should be viewed as a complex system of relationships affected by multiple levels of the surrounding environment; from the family and school to the cultural environment [7]. The young athletes' physical growth, maturation, development, and performance are governed by the joint effects of their genetic makeup and the environment they develop within [8–10]. The young athletes surrounding environment is widely recognized as vital in the identification and optimization of young athletes' performance, which in turn is linked to the continuous exposure to systematic training and competition.

In 2007, the Fédération Internationale de Football Association (FIFA) reported that 265 million people worldwide regularly played soccer, representing approximately 4.1% of the world's total population, and that 38 million of these were registered as players with a soccer organization [11]. In addition to individual factors, performance is also linked to team factors [12] within multifaceted traits expressed in physical, physiological, and technical terms [13]. Fransen et al. [14], using a mixed-longitudinal study of Belgian soccer players (aged 5–20 years), reported segmented linear trajectories of physical performance change with age, reaching a plateau around 15–17 years-of-age. Valente-dos-Santos et al. [15] described, in 11–17 years-old Portuguese players, a positive association between biological maturation and training experience with physical performance, and Ford et al. [16] indicated that it was not only the quality, but also the quantity of time spent in soccer specific training that was positively related to the acquisition of skills and increased levels of physical performance. In contrast, Di Giminiani and Visca [17] showed that although soccer training improved the rate of physical performance in young Italian players, no links were identified between physical performance rates and changes with biological maturation. In a sevenyear longitudinal study of Dutch players it was found that the knowledge of how to play the game increased not only with increasing age but was also dependent on field position [18]. Such overall findings have led to several organizations producing position statements. For example, the Canadian Dietitians and the American College of Sports Medicine position statements [19] endorse the fact that sports performance is directly mediated by an athletes' body composition.

In addition to body physique, a young soccer player's development is also linked with other factors such as psychological development, family support, coaches' knowledge, and the club environment, to name but a few [20]. It has been found that elite youth soccer players performance levels are positively associated with higher task-orientated motivation, anticipation and decision-making [21], and the support of parents [22] and coaches [23].

To better understand young soccer players' growth, maturation, development, and performance, within the various contexts of their training and competition, a holistic approach is required. Bronfenbrenner's ecological systems theory [7] relies on a complex set of variables emerging from two main sources: the player (biological at-tributes, skill/game proficiency, and psychological characteristics), and the environment (key roles of family, coach, and club). In the present paper we describe age-associated differences in body physique, body composition, physical performance, technical and tactical skills psychological and club characteristics in male soccer players, aged 12–14 years of age. It was hypothesized that body physique, body composition, physical performance, technical and tactical skills, and psychological development and club characteristics would different between 12, 13 and 14 years old.

METHODS

Setting

Soccer players were recruited as part of the In Search of Excellence—A Mixed-longitudinal Study in Young Athletes (INEX) study (2016–2019):

https://inexcifi2d.pt. The INEX study had three major aims: (1) to develop multivariate profiles of male youth athletes from 5 sports (soccer, basketball, handball, volleyball, and water-polo); (2) to model developmental trajectories, both within and between individuals, and to investigate predictors of success; and (3) to investigate the impact of competitive demands, with increasing age, on young athletes' path to excellence.

The INEX study was designed, organized, and implemented by the Centre of Re-search, Education, Innovation, and Intervention in Sport (CIFI2D), located in the Faculty of Sport at the University of Porto (FADEUP), Portugal. The INEX study randomly recruited ~1000 young athletes (~200 participants per sport) and followed them consecutively over 3–4 years.

Quality Assurance

Since quality assurance is a key priority when planning a longitudinal study, a varied set of actions were implemented before initiating data collection, as well as during follow-up, in order to promote data integrity and validity [24]. First, the INEX study was led by a steering committee including senior researchers from Canada, Portugal, and the USA. The committee oversaw the design of the study, planned its settings for data collection, and developed all materials linked to the INEX study four main domains: biological, skill/game proficiency, psychological, and contextual. Second, these actions were led according to the most recent and important available literature, but also received inputs from both senior researchers and sport coaches. Third, the principal investigators trained all members of the assessment teams (one team per domain) to certify them. Fourth, a series of pilot studies were conducted to verify putative problems in real assessments as well as for feasibility, reliability control, data quality and data entry. Fifth, since missing data are presumed to occur at random in longitudinal or mixed-longitudinal designs, an analytical software to handle missing data will be used [25].

Study Design and Eligibility Criteria for Soccer Players

Six soccer clubs were recruited from the Porto Metropolitan area. They were selected due to their different levels of competitive experience as well as their commitment to participate in the INEX study. A mixed-longitudinal design with three age-cohorts (12, 13 and 14 years) was used. (Table 1). At baseline, a random sample of one hundred and fifty-seven male soccer players was recruited, cohort 1 (n = 49), cohort 2 (n = 51) and cohort 3 (n = 57) and this data is reported in the present paper. The data collection initiated in 2016. All assessments were performed in December. Writ-ten, informed consent was obtained from parents or legal guardians of each player, as well as their individual assent. The Ethics Committee (CEFADE 13.2017) approved the study, and the Porto Football Association gave formal permission for data collection.

Table 1. Chronological age across cohorts, number of players per cohort (at baseline) and years overlap.

Cohorts	**Chronological Age**					
Cohort 1	12 (*n* = 49)	13	14	15		
Cohort 2		13 (*n* = 51)	14	15	16	
Cohort 3			14 (*n* = 57)	15	16	17

Measurements

Training Information

Players' training experience, expressed as years of formal soccer training, was obtained from self-report questionnaires filled-out by players and cross-checked with registration histories, available from the official website of the Portuguese Football Federation (FPF): https://www.fpf.pt/Jogadores (22 June 2020) [26]. A player registered for one competitive season in FPF indicates one year of formal soccer experience, for two competitive seasons, two years of experience, and so on. The weekly number, and the minutes, of the soccer-specific training sessions were also obtained from self-report questionnaires and completed by the managers/coordinators of the academies.

Study Domains

The biological, skill/game proficiency, psychological, and contextual domains were grouped into two main clusters: (i) the young soccer players and (ii) their sporting environment (see Table 2).

Table 2. Measures, scales, and variables of players' and clubs' domains.

Domain	Measure/Scale	Variables	Participation
Biological domain			
Anthropometry	Standard protocol (ISAK)	Height Sitting height Girths Skinfolds	All players
Body composition	Bioimpedance scale (Tanita BC-418MA)	Weight Fat percentage Fat-free mass BMI	All players
Biological maturation	Standard protocol	Maturity offset	All players
Somatotype	Heath-Carter method	Body physique	All players
Physical performance	Physical fitness tests	Yo-Yo IR1 Foot tapping pedal test 5, 20 and 30 m sprints Squat jump Countermovement jump Standing long jump Seated medicine ball throw Standing medicine ball throw Sit-ups Handgrip	All players

		Arrowhead test T-test Ball velocity	
Skill/game proficiency domain			
Technical skills	University of Queensland Football Skill Assessment Protocol	Passing accuracy over 20 m Lofted passing accuracy over 35 m Shooting accuracy over 20 m Wall-pass accuracy test Dribbling speed Juggling ability Passing rebound boards at 90° Passing rebound boards at 135°	All players
Tactical skills	TACSIS	Positioning and decisioning Knowing about ball actions Knowing about others Acting in changing situation	All players
Match-analysis	SAFALL-FOOT	Lower limb functional asymmetry	All players
	Global Positioning System (GPS)	Inter-individual coordination Inter, intra-team coordination Movement pattern (heat maps)	All players
	FUT-SAT	Offensive tactical performance index Defensive tactical performance index	All players
	Social networks	Passing networks	All players
Training information	FPF history registration Training history questionnaire	Soccer-specific years of training Soccer-specific weekly session Soccer-specific weekly minutes per session	All players
Psychological domain			
Goal orientation	PMCSQ scale	Task	All players

		Ego	
Motivational climate	TEOSQ scale	Performance climate Task climate Emphasis on mistakes climate	All players
Contextual domain			
Family structure	Questionnaire	Family size Demographics Family sports' history	All parents
Coach knowledge and competence	Questionnaire	Demographics Academic degrees and sports' history Indicators and criteria for player's selection	All coaches
Club information	Questionnaire	Characteristics Infrastructures Transportation availability Human resources Communication	All clubs

(1) Biological Domain

- Anthropometry

Anthropometric measurements were assessed with standard instrumentation and included height and sitting height measured with a wall mounted stadiometer (Holtain Ltd., Crymych, UK); either standing on the floor or seated on a sitting height table; bone widths measured with calipers (Siber Hegner GPM®, Zurich, Switzerland), girths with a anthropometric tape (Sanny® Medical (SN-4010), São Paulo, Brazil), and skin-folds with a skinfold caliper (Holtain Ltd., Crymych, UK) following standard procedures [27]. Players were measured in their soccer kits with shoes removed.

- Body Composition

Body mass (kg) and fat mass (% from bioelectrical impedance) were measured using a valid and reliable [28] Tanita scale (Tanita® model BC-418MA, Tokyo, Japan). Fat-free mass (kg) was derived according to the manufacturer's formula. The following instructions were observed during all assessments: (1) Evening meals prior to testing should be taken as usual following players' daily routines in terms of their nutritional habits; (2) Prior to arrival at the Lab players were asked to empty their bladder; (3) players were told to remain quietly positioned in the device as per the manufacturer instructions.

- Biological Maturation

A biological age—years from peak height velocity (PHV)—was estimated from anthropometrics using the Mirwald et al. [29] equation. Using measures of chronological age (years from birth), height, sitting height, body mass and their interactions the equation estimates the number of years the individual is from attainment of PHV, termed maturity offset. If maturity offset is positive (+) this indicates the number of years the subject is beyond the attainment of PHV, whereas a negative (–) maturity offset indicates the number of years the subject is prior to attainment of PHV. By subtracting maturity offset from chronological age, the age at peak height velocity can be estimated (age-at-PHV).

- Body Physique (Somatotype)

Somatotype components (endomorphy, mesomorphy, and ectomorphy) were derived from a set of 10 anthropometric measurements: height (cm), body mass (kg), biepicondylar humerus and femur widths (cm), arm flexed and calf girths (cm), triceps, subscapular, supraspinale, and medial calf skinfolds in mm, and body mass (kg) using the Health-Carter standard method [30].

- Physical Performance

Different components of physical performance were assessed using the following tests:

(1) high-intensity aerobic capacity was assessed using the Yo-Yo Intermittent Recovery Test—Level 1 (Yo-Yo IR1). Players performed repeated 2 × 20 m runs with an active recovery period of 10 s in between. The total distance covered (m) was used as the test result [31].

(2) lower limb speed movement was assessed using the foot tapping pedal test. Players performed the maximum number (reps) during 30 s in three trials and the best trial was used as the test result [32].

(3) running speed was assessed using the 5, 20 and 30 m sprint tests. Players ran in a straight line at full speed over 30 m. Time (s) was recorded using a photoelectric cells system, Speed Trap II (Brower Timing Systems LLC., Draper, UT, USA) with each pair of cells placed at each split (5, 20 and 30 m). Each player performed two trials and the best one was used as the test result [33].

(4) explosive strength was assessed using: (i) the squat jump and countermovement jump tests [34] using a AMTI OR6-WP force platform (Advanced Mechanical Technology Inc., Watertown, MA, USA) operating at 2000 Hz; jumping height (cm) was estimated; (ii) the standing long jump (cm) test [35]; and (iii) seated and standing 3 kg medicine ball throws (cm) [36]. Players performed three trails for each vertical jumping test and two trials for the standing long jump, and the best one was used as the test result. For the

3 kg seated and standing medicine ball throws, each player performed three trials and the mean was used as the test result.

(5) trunk strength and endurance were assessed using the sit-ups test. Players performed the maximum number (reps) of sit-ups during 60 s in two trials and the best trial was used as the test result [37].

(6) upper limb static strength was measured using the handgrip test. Players per-formed two maximal handgrip strength (kg^f) with both hands using a hand-held dynamometer (Takei Digital Grip Strength Dynamometer Model T.K. K.5401, Takei Scientific Instruments Co., Ltd., Tokyo, Japan). The mean of best trails of both hands was used as the test result [37].

(7) agility was assessed using (i) the arrowhead test [38] and (ii) the T-test [39]. Time (s) was obtained using the photoelectric cells system Speed Trap II (Brower Timing Systems LLC., Draper, UT, USA). Players performed two trials and the best one was used as the test result.

(8) maximum ball velocity ($m \cdot s^{-1}$) during shooting was estimated from kicking speed test that determined using a stationary Doppler radar gun (Stalker ATS II) Players performed with their dominant leg three trails and the best trial was used as the test result [40].

(2) Skill/Game Proficiency Domain

- Technical Skills

Soccer specific technical skills were assessed using the University of Queensland's Football Skill Assessment Protocol [41], which comprises eight tests: (1) passing accuracy (points/kick) over 20 m; (2) lofted passing accuracy (points/kick) over 35 m; (3) shooting accuracy (points/kick) over 20 m; (4) performance during a wall-pass accuracy (points/kick) test; (5) maximum dribbling speed (m/s); (6) average juggling ability (number/min); (7) dynamic passing (cycles/min) test using two rebound boards set at 90 angle; and (8) dynamic passing (cycles/min) test using two rebound boards set at 135 angles.

- Tactical Skills

Tactical skills were assessed using the Tactical Skills Inventory for Sports (TAC-SIS) self-assessment questionnaire developed by Elferink-Gemser et al. [42] and culturally adapted to Portuguese population by Pereira et al. [43]. The TACSIS consists of 22 items and comprises ("knowing about ball actions" and "knowing about others") and ("positioning and deciding" and "acting in changing situations"). All answers are on a 6-point Likert scale ranging from 1 (very poor) to 6 (excellent) or from 1 (almost never) to 6 (always).

- Match-Analysis

Match-analysis assessed behavioral events during competition, i.e., technical and tactical in medium-sided games (MSGs) 5 versus 5 with a goalkeeper adapting the field dimensions in 11 versus 11 to a 5 versus 5 configuration [44]. Further, the foot preference and lower limbs functional asymmetry index were obtained using the "System of assessment of functional asymmetry of the lower limbs in Football" (SA-FALL-FOOT) [45]. Using global positioning systems (GPS) derived variables, the disposition and position of a soccer player in inter-individual and inter, intra-team coordination were assessed [46], and movement patterns applying heat maps. The type and intensity of the player's movement frequency, duration in seven locomotor categories [47], known as time-motion analysis, were also measured. Players' tactical processual performance was assessed with two tools: (1) the Tactical Assessment System (FUT-SAT) with its macro-categories (observation and outcomes), and seven categories will be used to understand the efficacy in performing the game principal, namely; defensive and offensive [48]; and (2) social networks will also be used to investigate the complexity of the interaction process established between competing players [49].

(3) Psychological Domain

- Goal orientation

The goal orientation was assessed using the Task and Ego Orientation in Sport Questionnaire developed by Chi and Duda [50] and culturally validated for the Portuguese population by Fonseca [51]. Answers are on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). All players answered the questionnaire under the supervision of a trained member of the INEX research team.

- Motivational climate

The motivational climate was assessed using the Perceived Motivational Climate in Sport Questionnaire developed by Selfriz et al. [52] and culturally validated for the Portuguese population by Fonseca [53]. Answers are on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) that measures the players' perceptions of the degree to which their respective team's motivational climate is characterized by mastery and performance goals. All players answered the questionnaire under the supervision of a trained member of the INEX research team.

(4) Contextual Domain

- Family structure

Information about parental support and family structure was obtained via a questionnaire [54] designed to assess the family size (parents and siblings), demographics (sex, age, and educational level) and sports' history (past and current sports participation).

- Coach knowledge and competence

Coaches completed a questionnaire detailing: (1) demographics (age and sex); (2) academic degrees, sports' history as a player and professional experience as a coach; (3) criteria for player's selection based on performance factors and selection method-ologies; and (4) information about the selection process, namely importance of selection indicators and criteria.

- Club information

Comprehensive information of different aspects of soccer clubs was assessed using questionnaire developed by members of INEX committee and research team. The questionnaire assessed sports' infrastructures, equipment, human resources, communication, and developmental strategies linked to young players' sporting trajectories in their clubs. All clubs' presidents or directors completed the questionnaire under the supervision of a trained member of the INEX research team.

Statistical Analysis

Descriptive statistics are presented as means, standard deviations (±SD) and frequencies. ANOVA was used to compare means across the three age-cohorts and the Bonferroni's test for post-hoc multiple comparisons; partial eta square ($p\eta^2$) was used as a measure of effect size. ANCOVA was used to compare adjusted means accounting for weekly formal soccer training (combined from weekly number and minutes of formal soccer training) and biological maturation. All statistical analyses were performed using the IBM SPSS Statistics v.25 software and the significance level was set at 5%.

RESULTS

The descriptive statistics, organized by age groups (body physique, body composition, physical performance, skill/game proficiency, and psychological domains), are presented in Tables 3–5, respectively.

Biological domain

Fourteen years old soccer players were significantly ($p < 0.001$) taller, heavier, had greater fat-free mass, and were more mature than 12 years old and 13 years old (Table 3). Effect sizes ranged from $p\eta^2 = 0.237$ for weight (kg) to $p\eta^2 = 0.587$ for biological age (years from PHV). No significant differences ($p > 0.05$) were observed in fat mass nor for any of the somatotype components. A similar trend was observed in physical performance parameter (Table 4), with 14 years old showing significantly better results ($p < 0.001$) than their younger peers in almost all performance tests; effect sizes ranged from $p\eta^2 = 0.045$ in foot tapping pedal test with preferred foot to $p\eta^2 = 0.380$ in 20 m sprint. In sit-ups and foot tapping pedal test with non-preferred foot, no statistically significant differences ($p > 0.05$) were observed.

Table 3. Descriptive statistics [means and standard deviations (SD)], ANOVA results (F and post hoc tests), and partial eta square (pη^2) for the biological domain.

Biological Domain Variables	12 Years (*n* = 49) Mean ± SD	13 Years (*n* = 51) Mean ± SD	14 Years (*n* = 57) Mean ± SD	F	*Post Hoc*	pη^2
Decimal age (years)	12.49 ± 0.32	13.56 ± 0.25	14.47 ± 0.27	632.35 ***	C3 > C2 > C1	0.891
Anthropometry						
Height (cm)	155.21 ± 8.05	162.66 ± 8.68	168.00 ± 7.67	35.50 ***	C3 > C2 > C1	0.316
Sitting height (cm)	80.98 ± 3.96	84.56 ± 4.72	87.82 ± 4.54	31.13 ***	C3 > C2 > C1	0.289
Body composition						
Weight (kg)	44.70 ± 8.99	51.78 ± 10.15	57.76 ± 9.84	23.93 ***	C3 > C2 > C1	0.237
Fat mass (%)	18.01 ± 3.54	17.31 ± 4.10	17.09 ± 3.15	0.919 ns	-	0.012
Fat-free mass (kg)	36.92 ± 6.41	42.57 ± 7.14	47.67 ± 6.58	33.73 ***	C3 > C2 > C1	0.305
Biological maturation						
Maturity offset (years-to-PHV)	–1.18 ± 0.59	–0.19 ± 0.68	0.70 ±0.68	108.7 ***	C3 > C2 > C1	0.587
Somatotype						
Endomorphy	3.4 ± 1.7	2.9 ± 1.3	2.7 ± 1.1	2.67 ns	-	0.034
Mesomorphy	3.8 ± 0.9	3.5 ± 1.1	3.7 ± 1.0	1.08 ns	-	0.014
Ectomorphy	3.5 ± 1.2	3.5 ± 1.3	3.4 ± 1.6	0.07 ns	-	0.001
Physical performance						
Yo-Yo IR1 (m)	369.00 ± 154.9	533.60 ± 214.0	715.74 ± 276.27	26.17 ***	C3 > C2 > C1	0.281
Foot tapping pedal (pf) (reps)	29.69 ± 4.88	30.70 ± 6.86	32.63 ± 5.33	3.56 *	C3 > C1	0.045
Foot tapping pedal (nf) (reps)	22.63 ± 9.34	24.24 ± 11.55	25.41 ± 10.00	0.94 ns	-	0.012
5 m sprint (s)	1.40 ± 0.89	1.37 ± 0.10	1.28 ± 0.97	21.16 ***	C3 > C2, C3 > C1	0.218
20 m sprint (s)	3.88 ± 0.20	3.80 ± 0.20	3.52 ± 0.19	46.49 ***	C3 > C2, C3 > C1	0.380
30 m sprint (s)	5.43 ± 0.32	5.28 ± 0.29	4.90 ± 0.28	44.44 ***	C3 > C2, C3 > C1	0.369
Countermovement jump (cm)	24.23 ±4.36	25.62 ± 3.78	29.36 ± 4.27	21.98 ***	C3 > C2, C3 > C1	0.222
Standing long jump (cm)	172.71 ± 21.90	177.06 ± 21.17	196.22 ± 18.90	19.68 ***	C3 > C2, C3 > C1	0.205
Medicine ball throw (cm)	426.02 ± 98.64	494.86 ± 110.09	605.73 ± 100.89	40.71 ***	C3 > C2 > C1	0.347
Sit-ups (reps)	22.55 ± 4.60	21.75 ± 5.16	23.30 ± 5.04	1.32 ns	-	0.269
Handgrip (kg^f)	22.35 ± 4.67	27.08 ± 6.21	31.92 ± 5.63	38.82 ***	C3 > C2 > C1	0.337
T-test (s)	10.52 ± 0.65	10.35 ± 0.63	9.82 ± 0.53	19.12 ***	C3 > C2, C3 > C1	0.201

*** $p < 0.001$; * $p < 0.05$; ns = non-significant; pf = preferred foot; nf = non-preferred foot.

Skill game proficiency and training information domain

When looking at technical skill tests (Table 4) it was found that, apart from 20 m shooting—accuracy (pts/kick), 14 years old players systematically outperformed their younger peers from the other two age-cohorts ($p < 0.01$) in all tests, with effect sizes ranging from $p\eta^2 = 0.07$ in wall-pass to $p\eta^2 = 0.315$ in pass rebound 90°. No statistically significant differences ($p > 0.05$) between age-groups were found in any of the tactical declarative skills sub-scales. However, older soccer players had more years of formal experience in soccer, accumulated more weekly sessions, and minutes of soccer specific training (14 years = 278 h versus 13 years = 249 and 12 years = 209 h).

Table 4. Descriptive statistics [means and standard deviations (SD)], ANOVA results (F and post hoc tests), and partial eta square ($p\eta^2$) for the skill/game proficiency domain.

Skill/Game Proficiency Domain Variables	12 Years (n = 49) Mean ± SD	13 Years (n = 51) Mean ± SD	14 Years (n = 57) Mean ± SD	F	***Post Hoc***	$p\eta^2$
Technical skills						
Passing accuracy 20 m (pts/kick)	3.67 ± 1.08	3.54 ± 0.99	4.27 ± 1.30	6.28 **	C3 > C2, C3 > C1	0.075
Lofted passing 35 m (pts/kick)	2.61 ± 1.25	3.47 ± 1.66	4.89 ± 1.70	29.12 ***	C3 > C2 > C1	0.274
Shooting accuracy 20 m (pts/kick)	2.80 ± 1.01	3.00 ± 1.10	3.01 ± 1.19	0.587 ^{ns}	-	0.008
Wall-pass accuracy (pts/kick)	7.30 ± 3.40	9.14 ± 4.07	10.49 ± 4.24	8.62 ***	C3 > C1	0.101
Dribbling speed (m/s)	2.20 ± 0.19	2.33 ± 0.18	2.47 ± 0.16	28.26 ***	C3 > C2 > C1	0.270
Juggling ability (reps/min)	16.08 ± 11.62	22.61 ± 16.40	37.65 ± 19.22	17.00 ***	C3 > C2, C3 > C1	0.143
Pass rebound 90° (cycles/min)	0.58 ± 0.06	0.61 ± 0.05	0.68 ± 0.06	35.48 ***	C3 > C2, C3 > C1	0.315
Pass rebound 135° (cycles/min)	0.57 ± 0.06	0.60 ± 0.06	0.65 ± 0.05	22.60 **	C3 > C2, C3 > C1	0.227
Tactical skills						
Positioning and decisioning	4.51 ± 0.61	4.51 ± 0.66	4.67 ± 0.69	1.03 ^{ns}	-	0.013
Knowledge about ball action	4.57 ± 0.68	4.67 ± 0.62	4.53 ± 0.75	0.60 ^{ns}	-	0.008
Knowing about others	4.46 ± 0.62	4.55 ± 0.65	4.53 ± 0.73	0.25 ^{ns}	-	0.003
Action in changing situations	4.51 ± 0.69	4.47 ± 0.86	4.60 ± 0.77	0.46 ^{ns}	-	0.003
Training information						
Years of training (years)	4.33 ± 1.41	4.51 ± 1.30	5.68 ± 1.42	15.15 ***	C3 > C2, C3 > C1	0.165
Weekly session (n)	3.00 ± 0.00	3.18 ± 0.38	3.37 ± 0.48	13.38 ***	C3 > C2, C3 > C1	0.148
Weekly minutes	208.8 ± 25.77	248.82 ± 40.60	277.90 ± 44.83	42.82 ***	C3 > C2 > C1	0.357

*** $p < 0.001$; ** $p < 0.01$; ns = non-significant.

Table 5. Descriptive statistics [means and standard deviations (SD)], ANOVA results (F and post hoc tests), and partial eta square (pη2) for the psychological domain.

Psychological Domain Variables	**12 Years (*n* = 49) Mean ± SD**	**13 Years (*n* = 51) Mean ± SD**	**14 Years (*n* = 57) Mean ± SD**	**F**	***Post Hoc***	**$p\eta^2$**
Goal orientation						
Task	4.29 ± 0.65	4.50 ± 0.40	4.31 ± 0.48	1.35 ns	-	0.017
Ego	2.40 ± 0.90	2.37 ± 0.93	2.64 ± 0.99	1.31 ns	-	0.017
Motivational climate						
Performance climate	2.69 ± 0.71	2.65 ± 0.71	2.82 ± 0.63	0.962 ns	-	0.012
Task climate	4.45 ± 0.59	4.50 ± 0.43	4.35 ± 0.40	0.350 ns	-	0.005
Emphasis on mistakes climate	3.16 ± 0.87	3.43 ± 1.02	3.24 ± 0.93	1.062 ns	-	0.014

ns = non-significant

Psychological domain

The data for the psychological domain (goal orientation and motivational climate) are presented in Table 5. No statistically significant differences (p > 0.05) were found for any of the sub-scales among players of the three age-cohorts.

Controlling for biological maturation

Table 6 shows the ANCOVA results when controlling for biological maturation and weekly formal soccer training. Significant differences (p > 0.05) between 14 years old players and 13 years old in the physical performance set remained, except in tapping pedal test with preferred foot, handgrip, medicine ball throw, and 5 m sprint among the three age-cohorts (p > 0.05). Also, differences between age-cohorts in technical skills set only remained in dribbling and pass rebound 90° favoring 14 years old.

Table 6. Descriptive statistics [adjusted means and standard error (S.E.)] from ANCOVA (covariates: weekly formal soccer training sessions, and biological maturation) of young soccer players.

Variables	12 Years (*n* = 49) Mean ± SD	13 Years (*n* = 51) Mean ± SD	14 Years (*n* = 57) Mean ± SD	F	*Post Hoc*	$p\eta^2$
Physical performance						
Yo-Yo IR1 (m)	427.14 ± 47.04	520.14 ± 30.77	667.54 ± 41.05	5.81 *	C3 < C2, C2 < C1	0.082
20 m sprint (s)	3.76 ± 0.03	3.80 ± 0.02	3.63 ± 0.03	8.52 ***	C3 < C2	0.102
30 m sprint (s)	5.22 ± 0.05	5.29 ± 0.04	5.09 ± 0.05	5.45 **	C3 < C2	0.068
Countermovement jump (cm)	25.78 ± 0.82	25.56 ± 0.57	28.10 ± 0.74	3.72 *	C3 > C2	0.047
Standing long jump (cm)	181.86 ± 4.10	176.55 ± 2.81	187.81 ± 3.7	3.13 *	C3 > C2	0.046
T-Test (s)	10.39 ± 0.12	10.36 ± 0.08	9.96 ± 0.11	4.05 *	C3 > C2	0.052
Technical skills						
Dribbling speed (m/s)	2.26 ± 0.34	2.32 ± 0.23	2.43 ± 0.30	4.96 **	C3 > C1	0.062
Pass rebound 90° (cycles/min)	0.58 ± 0.01	0.61 ± 0.09	0.67 ± 0.11	10.08 ***	C3 > C2, C3 > C1	0.118

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Contextual domain

Table 7 shows clubs' characteristics revealing a substantial variability among them, namely in the number of sports available, in the number of soccer players as well as in the number of the clubs' soccer section. All clubs had their own facilities, video room, and warm-up area, but none had hydrotherapy. Most clubs had synthetic grass and four of them had natural grass fields. Almost all clubs had a physician, nutritionist, physiotherapist, and a psychologist. Clubs had mostly coached with Union of European Football Associations (UEFA) C (level 1) certification, and all used social media.

Table 7. Descriptive statistics for clubs' data.

Clubs (*n* = 6)	**Mean ± SD**	**Min-Max**	**n (%)**
Club characteristics			
Number of sports within the club	2.00 ± 0.63	1-3	
Number of soccer players	487.83 ± 139.99	325-700	
Number of years of the club's soccer section	72.70 ± 32.71	14-108	
Club infrastructure			
Own facilities (Yes/No)			6(100)/0(0.00)
Complementary equipment			
Gym (Yes/No)			5(83.3)/1(16.7)
Warm-up area (Yes/No)			6(100)/0(0.00)
Medical/Physiotherapy office (Yes/No)			6(100)/0(0.00)
Hydrotherapy (Yes/No)			0(0.00)/6(100)
Video Room (Yes/No)			6(100)/0(0.00)
Wooden/parquet flooring (Yes/No)			2(33.3)/4(66.7)
Synthetic grass (Yes/No)			5(83.3)/1(16.7)
Natural grass field (Yes/No)			4(66.7)/2(33.3)
Transportation availability			5(83.3)/1(16.7)
Bus			5(83.3)/1(16.7)
Metro			4(66.7)/2(33.3)
Human resources			
Number of coaches	35.17 ± 13.36	20-58	
Coaches' level category certification			
Number of coaches with level 1	35.17 ± 13.36	7-36	
Number of coaches with level 2	4.33 ± 1.50	3-7	
Number of coaches with level 3	1.00 ± 0.00	1-1	
Number of coaches with level 4	1.00 ± 0.81	0-2	
Staff			
Physician (Yes/No)		1-1	6(100)/0(0.00)
Psychologist (Yes/No)		0-1	5(83.3)/1(16.7)
Physiotherapist (Yes/No)		1-5	6(100)/0(0.00)
Nutritionist (Yes/No)		0-1	6(100)/0(0.00)
Nurse (Yes/No)		0-1	1(16.7)/5(83.3)
Club communication			
Social media (Yes/No)			6(100)/0(0.00)

DISCUSSION

The current study investigates soccer players age associated differences in body physique, body composition, physical performance. Technical and tactical skills psychological and club characteristics. Fourteen years old soccer players were more mature, taller, heavier and had less fat mass and greater lean mass than 12 and 13 years old. Fourteen years old were also less endomorphic and more mesomorphic. The oldest age group also and better physical performance and technical skills but not improved tactical skills. The significant differences between age groups for physical performance and technical skills remained in some of the measures when the confounders of maturity status and training were controlled. No significant differences were found for any of the psychological characteristics assessed or club characteristics.

It is well-known that young players' development is multidimensional and complex, however the challenge is to assess and integrate results appropriately [8]. It is also important that a more encompassing understanding of young athletes' pathways to success incorporates the relationships of performance to environmental exposures [55,56]. This is a daunting task that requires a coherent and encompassing holistic framework [57,58]. The present paper identifies some of the challenges and aims to fill this gap using Bronfenbrenner bio-ecological model [7].

The present cohort of soccer players started their formal soccer training during childhood, and we concur with Ford et al. [59] that early exposure to organized systematic practice may expedite developmental attainments in physical performance and technical skills. Furthermore, we found that weekly soccer specific training sessions increased from three, at 12 years of age, to four sessions for older players. This led to a greater accumulation of minutes per week of soccer training and these results are consistent with Ford et al. [60] data. It has been predicted that conducting adequate training in these windows of opportunity will accelerate and enhance the development of youth performance capacities [56].

Biological domain

Our results showed that soccer players' physical, performance and skill characteristics differ between age groupings, favoring the older and more mature players. A similar trend was also reported in young soccer players by Slimani and Nikolaidis [61] systematic review and is supported by empirical research in athletic youth from individual and team sports [62], as well as in other studies of young soccer players [14,63,64]. During the adolescent growth spurt, age-differences in physical performance become pronounced [65] due to dissimilarities among players' timing and tempo of their statural growth. Furthermore, increases in muscle mass, governed by a complex hormonal cascade affecting aerobic and anaerobic enzyme systems tend to favor older youth [5].

After controlling for differences in biological maturation and soccer training, many previous un-controlled physical performance differences became non-significant between 12 and 14 years of age. This result is in line with other research emanating from other cohorts of Portuguese soccer players [15]. We contend that different training foci across age categories [66] associated with advancing biological maturation moderated the affects [16] which maximized young players' training responses [17] and prepared them for competition [56]. However, this was not true for all tests of performance. In the Yo-Yo IR1, speed (20 and 30 m sprint), jumps and agility tests differences still favored 14 years-old relative to 13 years-old, after adjusting for biological maturation and weekly training. This may be due to increased specificities of training demands, differences in lower-limb lengths favoring 14-year-olds as well as increased neuromuscular coordination in the older age group [67].

Skill game proficiency domain

In line with previous reviews [11,68], we found that older players outperformed their younger peers in soccer-specific skills and support previous results [15,64]. Young soccer players systematically improve from 12 to 14 year of age in all technical skills tests, except in the shooting accuracy. This improvement can be explained in part by the combined effects of organized practice [69], and by the process of normal growth [70]. However, after adjusting for biological maturation and weekly formal soccer training, significant differences disappeared between age-cohorts apart from dribbling and rebound pass 90° test. It can be speculated that 14-year-olds advantages may be due to their increased coordinative abilities, for example spatial orientation and kin-esthetic differentiation [71]. Furthermore, since dribbling is one of the most performed techniques during match play, followed by passing [72] and 14-year-old players have played and practices for longer, this could explain these results [73].

In contrast with Kannekens et al. [18], who assessed tactical declarative skills using the TACSIS in elite youth soccer players, we found no significant differences across age-groups, despite the relatively high scores. It is important to emphasize that tactical skills were assessed with a self-reporting inventory that evaluates perceptual-cognitive skills and are linked to knowledge about rules and goals of the game associated to perception of response nomination (i.e., "knowing what to do") which reflects players' own perceptions competence in soccer [74]. Our findings probably reflect players' narrowed age distribution (12–14 years old), with their putative limited exposure to systematic competitive events, and/or their willingness to cope with socially desirable answers.

Psychological domain

In the psychological domain, results from both goal orientation and motivational climate showed no statistically significant differences between age-cohorts. Nevertheless, our results are in line with a study highlighting that young soccer players experience their goal orientation mostly as task orientation [75]. This suggest that our soccer players tended to be self-focused and target improvement may also adopt personal development strategies as well as learning new skills as criteria for competence. Indeed, Nicholls [76] described achievement goal orientations as internalizations of the contextual achievement cues. Additionally, our data also suggests that players perceived the motivational climate as task climate. As Ames [77] argued, there is a socialization influence on young people's achievement goal orientations, and exposure to a strong motivational climate can influence the salience and adoption of the related achievement goal orientation. Therefore, the findings of present study may indicate a putative positive effect of players' contexts (e.g., training environment perceptions and coaches' expectations) to elevate their levels of task achievements [23,78,79].

Contextual domain

According to the ecological approach [7], researchers need to consider the environment in which young soccer players are embedded to be able to better understand the complexities of their development [80]. The results of this study draw some parallels with previous data [81], i.e., we reported that the INEX enlisted soccer clubs represent local grassroots clubs and can be considered as critical elements in also scouting and recruitment. Furthermore, they offered an environment focusing on providing players with resources both on and of the pitch, using systematic methodologies that may accelerate and maximize youngsters' soccer potentials and smooth their career transitions [82].

This study is not without limitations. First, our sample is small, but similar to estimates given by G*Power (effect size = 0.25, α = 0.05, power = 0.80, number of groups = 3: ANOVA, fixed effects, omnibus, one-way); further, it is not representative in terms of players and clubs of the Portuguese youth soccer population. It is recommended that care be taken when generalizing the present results. Second, we only focused on a set of variables that may be more appealing to Human Biologists like growth, biological maturation, motor performance, perceived knowledge, and psychological factors. However, the overall INEX study also has several strengths: (1) it is framed within Bronfenbrenner's bio-ecological theory on human development; (2) considers a wide range of variables evolving from two main sources—the player orbit (biological, skill/game proficiency, psychological) as well as its contexts (family, coach, club); (3) has a series of coherent procedures to guarantee the quality of data acquisition during the four years; and (4) its steering committee comprises well-known experts in the field that are "safe guards" of the overall importance of the study.

Implications for Human Biology

The interest of Human Biologists in studying the various implications of children and adolescents' normal and abnormal growth, physical performance and development within a variety set of conditions and contexts are always with us in a rapid changing world. Furthermore, young athletes, as a special group from any population, also require their utmost attention given: (1) their constant exposure to the manifold demands of training regimens and competitions; (2) physiological and psychological adaptations as well as increased likelihood of injuries; (3) coaches, parental and societal expectations for success. In summary, this research project, with its future aims to describe longitudinal trajectories of development has promises for a broader under-standing on the complex dynamical relationships in young soccer players' growth, body composition and body shape, biological maturation, physical performance, and soccer-specific skills within the network of influences from their varied contexts (family, coaches, and clubs).

CONCLUSIONS

In conclusion, 14 years-old players were found to be more advanced in body physique and had body compositions that were in line with their advanced biological maturation. Furthermore, the 14 years-old outperformed their younger peers in all physical performance and tactical skills components. These components were related to both advanced maturity and increased training. Young soccer players' tactical skills as well as psychological characteristics (goal orientation and motivational climate) did not differ across age-cohorts. Finally, clubs offer a variety of conditions aiming to enhance players success in their response to training and competition.

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Data Availability Statement: Data are available upon request due to ethical restrictions. Individuals or readers interest in the data should contact Dr José Maia (jmaia@fade.up.pt).

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CHAPTER III

LITERATURE REVIEW

PAPER II

Motor performance in male youth soccer players. A systematic review of longitudinal studies.

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ABSTRACT

The aim of this systematic review was to identify and synthesize the available information regarding longitudinal data addressing young soccer players' motor performance changes. Following the Preferred Reporting Items for Systematic and Meta-analyses (PRISMA) statement, literature searches were performed in three databases: PubMed, ISI Web of Science and SCOPUS. The following descriptors were used: football, soccer, youth, young, player, athlete, physical performance, motor performance, longitudinal. The inclusion criteria were original articles in English with longitudinal data of young males (aged 10–18 years), with the aim to investigate motor performance serial changes. The initial search returned 211 records, and the final sample comprised 32 papers. These papers covered the European continent, used mixed and pure longitudinal design with variation in sample size and age range. Reviewed studies tend to use different tests to assess the motor performance and aimed to identify changes in motor performance in several ways. In general, they indicated motor performance improvements with age with a marked influence of biological maturity, body composition and training stimuli. This review highlights the need for coaches and stakeholders to consider players´ motor performance over time whilst considering biological maturation, biological characteristics, and training stimuli.

Keywords: longitudinal; young; soccer players; motor performance

INTRODUCTION

Soccer is the world's most popular sport and participants represent ~4.1% of the total sporting population [1]. With such large numbers of participants, governing bodies and other stakeholders invest significant amounts of money in soccer players' talent identification. The identification and development of the next generation of young soccer players is a key goal for these organisations [2,3]. Thus, the design and implementation of appropriate programmes to unravel youth soccer players' potentials are common practice within soccer academies. These academies support the early development [4] and then the transition of young players into the senior professional world [5,6].

In a cross-sectional study data are collected from many different individuals at a single time point and comparisons are made between different populations. In contrast, in a longitudinal study the same data is collected in the same individuals over short or long periods of time. So, whilst a cross-sectional study considers a snapshot in time, the longitudinal study design considers what happens before or after the snapshot is taken. The benefits of the cross-sectional design are that it allows researchers to compare many different variables at the same time. However, the disadvantage is that cross-sectional studies are not able to provide definitive information about cause-and-effect relationships. A longitudinal study can detect development or changes in population characteristics at both the group and individual level. Thus, longitudinal studies can establish sequences of events and enable the researcher to address cause-and-effect relationships. In youth soccer studies, the longitudinal design allows the researcher to distinguish the effects of training and competition from those associated with normal growth and development. There is much research devoted to describing and interpreting the manifold expressions of soccer players' characteristics and their response to training and competition. Unfortunately, most available evidence is based on cross-sectional data [2] with few longitudinal reports or well-controlled experimental studies. This limits the current knowledge concerning youth soccer players' development [7,8].

Recent systematic reviews of young soccer players have dealt with match running performance [9], talent identification [10], and anthropometric-physiological profiling [11]. These reviews have identified a series of inconsistencies and gaps in the literature which have hampered practitioners' abilities to make evidence-informed decision making [2,12,13]. Further, there is an absence of research in young soccer players' un-folding processes like the interactions of their physical growth and biological maturation with systematic training stimuli, estimation of velocities and spurts in their motor performance and specific skills' levels, as well as players' systematic responses to training and competition [8].

To the best of our knowledge there apparently is no available systematic review dealing with young male soccer players' longitudinal development of motor performance. Therefore, our goal is to provide a summary of existing longitudinal data dealing with male soccer players' motor performance changes during adolescence which is a very important time-window for the nurturing of soccer players' careers.

METHODS

Protocol

This review used the "Preferable Reporting Items for Systematic Reviews and Meta-Analyses Protocols" (PRISMA-P) [13,14] to probe the literature of longitudinal studies in young soccer players' motor performance. We also complied with the Cochrane Handbook for Systematic Reviews of Interventions (version 5.1.0; http://handbook-5-1.cochrane.org/,accessed on 10 October 2020).

Information Sources and Search Strategy

The search strategy comprised two stages. First, the electronic databases MED-LINE (PubMed/PubMed Central interface), Web of Science™ Core Collection and SCOPUS were searched up-to January 2021. The online search was performed based on the following strategy: (football OR soccer) AND (youth OR young OR player OR athlete) AND (physical performance OR motor performance) AND (longitudinal). Second, the reference list of the selected papers was searched for possible studies to be included in the review. Full description of input arguments used in each database is also pro-vided

(Electronic Supplementary Material Table S1). EndNote software (version X9.0, X7.0.1, Thomson Reuters©, USA) was used as citation manager during the processes of search, deduplication, selection and management of the studies.

Eligibility criteria

To be included in the review, original studies had to: (i) have a longitudinal design following players over time, i.e., with at least two repeated observations; (ii) have a sample of young male soccer players, i.e., athletes aged between 10–18 years; (iii) aim to investigate physical fitness/physical/motor performance and/or functional capacities (expressed by muscular strength and/or power, aerobic/anaerobic power, agility, flexibility, movement coordination and speed, as well as specific soccer technical performance like dribbling and shooting, for example) serial changes; (iv) be published in English and in peer-reviewed journals. Studies were excluded if: (i) psychological facets were mainly assessed, (ii) used impaired players, and (iii) concentrated on match-analysis.

Study selection

Two researchers (MA, TNG) independently conducted the online search. Grounded on the eligibility criteria, papers were firstly selected based on their title and abstract, and those selected were screened in full text. To be included in the present re-view, eligible papers had to be selected by the two researchers, and if any discrepancies were observed at this stage, reviewers discussed and resolved inclusion and/or asked for the judgement of a senior researcher (JM). The senior-researcher examined each situation on a case-by-case basis and determined the inclusion or exclusion of a given article using his experience in the field. After the selection of the manuscript to be included, one of the researchers screened the reference lists of the selected papers to identify any other potential paper to be included in the review. Those studies selected in this stage were re-checked by the second researcher, and only those approved by both were considered for inclusion in the present study.

Methodological quality assessment

The quality of the included articles was assessed with the modified version of current established scale used in sport science, health care and rehabilitation [i.e., Cochrane, Coleman, Delphi, and Physiotherapy Evidence Database

(PEDro)]. The cur-rent scale (Table 1) was adapted from a recent review by Sarmento et al. [16]. Articles were assessed based on their purpose (Q1), participants' characteristics (Q2), sample justification (Q3), motor performance assessments (Q4), statistical procedures used (Q5), results and outcome (Q6), study method conclusion (Q7), practical implications (Q8), limitations (Q9), and future direction (Q10). All ten quality criteria were scored on three levels (2-point per item), i.e., a score of zero (no), one (maybe), two (yes) given for each item. The results in total scoring ranged between zero and twenty. A sum of scores from all questions was subsequently computed. To make a fair comparison be-tween studies with different designs, the decision was made to calculate a percentage score as final measure of methodological quality. For this, the total score was converted into percentages, ranging from zero to 100% to ensure that the quality assessment was equitable across all the included articles. Studies were categorised in 3 levels; high (≥ 75%), moderate (50-74%) and low (<50%) methodological quality scores [16]. Methodological quality was not evaluated for the purpose of including/excluding studies. Two researchers (MA, TNG) performed independent assessments. If discrepancies occurred, these were resolved in a consensus discussion with third senior re-searcher (JM).

Table 1. Methodological quality scoring system (adapted from Sarmento et al., 2018 [16]).

	Question	Answer	Score
Q1	Was(were) the aim(s) of study clearly set out?	Yes=2; Maybe=1; No=0	0-2
Q2	Were characteristics of participants presented in detail in methods section? (number of subjects, sex, age, country/city)	Yes=2; Maybe=1; No=0	0-2
Q3	Was sample size justified?	Yes=2; Maybe=1; No=0	0-2
Q4	Are the motor performance to be measured clearly described in the methods section?	Yes=2; Maybe=1; No=0	0-2
Q5	Were statistics clearly presented?	Yes=2; Maybe=1; No=0	0-2
Q6	Results´ details (means and standard deviations and/or change/ difference, effect size/mechanistic magnitude-based inference)	Yes=2; Maybe=1; No=0	0-2
Q7	Were conclusions appropriate given the study methods and the objectives?	Yes=2; Maybe=1; No=0	0-2
Q8	Are there any implications for practice given the results of the study?	Yes=2; Maybe=1; No=0	0-2
Q9	Were limitations of the study acknowledged and described by the authors?	Yes=2; Maybe=1; No=0	0-2
Q10	Are there any future direction described by the authors?	Yes=2; Maybe=1; No=0	0-2
Total			0-20
Strict rules applied (No information = 0 point; 1 – 2 items described = 1 point; all items described = 2 points)			

Strategy for data synthesis

A descriptive synthesis of the findings from the included studies is presented in table 2, where summaries with reference to authors and years of publication were pro-vided. Then, the terminologies used in motor performance variable(s) definition and assessment(s) were examined. Demographic details were extracted, including sample size, age/ age group of participations, and the geographical location of the players. Design aspects (mixed-longitudinal, longitudinal), configuration (duration), and measurement techniques/equipment were also included. Finally, general results regarding changes in motor performance were extracted and main findings were organized and described.

RESULTS

Included studies

Study collection database searches retrieved 267 citations. Figure 1 shows the number of articles found in each electronic database and the literature search/selection processes, including all the steps performed. After exclusion of duplicates, two hundred and five articles remained, and eight additional articles identified through other sources were included in the selection process. The remaining 213 articles were screened based on their title and abstract, and one hundred and seventeen articles were excluded at this stage. The remaining 35 studies were screened for full text assessment. One study was not full text available, and two other articles were excluded since they did not precisely examine the development of motor performance variables. Thirty-two articles fulfilled all the inclusion criteria and were chosen at the end of the screening procedure for the in-depth analysis (i.e., qualitative analysis) and review.

Methodological Quality

Quality scores attributed to studies are found in Table 2 and in the Electronic Supplementary Materials (Table S2). The quality of indicators was as follows: (i) the mean±standard deviation score of the 32 articles was 79±10 percent; (ii) none of the studies achieved the maximum score of 100% or scored below 50% (low quality); (iii) eight articles were classified as of moderate quality (ranging between 51 and 75%) [16-23], but (iv) twenty-four received high methodological quality scores (>75%). Putative deficiencies were mostly related to question 3 (justification of the study sample size), and question 9 (limitations of the study acknowledged).

Studies' characteristics

Location

All studies are from the European continent: eight were conducted in Portugal (25.8%) [18,21,24-29], seven in Belgium (22.6%) [16,22,30-34], four in the United Kingdom (12.9%) [35-38], three in the Netherlands (9.7%) [17,39,40], three in Spain (9.7%) [23,41,42], two in Italy (6.5%) [19,43]. Single studies were conducted in Austria [44], Finland [45], Germany [46], Switzerland [20], and Serbia [47] (Figure 2).

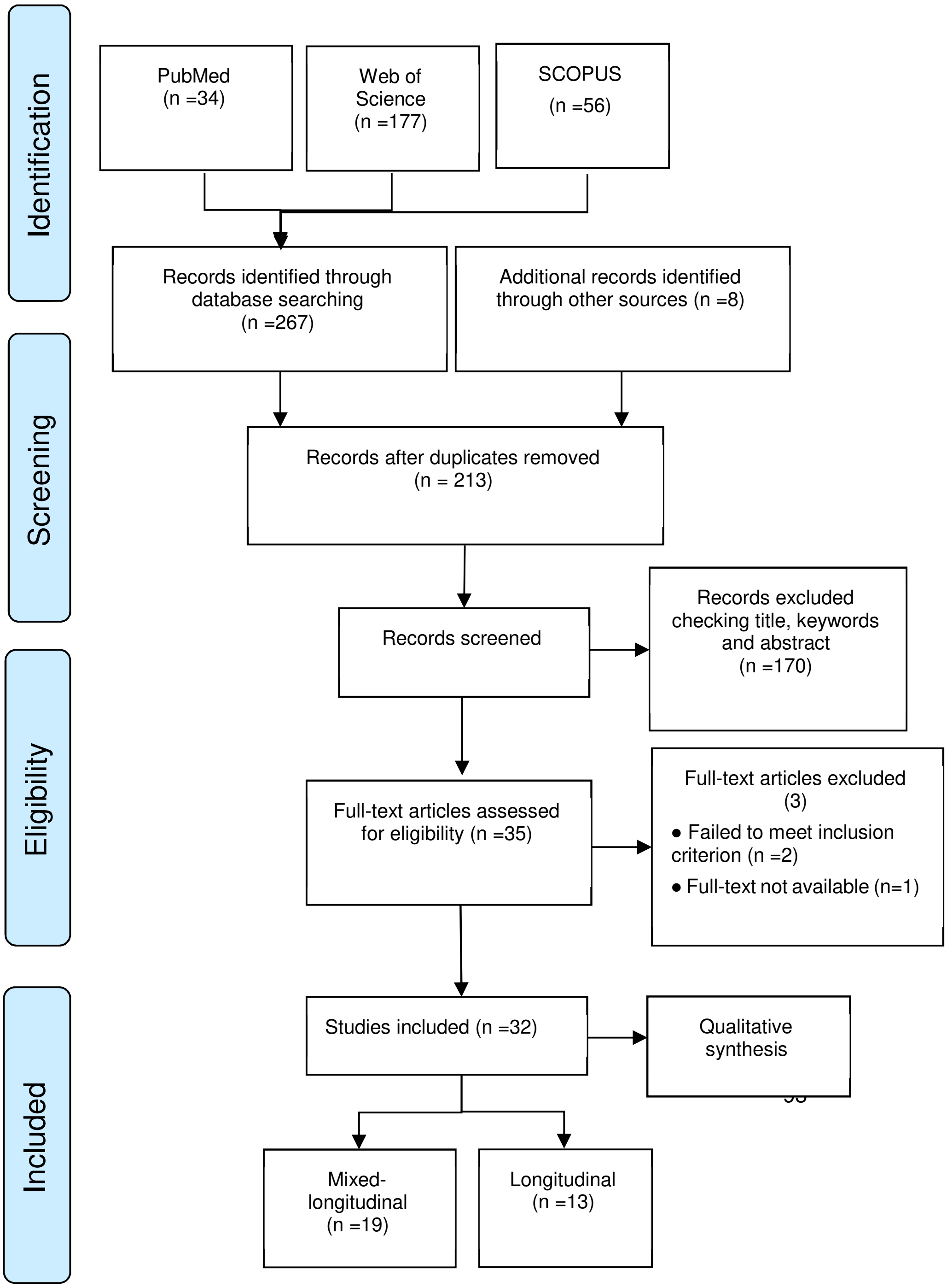

Figure 1. Flow chart including literature search and selection steps following the Preferred Reporting Items for Systematic and Meta-analyses (PRISMA) statement.

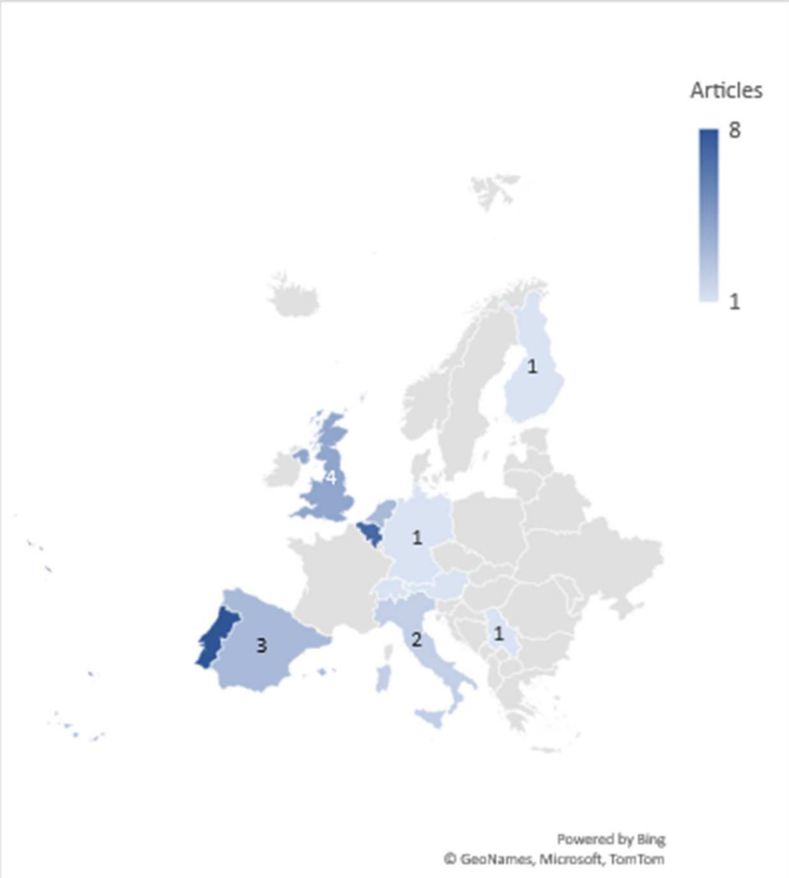

Figure 2. Number of studies by country.

Sample size and design

Motor performance was investigated in a total of 12,190 youth soccer players, representing an average of ~380 players per study. Nineteen studies used a mixed-longitudinal design, with sample sizes ranging between 16 [21] and 2228 [34], and age ranging from 5 to 20 years. Time durations (serial data collection) ranged from three [40] to nine years [44]. Thirteen studies used a pure longitudinal design lasting from ten weeks [29] to eleven years of prognostic period [37]. Sample sizes varied from 6 [36] till 2875 subjects [37], and players age ranged from 7 years [19] to 19 years [37] (Figure 3).

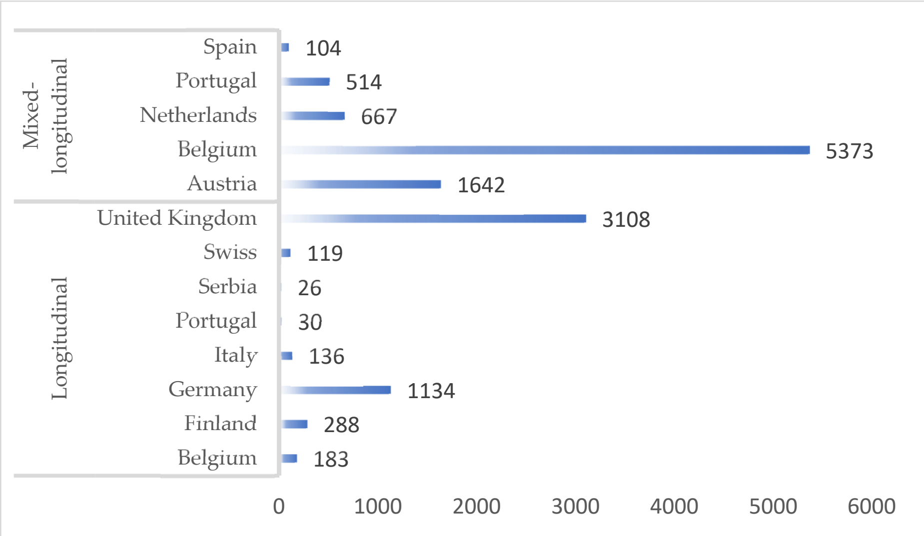

Figure 3. Total number of subjects across studies by country.

Motor performance assessments (tests)

Motor performance, soccer-specific motor performance, and soccer-specific skills were distinctively assessed. Twenty-five studies [16-26,28-30,32-38,42-46] used tests such as: plate tapping, sit and reach, sit-ups, bent arm hang, standing long jump, vertical jump with and without free arm, endurance shuttle run, sprints (10m,15m, 20m, 30m), medicine ball throw 2 kg, 20 multi-stage endurance run, agility (505 test, barrow zigzag run, 8-figure, T-Test hurdles run, slalom course, slalom running with obstacles) and the multistage fitness tests. Seventeen studies [16-18,20,25-28,30,31,34,35,39,41,42,44,47] assessed soccer-specific motor performance namely: 30 m repeated sprint (RSA), agility shuttle run 5×10 m (SHR), intermittent endurance (ISRT), The Yo-Yo Intermittent Recovery Tests, slalom sprint and shuttle sprint. Also, a dozen [17,19-21,26-28,37,40,43,45,46] of them also assessed soccer-specific skills with dribbling, dribbling with pass, shooting, shooting accuracy, ball control, touch of the ball with the body and the head, juggling, passing, and wall pass.

Table2. Characteristics of studies included in the review

Author/Country	Study design Duration	Participants		Motor performance assessments (tests)	Main results	Quality score
		Age	Number			
(Philippaerts et al., 2006) [16]/ Belgium	Mixed-longitudinal 5 yrs	11-13 yrs at baseline	33	Physical performance: Plate tapping, sit and reach (SR), sit-ups, bent arm hang, standing long jump (SLJ), vertical jump (VJ), endurance shuttle run (ESHR). Soccer specific physical performance: 30 m repeated sprint (RSA), agility shuttle run 5×10 m (SHR).	Physical performance improved non-linearly and reached its peak around peak height velocity (PHV), yet with different timing and tempo.	65%
(Huijgen et al., 2010) [17]/ Netherlands	Mixed-longitudinal 5 yrs	12-19 yrs at baseline	267	Physical performance: shuttle sprint and dribble test. Soccer specific skills: slalom sprint and dribble test.	Speed and dribbling improved with age mainly at 12-14 yrs, but with different tempo. Dribbling improved after 16 yrs and sprinting from 14 to 16 yrs. Also, fat free mass, weekly hours of practice and playing position were positively associated with dribbling changes.	70%
(Mirkov et al., 2010) [47]/ Serbia	Longitudinal 4 yrs	11 yrs at baseline	S_g=26 C_g=63	Physical performance: SR, SLJ, countermovement jumps (CMJ) with and without arm swing, slalom running with obstacles, SHR.	Physical performance improved with age in both groups, yet soccer players performed better in agility and motor coordination.	85%

(Roescher et al., 2010) [39]/ Netherlands	Mixed-longitudinal 5 yrs	12-19 yrs at baseline	Pro=53 N_pro=77	Soccer specific physical performance: intermittent endurance (ISRT).	Aerobic capacity increased non-linearly with age but differences between groups occurred from 17 yrs onwards. Training was positively associated with performance.	75%
(Williams et al., 2011) [38]/ United Kingdom	Longitudinal 3 yrs	U12-U16 at baseline	200	Physical performance: sprints 10 m (S10m), 30 m (S30m), VJ.	Physical performance improved linearly but with different rates for 10 m speed, 30 m sprint and vertical jump.	80%
(Gonaus & Muller, 2012) [44]/ Austria	Mixed-longitudinal 9 yrs	14-17 yrs at baseline	1642	Physical performance: S20m, hurdles agility run, CMJ, drop jump, foot tapping reaction medicine ball throw 2 kg, SR, 20 m multi-stage endurance run (MSER). Soccer specific physical performance: (SHR).	Speed, power, flexibility, and endurance improved with age. Power and flexibility as well as endurance effect sizes decreased with age; however, in speed results were stable from 14 to 17 yrs.	80%
(Valente-dos-Santos, et al., 2012) [24]/ Portugal	Mixed-longitudinal 5 yrs	11-13 yrs at baseline	83	Physical performance: MSER.	Aerobic performance unfolding was related to chronological and skeletal ages, and training stimuli.	90%

(Valente-dos-Santos, et al., 2012) [18]/ Portugal	Mixed-longitudinal 5 yrs	11-13 yrs at baseline	83	Physical performance: MSER, CMJ. Soccer specific physical performance: RSA.	Repeated sprint performance changes were related to chronological and skeletal ages, as well as fat free mass, aerobic endurance, and lower limb explosive strength.	55%
(Valente-dos-Santos, et al., 2012) [25]/ Portugal	Mixed-longitudinal 5 yrs	11-13 yrs at baseline	83	Physical performance: MSER, CMJ. Soccer specific physical performance: RSA.	Repeated sprint performance development was related to chronological age, maturity status, fat free mass, body size, aerobic endurance, and lower limb explosive strength and annual training.	80%
(Valente-dos-Santos, et al., 2012) [26]/ Portugal	Mixed-Longitudinal 5 yrs	11-13 yrs at baseline	83	Physical performance: SHR, MSER, CMJ. Soccer specific physical performance: RSA. Soccer specific skills: Ball control, dribbling speed, Shooting accuracy, wall pass.	Overall physical performance development was related to chronological age, maturation status, fat mass, dribbling speed and training stimuli. In general, soccer skills unfolding was related to chronological age, playing position, fat and fat-free mass, repeated sprint and aerobic endurance and training stimuli.	90%
(Huijgen et al., 2013) [40]/ Netherland	Mixed-longitudinal 3 yrs	10-18 yrs at baseline	270	Soccer specific skills: Loughborough Soccer Passing (LSPT).	Soccer skills improved non-linearly: 18% in speed pass, and 32% in speed and accuracy pass with age.	85%

(Carvalho et al., 2014) [41]/ Spain	Mixed-Longitudinal 4 yrs	U11 age category at baseline	33	Soccer specific physical performance: The Yo-Yo Intermittent Recovery Test (YYIR1).	Aerobic performance increased non-linearly with chronological age; yet, between 12-13yrs decreased. Also, aerobic performance was related to training stimuli but not with body size and maturity status.	80%
(Deprez et al., 2014) [30]/ Belgium	Longitudinal 5 yrs	11-14 yrs at baseline	162	Soccer specific physical performance: YYIR1.	Aerobic performance improved non-linearly with age and was related to stature, fat-free mass, and motor coordination.	85%
(Valente-dos-Santos, et al., 2014) [27]/ Portugal	Mixed-longitudinal 5 yrs	10-14 yrs at baseline	83	Physical performance: SHR. Soccer specific skills: Dribbling.	Agility development was related to chronological and skeletal age, stature, fat-free mass and playing position. Dribbling changes were related to chronological and skeletal age, stature, playing position and training stimuli.	85%
(Valente-dos-Santos, et al., 2014) [28]/ Portugal	Mixed-longitudinal 5 yrs	11-13 yrs at baseline	83	Physical performance: SHR, MSSE, CMJ. Soccer specific skills: Dribbling.	Agility changes were related to skeletal age, maturity status, fat-free mass, aerobic endurance, and explosive strength. Dribbling changes were associated with skeletal age, maturity states, fat-free mass, aerobic endurance, explosive strength, and training stimuli.	75%

(Wrigley et al., 2014) [35]/ United Kingdom	Longitudinal 3 yrs	U12-U16 age category at baseline	S_g=27 C_g=18	Physical performance: S10m, S20m, CMJ, agility (505 test). Soccer specific physical performance: RSA, YY IRT2.	Systematic soccer specific training stimuli had significant effects on physical performance changes in young male players independently from baseline levels of performance and biological maturation.	90%
(Bidaurrazaga-Letona et al., 2015) [23]/ Spain	Mixed-Longitudinal 4 yrs	U11 age category at baseline	38	Physical performance: CMJ, agility (barrow zigzag run), S15m.	Non-linear improvement in explosive strength and agility performance with higher development rates for early matures. However, late matures had better linear improvements in speed performance.	75%
(Deprez, et al., 2015) [31]/ Belgian	Longitudinal 2yrs and 4yrs	4yr: ~12 yrs at baseline 2yrs: ~13 yrs at baseline	21 21	Soccer specific physical performance: YYIR1.	Aerobic performance stability was moderate in 4yrs and high over 2 yrs.	85%
(Deprez, et al., 2015) [32]/ Belgian	Mixed-Longitudinal 7 yrs	7-17 yrs at baseline	555	Physical performance: CMJ, standing broad jump (SBJ).	Explosive strength development was related to chronological age and motor coordination. However, in 11-15yrs was positively influenced by stature and negatively by fat mass, but in 16-20yrs positively influenced by fat free mass.	75%

(Deprez, et al., 2015) [33]/ Belgian	Mixed-Longitudinal 7 yrs	11-14 yrs at baseline	356	Physical performance: CMJ, SBJ.	Explosive strength performance improved non-linearly with age in CMJ test and linearly is SBJ. Also, explosive strength performance was related to leg length, fat free mass, flexibility, and motor coordination also maturity status except in SBJ test.	90%
(Forsman et al., 2016) [45]/ Finland	Longitudinal 1 yr	12-14 yrs at baseline	288	Physical performance: S30m, agility (8-figure). Soccer specific skills: Dribbling, passing.	Physical performance and soccer skills remained relatively high and stable across the period of one year.	85%
(Francioni et al., 2016) [19]/ Italy	Longitudinal/ one season	U8-U12 age category at baseline	103	Physical performance: CMJ with and without free arm, S15m. Soccer specific skills: Touch of the ball with the body and the head, passing, shooting, dribbling, dribbling with pass.	Physical performance and soccer specific skills increased with age in one season.	70%
(Zuber et al., 2016) [20]/ Swiss	Longitudinal 3 yrs	U13 age category at baseline	119	Physical performance: S40m, CMJ. Soccer specific physical performance: YY IRT1. Soccer specific skills: Dribbling, passing, Juggling.	Change pattern showed to be partial structural with high individual motor performance stability.	70%

(Carvalho et al., 2017) [42]/ Spain	Mixed-Longitudinal 6 yrs	U11 age category at baseline	33	Physical performance: Agility (barrow zigzag run), S15m, CMJ. Soccer specific physical performance: YYIR1.	Agility and aerobic performance improved non-linearly and reach a steady rate around 3-4yrs after PHV. Sprint and explosive strength maximum velocity occurred around 2 yrs after PHV.	80%
(Fransen et al., 2017) [34]/ Belgian	Mixed-Longitudinal 6 yrs	5-20 yrs at baseline	2228	Physical performance: Agility (T-Test), S10m, S20m, S30m, SR, hand grip. Soccer specific physical performance: YYIR1.	Linear increases of all physical performance tests. Yet, there is a suggestion of reaching a plateau around 15-17 years-of-age.	75%
(Rebelo-Goncalves et al., 2017) [21]/ Portugal	Mixed-Longitudinal 5 yrs	11-13 yrs at baseline	16	Physical performance: MSSE. Soccer specific skills: Dribbling speed, wall pass.	Aerobic capacity and passing skills improved linearly in goalkeepers yet dribbling speed development was non-linear. Soccer skills improvement were mostly explained by training stimuli not by fat-free mass increases.	60%
(Francioni et al., 2018) [43]/ Italy	Longitudinal one season	U14 age category at baseline	33	Physical performance: CMJ with and without free arm, S15m. Soccer specific skills: Touch of the ball with the body and the head, passing, shooting, dribbling, dribbling with pass.	Motor performance improved in U14 age categories during one soccer season independent of training exposure.	80%

(Coutinho et al., 2018) [29]/ Portugal	Longitudinal 10 weeks	U15, U17 age category at baseline	E_g=15 C_g =15	Physical performance: CMJ, S30 m, agility (repeated change of direction).	Physical performance of U15E improved in 10 weeks. Training had a moderate effect in U15E agility and in U17E CMJ improvements.	95%
(Leyhr et al., 2018)/ [46]/ Germany	Longitudinal 3 yrs	U12 age category at baseline	1134	Physical performance: S20m, agility (slalom course). Soccer specific skills: Dribbling, ball control, shooting.	Motor performance improved non-linearly with time. Future professional players performed better at baseline and maintained their superiority across time.	80%
(Bennett et al., 2019) [22] /Belgium	Mixed-longitudinal	6-20 yrs at baseline	2201	Physical performance: CMJ, SBJ.	Explosive strength improved non-linearly with age. The length of the time between assessments did not show a strong impact on player's future performance.	70%
(Moran et al., 2020) [36]/ United Kingdom	Longitudinal 6 yrs	U10 age category at baseline	6	Physical performance: S10m, S20m, CMJ.	Straight speed and lower limb explosive strength performance can arise rapidly and in radical fashions.	90%

(Saward et al., 2020) [37]/ United Kingdom	Longitudinal 11 yrs	U9-U19 age category at baseline	2875	Physical performance: S20m, agility (slalom test), CMJ, the multistage fitness tests/ 20m multi (MSER) (MSFT).	Agility, explosive strength, and speed improved non-linearly except aerobic capacity which improved linearly with age. Differences in playing position occurred in physical performance development. Future professional players had a faster rate as they get older, with different development patterns in explosive strength and agility.	90%

n=number of participations, yrs=years g=group, Pro=professional, S=soccer, C=control, E=experimental.

Changes in motor performance

Overall, reviewed studies aimed at identifying changes in motor performance in different ways: (i) modelling mean trends as well as their covariates [17,18,21,22,24-28,30,32,33,37,39-42,46]; (ii) describing mean changes across time [19,29,31,34,35,38,43-45,47]; (iii) aligning changes by age-at-peak height velocity [36,42]; (iv) identifying timings of spurts in different motor performance tests [16], and (v) describing patterns of change [20].

Most multilevel/mixed modelling with polynomial age trends (age, age^2, and age^3) showed systematic increases in soccer players' aerobic capacity [24,30,39,41], however two did not [21,37]. Training stimuli [24,39] and playing position [37] were linked to aerobic capacity differences, except for goalkeepers [21]; maturity status was not related to these trends [30,41]. There is evidence [23,32,33,37] for lower limb explosive strength (counter-movement jump) non-linear increases with increasing age, but linearly in standing broad jump test [22]. These were related to maturity status [23,33], fat-free mass [33], playing position [37], and previous performance [22]. There are also reports [23,27,28,37,42,46] showing non-linear improvements in change of direction which were explained by training stimuli [23], fat-free mass [27,28], and playing position [27,37].

Most straight speed [23,37,42,46] and repeated sprint ability [18,25] showed non-linear trends, although one showed a linear trend [23]. Maturity status [24], fat-free mass and playing position [37] were associated with these changes. Also training stimuli, lower limb explosive strength, and fat-free mass were identified as additional repeated sprint covariates [18,25]. Furthermore, there was also evidence that future-professional players had systematic higher physical performance levels than future non-professionals [37,46]. Additionally, non-linear trends were observed in soccer technical skills [21,27,28,40,46]. Players with more training stimuli [21,27,28] and more lower limb explosive strength [28] and midfielders [27] were better in dribbling speed.

During soccer seasons significant differences were evident in motor performance [19,34,38,44]. However, one study did not identify such changes in different age groups [38]. There is also evidence that motor performance remained relatively high and stable during the period of one year [45], and in particular aerobic capacity showed a high stability over two years and moderate stability over four years [31]. Three years training was associated with changes is physical performance independent of baseline levels and maturational change [35]. Ten weeks of physical and tactical training in small-sided game had a moderate association on U15 change of direction, moderate improvements on U17 lower limb explosive strength, and a positive effect on attacker' physical performance [29]. In contrast, one study reported that a season follow-up improved U14 players' motor performance independent of training stimuli [43].

Two studies aligned motor performance changes by age-at-peak height velocity (PHV) [36,42]. A case study reported systematic fluctuations in players' straight speed and lower limb explosive strength performance [36]. On the other hand, maximum velocity of lower limb explosive strength occurred 2 years after PHV, straight speed was coincident with PHV, whereas change of direction and aerobic capacity started levelling-off their increases 3-4 years after PHV [42]. Contrarily, one study showed that almost all physical performance peak spurts occurred at PHV and that a plateau in straight speed, lower limb explosive strength and upper-body endurance development occurred after PHV [16]. Finally, one study used a person-centred approach aiming to identify players' patterns of change and showed partial structural stable clustering as well as high individual stability [20].

DISCUSSION

In this systematic review our aim was to provide a comprehensive overview of the current body of evidence of existing longitudinal research concerning young soccer players' motor performance. Across studies, there is evidence of motor performance improvements with chronological age, as well as marked influences of biological maturity, body composition and training stimuli. Further, researchers based their analyses and conclusions on data from pure longitudinal and mixed-longitudinal designs. Notably, all studies sampled European adolescent players.

Study quality

Overall, studies tended to adhere to high quality standards. Yet, a less favourable point is related to the apparent absence of sample size justification and a putative insufficiency of this aspect is evident when discussing results' generalization.

This, in turn, may weaken to a certain degree their external validity [48]. In any case, it is also important to consider pragmatic factors and/or research design requirements when sampling players and have their regular assessments which are often conditioned by their training schedules and academic obligations. This is a viable argument when there is a need for systematic and highly regular assessments [49]. As such, we suggest that future studies should discuss potential flaws of their designs, especially sample size, as well as ways of adequately dealing with missing data [50] before concluding about results' transferability to other settings, namely coaches' decisions when planning their training sessions as well as their expectations.

Location

Although one important aim of the grassroots FIFA programme focuses in "Develop the game" for all [51], there apparently is no doubt that appropriate nurturing of young soccer players is time and money consuming, as well as being a challenging process [52]. Studies retrieved in this systematic review are from European countries that received some form of funding from their governmental agencies. Further, not only their progressive government sport policies incorporated elements of soccer grassroots [53,54], but this is also interest of coaches and managers from private soccer clubs. We suggest that future longitudinal research with young soccer players should also be worldwide. This requires, of course, the presence of collaborative research teams from different countries and continents, linking soccer producer countries with those apparently less advanced in terms of research, team building, and soccer education.

Motor performance assessments

Physical performance tests offer objective assessments of young soccer players that can generally be used for different purposes – description of systematic changes and their covariates, selection and placement, assess individual progress, i.e., diagnostics, prediction, and evaluation of training intervention programs [55]. Most reviewed papers dealt with the description of mean changes in important physiological markers like aerobic capacity, lower limb explosive strength and speed, by the use of different tests. A similar trend was observed for soccer-specific physical performance and technical skills. In general, technical skills improved with chronological age as expected from players' regular training schedules. Even though tests were different for measuring the same construct across studies, similar results were identified and may be linked (i) to the fact that tests were appropriate for the age range and sample characteristics, and (ii) to expected changes during adolescence as part of their natural developmental course plus the systematic and cumulative effects of training and competition.

It was found that soccer physiological demands and technical skills are different for goalkeepers and outfield players [56], and this is probably the main reason why most studies [17,24,27,40] decided to not include goalkeepers during data sampling and/or their analysis. However, Rebelo-Gonçalves et al. [21] sampled 16 goalkeepers that were similarly tested (aerobic capacity, dribbling and passing skills) as their outfield players peers. Yet, in a previous study [27] using the sample from the same research project from Rebelo-Gonçalves et al. [21], authors decided to exclude goalkeepers during sample selection/data analysis because the sample size was very small. Hence, we emphasize the need for future research to direct its goal to goalkeepers' physical performance characteristics and as well as their specific technical skills.

Statistical procedures and changes in motor performance

There apparently is no specific trend in statistical procedures used to analyse motor performance changes across studies' publication years. Most studies [17,18,21,22,24–29,30,32,33,38–42,46] used multilevel/mixed modelling independent of study design, duration, and sample size. In general, they relied on polynomials of age (age, age^2, age^3) to estimate motor performance mean trends (linear and non-linear) as well as adding different predictors of such trends, namely training stimuli and maturity status [21,23,24,27,28,33,39], and reported their different effect sizes.

When focusing on mean changes across time, there apparently is no parallel trend across studies. For example, when using independent factors as group - control versus experimental [47] - or players' levels [29,44], training effects on motor performance as well as its stability vary by using different statistical methods like analysis of variance [29,36], or the general linear model [32]. Yet, we were not able to localize a study that investigated the tracking of players' motor performance notwithstanding the fact that stability of changes was mentioned [31,45]. One study [16] used a non-smoothed polynomial method to identify spurts in several physical performance markers aligned by age-at-PHV, and showed that in spite of their different intensities, they tend to peak around PHV. Another study used a person-centred approach with a cluster analysis to describe players' patterns of change and obtained partial structural stable clustering alongside with high individual stability [20]. One case study [36] showed that physical performance trajectories are irregular occurring quickly and in a radical fashion, suggesting that individual differences between soccer players tend to be temporary. We concur with the authors that there is a novel need to longitudinally investigate young players as single cases, aiming to a better understanding of their erratic and systematic changes in order to assist coaches when structuring their training programmes as well as when making selection decisions.

There is a strong suggestion that motor performance changes are related to biological maturation differences, between and within players, as well as their training stimuli. Yet there apparently is no unequivocal proof of the effects of different training interventions and bio-banding [57] on players' motor performance. Therefore, we recommend additional research for a deeper understanding of the impact of training interventions on motor performance during puberty, especially their hormonal and physiological mechanisms. Additionally, we could not find a theoretical basis for conducting research apart from using ANOVA's or the multilevel/mixed model. We contend that future research should also consider players' contexts, i.e., their families, coaches and clubs. Young players' development occurs within these contexts, and they should be acknowledged. In sum, there is a need to also use multidimensional and/or ecological approaches to enhance our understanding of the complexities of young players' unfolding [7].

Limitations of the current review

This most probably is the first systematic review on young male soccer players' motor performance development based on serial data (pure longitudinal and mixed-longitudinal) and is not without limitations. First, we restricted our search to only English written literature in two databases, which probably limited our scan. Yet, there apparently is little doubt that the most relevant reports are written in English and available is the two most important web repertoires – PubMed and Web of Science. In any case, we urge future systematic reviews to also integrate research written in other languages and available in other data bases. Second, it is possible that the retrieved publications are not free from bias towards positive results. As such, we suggest future studies to combine available data for meta-analyses with proper statistical evaluation of publication bias. Third, we restricted our criteria to only include male players. We urge future research to also consider female players' motor performance serial data. Fourth, it is also possible that the review criteria and search strategy may have limited our scan. Fifth, although no study used in this systematic review reported injuries nor orthopaedic problems, care must be taken when interpreting data because of a putative equinus condition [58].

In spite of these limitations, we tried to present a comprehensive description of available longitudinal data during players' puberty given that it is considered a very important time window that may likely benefit soccer stakeholders to employ better developmental sporting strategies in their organizations to maximize young soccer players potentials and smooth their career transitions.

CONCLUSION

The present study compiled current empirical evidence on longitudinal data dealing with male soccer players' motor performance changes during puberty. Puberty has been found to be a crucial time for nourishing soccer players' future quality vocations. Amongst studies, it was observed that motor performance improved with chronological age, which was linked to biological maturity, body composition changes and training stimuli. Coaches and stakeholder of young soccer players should be aware of the positive influence of physical and biological maturation, training stimuli and systematic fluctuations on players' immediate motor performance. This suggests that selection and deselection decisions should be made based on longitudinal rather than cross-sectional information. We propose that future longitudinal studies with young soccer players also be global, with a focus on playing position, cases study, tracking methods, and deeper understanding of the impact of training interventions on motor performance during puberty, especially their hormonal and physiological mechanisms. Finally, there is a need for more research on the contextual and environmental aspects impacting motor performance development.

Supplementary Materials: Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/sports9040053/s1 , Table S1: Full search strategy for each database with arguments presented as they were used, Table S2: Scores attributed to each study according to twelve criteria used in evaluating methodological quality.

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Electronic Supplementary Materials

Table S1. Full search strategy for each database with arguments presented as they were used.
PubMed
("football"[All Fields] OR "soccer"[All Fields]) AND ("youth"[All Fields] OR "young"[All Fields] OR "player"[All Fields] OR "athlete"[All Fields]) AND ("motor performance"[All Fields] OR "physical performance"[All Fields]) AND "longitudinal"[All Fields]
Web of Science
((football OR soccer) AND (youth OR young OR player OR athlete) AND (motor performance OR physical performance) AND (longitudinal)) - Refined by "Document Types": Article
SCOPUS
TITLE-ABS-KEY((football OR soccer) AND (youth OR young OR player OR athlete) AND ("motor performance""physical performance") AND longitudinal)

Table S2. Scores attributed to each study according to twelve criteria used in evaluating methodological quality

Citied	Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Total (∑)	Percent	Quality
16	(Philippaerts et al., 2006)	2	2	0	1	1	1	2	2	0	2	13	65%	[moderate]
17	(Huijgen et al., 2010)	2	1	1	2	2	2	2	0	2	0	14	70%	[moderate]
47	(Mirkov et al., 2010)	2	1	1	2	2	1	2	2	2	2	17	85%	[high]
39	(Roescher et al., 2010)	2	1	0	2	2	2	2	2	0	2	15	75%	[high]
38	(Williams et al., 2011)	2	1	1	2	2	2	2	2	0	2	16	80%	[high]
43	(Gonaus & Muller, 2012)	1	1	0	2	2	2	2	2	2	2	16	80%	[high]
24	(Valente-dos-Santos, et al., 2012)	2	2	0	2	2	2	2	2	2	2	18	90%	[high]
18	(Valente-dos-Santos, et al., 2012)	2	1	0	2	2	2	2	0	0	0	11	55%	[moderate]
25	(Valente-dos-Santos, et al., 2012)	2	1	1	2	2	2	2	2	2	0	16	80%	[high]
26	(Valente-dos-Santos, et al., 2012)	2	2	1	1	2	2	2	2	2	2	18	90%	[high]
40	(Huijgen et al., 2013)	2	1	0	2	2	2	2	2	2	2	17	85%	[high]
41	(Carvalho et al., 2014)	2	1	1	2	2	2	2	2	2	0	16	80%	[high]
30	(Deprez et al., 2014)	2	2	0	1	2	2	2	2	2	2	17	85%	[high]

27	(Valente-dos-Santos, et al., 2014)	2	2	0	2	2	2	2	2	1	2	17	85%	[high]
28	(Valente-dos-Santos, et al., 2014)	2	2	0	2	2	2	2	0	1	2	15	75%	[high]
35	(Wrigley et al., 2014)	2	1	2	1	2	2	2	2	2	2	18	90%	[high]
23	(Bidaurrazaga-Letona et al., 2015)	2	1	0	2	1	2	2	2	0	2	14	70%	[moderate]
31	(Deprez, et al., 2015)	2	1	0	2	2	2	2	2	2	2	17	85%	[high]
32	(Deprez, et al., 2015)	2	2	0	1	2	2	2	2	0	2	15	75%	[high]
33	(Deprez, et al., 2015)	2	2	0	2	2	2	2	2	2	2	18	90%	[high]
45	(Forsman et al., 2016)	2	2	0	2	2	1	2	2	2	2	17	85%	[high]
19	(Francioni et al., 2016)	2	1	2	1	2	2	2	2	0	0	14	70%	[moderate]
20	(Zuber et al., 2016)	0	2	1	2	1	2	2	0	2	2	14	70%	[moderate]
42	(Carvalho et al., 2017)	2	1	1	1	2	2	2	1	2	2	16	80%	[high]
34	(Fransen et al., 2017)	2	1	0	1	2	1	2	2	2	2	15	75%	[high]
21	(Rebelo-Goncalves et al., 2017)	1	2	0	2	2	2	0	1	0	2	12	60%	[moderate]
43	(Francioni et al., 2018)	2	2	1	1	2	2	2	2	2	0	16	80%	[high]
38	(Coutinho et al., 2018)	2	2	1	2	2	2	2	2	2	2	19	95%	[high]
46	(Leyhr et al., 2018)	2	2	2	1	2	2	2	0	1	2	16	80%	[high]

22	(Bennett et al., 2019)	1	2	1	1	2	1	1	1	2	2	14	70%	[moderate]
36	(Moran et al., 2020)	1	2	2	2	1	2	2	2	2	2	18	90%	[high]
37	(Saward et al., 2020)	2	2	0	2	2	2	2	2	2	2	18	90%	[high]

CHAPTER IV

MODELLING PERFORMANCE

Paper III

Change and stability in straight speed and agility in young male Portuguese soccer players. The INEX study

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Under submition

ABSTRACT

We modelled young Portuguese soccer players' physical performance trajectories in 20- and 30-meters straight speed and agility and examined their relationships with chronological age, biological maturity, explosive strength and weekly training. A total of 314 male soccer players clustered into three age-cohorts (12, 13 and 14 years) were recruited from six soccer clubs and were followed consecutively over 4-years using a mixed-longitudinal study design. A multilevel hierarchical linear model was used for data analysis. Linear negative trends ($p<0.01$) were observed in 20- and 30-meters straight speed and agility, i.e., they needed less time to perform the tests. On average, players with higher accumulated hours in weekly soccer training, lower limb explosive strength were faster and more agile ($p<0.01$). Maturity offset independently explained differences in players' trajectories in straight speed and agility development ($p<0.01$). This indicates that soccer-specific training impacts players physical performance during puberty. This highlights the importance of key stakeholders to be aware of the positive influence of physical, biological maturation, and training stimuli to ensure a positive developmental sporting policy to expand young soccer players' capabilities and smooth their career transitions.

Keywords: maturity, soccer, youth, training, change of direction, explosive strength

INTRODUCTION

Soccer is characterized by continuous, yet unpredictable, physical performance levels occurring at different intensities and modes during a match situation (Dolci et al., 2020, Turner and Stewart, 2014). Young soccer players' technical and tactical performance are linked to their levels of speed (Williams et al., 2020). The winning team during a soccer match depends on the players' body size, shape, and body composition, suitable levels of strength, speed, and technical characteristics combined with appropriate team tactics (Barreira et al., 2020, Lepschy et al., 2018, Rebelo et al., 2013, Tuo et al., 2019, Yi et al., 2019). Consequently, young players must respond quickly to the ever-changing constraints of competitive performance settings while attaining different types of speed-related actions and accelerating and decelerating the body during the game (Jeffreys et al., 2018). In addition, the soccer player relies on attacking and defence play, repossession, passing through the defenders and or one-on-one interactions. These performance trends have been observed to be present worldwide (Barnes et al., 2014, Dellal et al., 2011, Haugen et al., 2013, Lepschy et al., 2020, Mitrotasios et al., 2019).

Adequate levels of expression of physical performance emerge as an important contributing factor of success in soccer, whatever the competitive level. For example, Faude et al. (2012) analysis of 360 goals in the first German national league highlighted that straight speed was the most dominant physical action when scoring goals, followed by changes of direction. Further, it has been suggested that the ability to perform sudden changes of direction and body control as well as maximum straight speed are viewed as valid criteria for players' detection at different ages and competition levels (Stolen et al., 2005). In summary, all these arguments and data highlight the critical importance of straight speed and agility in soccer for success. Yet, the developmental patterns are still open to debate, as well as what predicts them throughout players' long-term development (Kelly and Williams, 2020).

Recent longitudinal data from German soccer players Under 12 (U12) to U15 age categories, as well as from English (U9-U19) talent development systems (Leyhr et al., 2018, Saward et al., 2020), showed non-linear trends with increasing chronological age in both straight speed and agility. In contrast, in a mixed-longitudinal study with Belgian soccer players (5-20 years' old), linear trajectories were found for agility and speed, with a putative plateau attained around 16 years (Fransen et al., 2017). Valente-dos-Santos et al. (2014) reported positive associations between maturity status, body composition, lower limb strength, and aerobic capacity with change of direction in 11-17 yrs-old Portuguese players, but Bidaurrazaga et al. (2015) showed that the interaction of chronological age with maturity status was not significantly related to agility changes. Further, Ford et al. (2011) illustrated the importance of conducting adequate training stimuli to increase straight speed and agility during the adolescent years which was later shown by Di Giminiani and Visca (2017) in 13-15 years old Italian players. Yet, although seasonal changes in English players' speed and agility were linked to their soccer training, maturity status may have influence upon them (Morris et al., 2018). On the other hand, Meyers et al. (2017), Patel et al. (2020) and Loturco et al. (2020) emphasised that there is currently poor quantitative evidence validating the factors that strengthen the natural unfolding of straight speed and agility in youth soccer players. Accordingly, it is cardinal to examine the longitudinal development, as well as stability in changes (i.e., tracking) in straight speed and agility for a more comprehensive understanding during players' adolescent years.

Therefore, the present study aims to: (1) to model mean changes in 20 and 30 m straight speed and agility, (2) to investigate the putative influences of maturity offset, explosive strength, and weekly training, and (3) to describe the tracking of soccer players' performance in straight speed and agility.

METHODS

Study design and sample

Youth soccer players were selected from participants in the In Search of Excellence in Sport – A Mixed-Longitudinal Study in Young Athletes (INEX) study (2016–2019): https://inex-cifi2d.pt/. INEX was conducted in the Porto metropolitan area, northern Portugal. In brief, this project investigates the dynamics of growth, physical performance, specific-skills, game knowledge and psychological characteristics of Portuguese adolescent basketball, handball, soccer, volleyball, and water polo athletes within the contexts of their sports clubs. The INEX project is grounded on the bio-ecological systems theory (Bronfenbrenner, 2005) and uses a multilevel model (Snijders and Bosker, 2012) analytical framework to analyses data collected from 3 to 4 years of data collection across 3 age cohort. Such a study design is called a mixed-longitudinal study. Given the flexibility of the multilevel model and the parameter estimation procedures this allows for the handling of missing data. In practice this means there is no need to have complete data on every subject at every visit occasion (Hedeker and Gibbons, 2006, Laird and Ware, 1982).

In total 314 young male football players (from all 3 age-cohorts) were measured annually over four consecutive years (Abarghoueinejad et al., 2021). Participants were randomly selected to participate by their coaches and/or club team managers. To be included in the present analysis complete valid data was required from a minimum of two-time points to a maximum four-time points. In total, 178 players fulfilled this criterium and their data is presented here. The study design considered 3 age cohorts (12, 13, 14) at study entry. These age cohort overlapped during the 3 years of continuous data collection. cohort 1 (12-15 years), cohort 2 (13-16 years), and cohort 3 (14-17 years). Table 1 shows the number of measurements per time-period for each age category.

All measurements were performed annually during the same time-period (in December of each year within a 2-3 weeks' time window). Legal authorization was obtained from clubs' directors, and parents gave their informed consent and players informed ascent. The Ethics Committee (CEFADE 13.2017) of the Faculty of Sport, University of Porto (FADEUP) approved the project, and the Porto Football Association provided permission for data collection.

Table 1. Number of soccer players measured by age and time-point.

Age (years)	Time-moments				Total
	December 2016	December 2017	December 2018	December 2019	
12.0 (12.00-12.99)	24	28			52
13.0 (13.00-13.99)	39	37	37		113
14.0 (14.00-14.99)	48	44	31	28	151
15.0 (15.00-15.99)		48	35	16	99
16.0 (16.00-16.99)			22	14	36
17.0 (17.00-17.99)				11	11
Total	111	157	125	69	**462**

Anthropometry

Anthropometric measurements were performed by trained staff of the Kinanthropometry Lab (FADEUP) following standard protocols (Ross and Ward, 1986). Standing height (Harpenden portable stadiometer; Holtain Ltd., Crymych, UK) and sitting height (Harpenden sitting table; Holtain Ltd., Crymych, UK) were measured to the nearest 0.1 cm with subjects' heads positioned to the Frankfurt plane. Leg length (accuracy=0.1 cm) was calculated as the difference between standing height and sitting height (trunk length). Weight was measured using a bioelectrical impedance scale (Tanita® model BC-418MA, Tokyo, Japan) with a 0.1 kg precision. Players were measured in their soccer kits without shoes.

Biological Maturation

A measure of maturity offset was used to assess a biological age, an estimation of maturation using the Mirwald et al. (2002) equation: Maturity offset = -9.236 + (0.0002708 * (Leg Length *Sitting Height)) + (-0.001663 * (Age * Leg Length)) + (0.007216 * (Age*Sitting Height)) + (0.02292 * (Weight/Height*100)). The maturity offset estimates the temporal distance (in decimal years) from age-at-peak height velocity (PHV) at the time of measurement. The error is within ±1.14 years in 95% of cases. A positive (+) maturity offset represents the number of years the participant is post attainment of PHV, whereas a negative (-) maturity offset indicates the number of years the participant is prior to attainment PHV. Age at PHV is calculated by adding chronological age to maturity offset age.

Physical performance

Physical performance was assessed in an indoor stadium with subjects in their soccer kits and running shoes:

- Straight speed was assessed with 20- and 30-meters tests: players ran in a straight line at full speed. Time (s) was recorded using the photoelectric cells system Speed Trap II (Brower Timing Systems LLC., USA) mounted on tripods which were set ~ 1 m above the floor at market points beginning (RS-20 m) 20 meters and (RS-30 m) 30 meters. Subjects were instructed to starting from a stationary position with their preferred foot forward, placed on a line marked on the floor. Participants performed two maximal trials over the 30 m distance with 2-minute rest intervals. The best time performance (seconds) at each distance was considered as the test result (Kirkendall et al., 1987).

- Agility was measured with the T-Test (Semenick, 1990). Time (s) was recorded using photoelectric cells system Speed Trap II (Brower Timing Systems LLC., USA) which were mounted ~ 1 m above the floor and were positioned 3 m apart facing each other on either side of starting line. Four cones were placed in a T shape: two 10 m apart and two placed 5 m on either side of the second cone. Players were directed to start from a stationary position with their preferred foot forward, placed on a line marked on the floor, the athlete runs straight between the first two cones and then shuffles to the left 5 m and then shuffles to the right 10 m, and then back to the middle point, and the runs back to the start line. Each player performed two trials with ~2 minutes rest intervals and the best time (seconds) was used as the test result.

- Explosive strength was estimated from countermovement jumps (Bosco et al., 1983). During each trial, players started in a standing position on an AMTI OR6-WP force plate (Advanced Mechanical Technology Inc., Watertown, MA, USA) operating in 2000 Hz. Feet were placed hip-width to shoulder-width apart and hands akimbo. Participants were then instructed to start with equal weight distribution; and then drop into the countermovement position, followed by a maximal effort vertical jump, and landing in an athletic position on the force plate. The player resets to the starting position after each jump, and the procedure was completed for a total of three jumps, with approximately 2 minutes rest intervals. The best jump height (cm) was considered as the best performance and used for further analysis.

Training information

Weekly hours of soccer-specific training sessions were obtained from players' self-reported questionnaires and confirmed by the managers/coordinators of their academies.

Statistical Analyses

Descriptive statistics were performed in SPSS version 27.0 (SPSS, Chicago, IL, USA) and include means and standard deviations. While the statistical parametric mapping analysis for the countermovement jump (CMJ) was performed in MATLAB, the force plate data were post-processed using a custom Matlab2019a routine (MATLAB, MathWorks Inc., Natick, MA, USA). The CMJ phases were identified as advised (Linthorne, 2001), as were the jump height calculation methods.

Given the nested structure of the data hierarchical multilevel linear model were used to predict physical performance developmental trajectories (Hedeker and Gibbons, 2006). For each physical performance variable (20m, 30m and agility), a two-level hierarchical structure was defined with repeated measures (level 1) nested within soccer players (level 2). Given the cohorts' sequential waves of data collection, Hedeker and Gibbons (2006) methodology was used to centre the time (age) metric as the age of the youngest cohort, 12 years. Centring age at 12 years gives age centred values of 0, 1, 2, 3, 4, 5 which corresponds to 12, 13, 14, 15, 16, 17 years of age. The important advantage of using hierarchical linear models to study development in conjunction with maximum likelihood estimations is the flexibility of the approach in handling missing data. Unlike conventional methods, the approach can readily incorporate all participants who have been observed at least once. Results of the analysis can be interpreted as if no missing data were present under the assumption that the data are missing at random. Kenward and Roger (1997; 2009) methodology for inferences in fixed effects, as well as its restricted maximum likelihood parameter estimates were implemented using STATA 16 software .The following modelling strategy was used: first, spaghetti plots were derived and inspected for putative time trends (Electronic Supplementary Material Figure S1); second, linear trends were fitted to the data in each physical performance test (model 1) third, we fitted a new model (model 2) including time-varying predictors, namely: maturity offset, CMJ, and weekly hours of training.

To describe 20m, 30m and agility unfolding stability, or tracking, we relied on Foulkes and Davis (1981) γ statistic which computes the probability that two growth curves do not intersect (cross) over time, i.e., pairs of growth curves tend to maintain their relative position over the time frame of the study. The γ statistic only takes positive values, ranging from 0 to 1. According to their developers, if $\gamma \leq 0.50$ there is no tracking; if $0.50<\gamma<1.00$ tracking is present, and if $\gamma=1.00$, tracking is said to be perfect. In this analysis we used the LDA software (Schneiderman and Kowalski, 1993). Finally, in all analysis alpha was set to 5%.

RESULTS

Descriptive statistics for anthropometry, biological maturation, physical performance, and training information of players by age group are shown in Table 2. As expected, all scores generally improved with age (lower scores for time elapsed tests correspond to better performance). Older soccer players tend to be taller and heavier, on average, and they were also more biologically mature than younger players. Similarly, physical performance tests also tend to show best results for older players (greater lower limb explosive strength, faster and more agile than their younger peers). Further, older soccer players also accumulated more hours in weekly soccer training.

Table 2. Descriptive statistic [means and standard deviations (SD)] by age group (n=462).

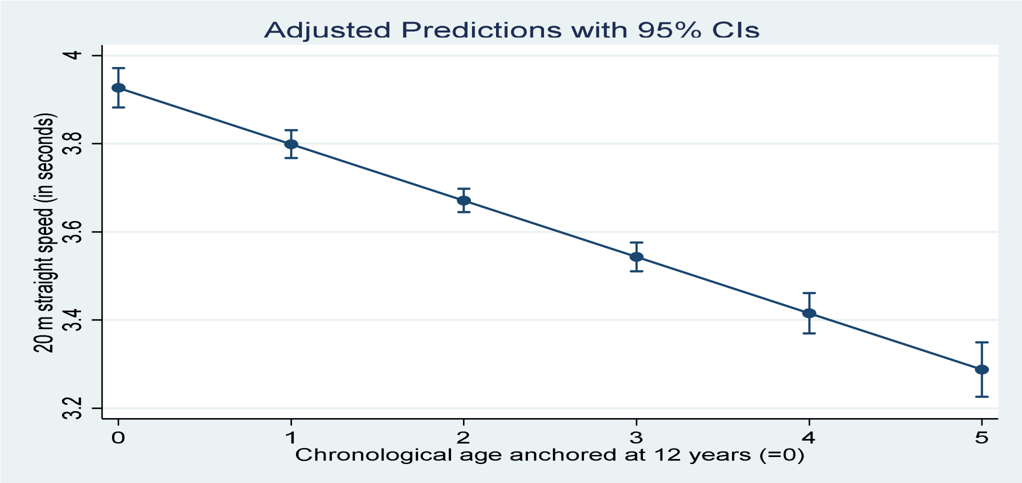
	12 yrs (n= 52)	13 yrs (n= 112)	14 yrs (n= 152)	15 yrs (n= 99)	16 yrs (n= 36)	17 yrs (n= 11)
Variable	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Decimal age (yrs)	12.55±0.30	13.57±0.28	14.51±0.30	15.50±0.27	16.47±0.26	17.47±0.33
Anthropometry						
Height (cm)	155.32±7.85	162.20±8.09	168.02±7.35	172.25±6.46	172.61±5.60	176.40±4.84
Sitting height (cm)	80.51± 3.83	84.00±4.45	86.91± 4.34	89.65±3.72	90.33±3.20	93.16±3.81
Weight (kg)	43.90±9.21	51.17±9.76	57.11±9.33	62.16±9.30	63.75±6.72	70.50±11.20
Biological maturation						
Maturity offset (yrs-to-PHV)	-1.23±0.55	-0.26±0.67	0.60±0.68	1.49±0.60	2.10±0.40	3.11±0.64
Physical performance						
Sprint 20m (s)	3.93±0.26	3.84±0.25	3.63±0.24	3.54±0.22	3.44±0.16	3.21±0.21
Sprint 30m (s)	5.50±0.32	5.31±0.33	5.01±0.33	4.48±0.30	4.65±0.20	4.36±0.26
Agility T-test (s)	10.41±0.77	10.36±0.77	9.77±0.75	9.36±0.77	9.24±0.70	8.90±0.44
Countermovement jump (cm)	22.90±3.71	24.81±4.72	27.07±4.67	30.08±4.87	32.56±4.31	32.60±4.74
Training information						
Weekly hours of training ($h \cdot w^{-1}$)	3.60±0.57	4.07±0.69	4.60±0.78	5.08±0.81	5.18±0.82	5.36±0.50

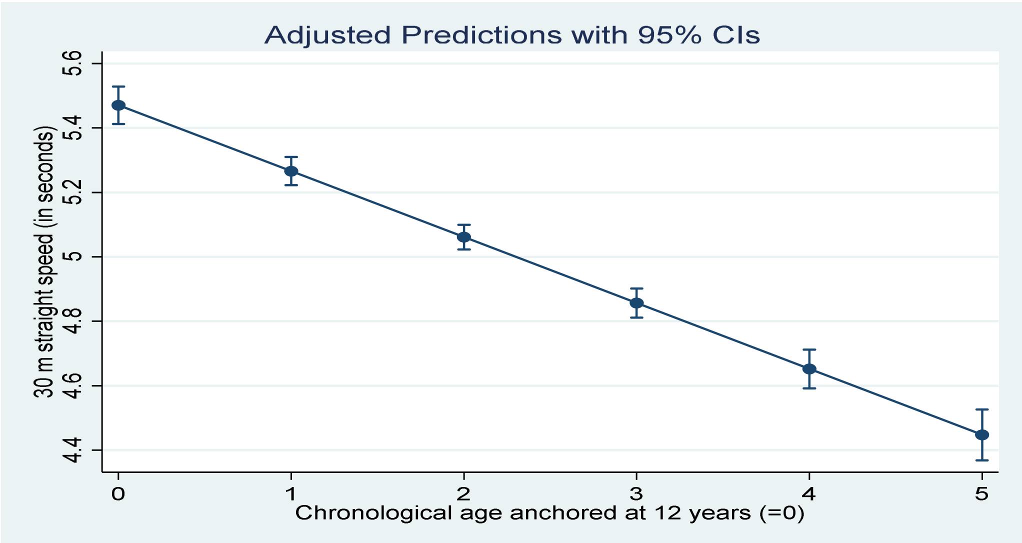
The results of multilevel models are shown in Table 3 we present results for model 1 (without any time-varying predictor, and plotted in Figures 1), also for model 2 (full model with all covariates) that fitted the data better. The significant random effects show that the predicted variable is increasing over time (Residual) and that Players has different intercepts. The fixed effects show that on average, a random 12-year-old soccer player (see intercept) runs the 20 meters straight in 3.770±0.030 s, and the 30 meters in 5.240±0.040 s; his agility time to complete the test is 10.171±0.104 s, and that all these estimates are statistically significant ($p<0.001$). Also found were significant independent time dependant effects of age centred β=-0.382±0.173, p<0.05, (β=-0.062±0.023, p<0.01), and (β=-0.131±0.062, p<0.05 for the 20, 30-meters straight speed and agility test. Indicating that with age soccer players become faster and more agile. Biological age (maturity offset) was also significantly independently related with the developmental trajectories of 20m (β=-0.509±0.016, p<0.01), 30m (β=-0.107±0.024, p<0.001), and agility (β=-0.165±0.061, p<0.01). Similarly, players with higher explosive strength were systematically faster in 20m (β=-0.007±0.001, p<0.001), 30m (β=-0.009±0.001, p<0.001) and were more agile (β=-0.020±0.004, p<0.001). Finally, more weekly hours of training were, on average, related to higher performance levels in 20m (β=-0.095±0.014, p<0.001), 30m (β=-0.108±0.019, p<0.001), also demonstrated higher agility and body control (β= -0.150±0.050, p<0.01).

Table 3: The multilevel regression models for physical performance development: parameter estimates (± standard-errors) for fixed and random effects.

Variables	20-meters		30-meters		Agility	
	M_1	M_2	M_1	M_2	M_1	M_2
Fixed effects						
Intercept (12 years)	3.926±0.022***	3.770±0.030***	5.45 ±0.030***	5.240±0.040***	10.545±0.722***	10.171±0.104***
Age	-0.27±0.009***	-0.382±0.173*	-0.204±0.011***	-0.062±0.023**	-0.357±0.072***	-0.131±0.062*
Maturity offset (yrs-to-PHV)		-0.509±0.016**		-0.107±0.024***		-0.165±0.061**
Countermovement jump (cm)		-0.007±0.001***		-0.009±0.001***		-0.020±0.004***
Weekly soccer training ($h \cdot w^{-1}$)		-0.095±0.014***		-0.108±0.019***		-0.150±0.050**
Random effects						
Player	0.015±0.003	0.002±0.003	0.044±0.007	0.022±0.005	0.155±0.037	0.123±0.350
Residual	0.041±0.003	0.043±0.004	0.055±0.005	0.054±0.005	0.426±0.036	0.410±0.356
Model summary						
Log restricted-likelihood	11.733	37.097	-90.102	-61.027	-511.260	-498.510
Number of estimated Parameters	4	7	4	7	4	7

Model= M, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$





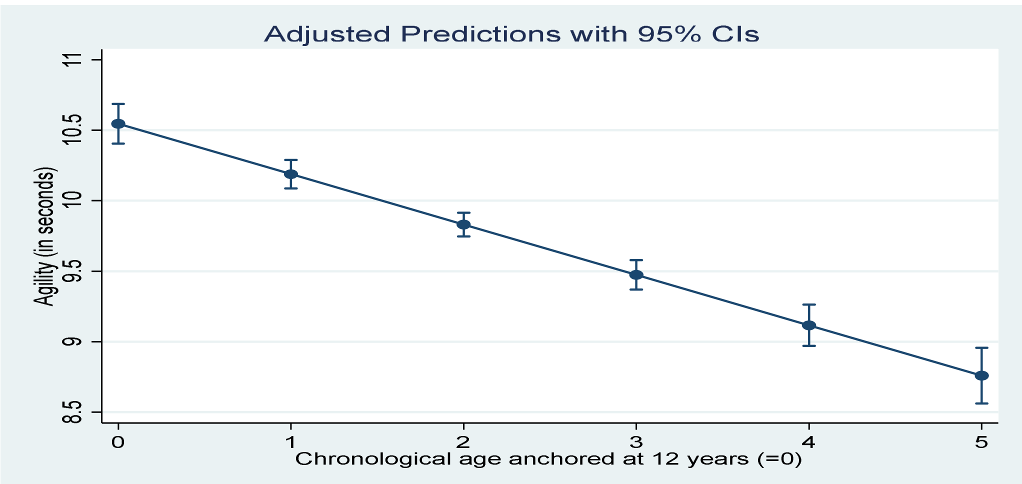


Figure 1: Predicted 20m, 30m straight speed and agility by age centred from models in table 3; linear trends with 95% confidence intervals.

In a preliminary analysis (results not shown) we did not find any statistically significant cohort effects in PP's trends. Therefore, data from the three cohorts were lumped together, and Foulkes and Davies γ was computed for all subjects. For 20 m, γ=0.572±0.020, for 30m, γ=0.695±0.015, and for agility, γ=0.618±0.0190 suggesting some degree of tracking of intraindividual change trajectories within interindividual differences.

DISCUSSION

The study found that 20 and 30 m straight speed and agility all improved with age, that chronological age, biological age, explosive strength and weekly training hours all were significant predictors of 20 and 30 m straight speed and agility and that some degree of tracking of soccer players' performance in straight speed and agility was present.

This mixed-longitudinal study modelled changes in 20- and 30-meters straight speed and agility as well as the associations with time-varying covariates (maturity offset, lower limb explosive strength and weekly soccer-specific training) in young male Portuguese soccer players aged 12 to 17 years. Key findings showed systematic linear increases in physical performance, i.e., with increasing age players get faster and more agile, besides being more biologically mature, with greater lower-limb explosive strength and accumulating more hours in weekly soccer-specific training. These results have critical and direct implications for coaches and sport scientists engaged in the development and training of soccer players.

It has been suggested that speed and agility are key requirements and discriminant variables in young soccer players (Williams et al., 2020), and our study empirically showed that they increase with age from 12 to 17 years of age and in addition were influenced by level of maturity. This trend is similar to other mixed-longitudinal/pure-longitudinal studies with different time durations in Portugal (Valente-dos-Santos et al., 2014), Spain (Bidaurrazaga-Letona et al., 2015), Belgium (Fransen et al., 2017), Germany (Leyhr et al., 2018), and England (Saward et al., 2020). Further, our data suggest that from twelve to seventeen years straight speed and agility development continues without plateauing (Figure 1) which are in in partial agreement with Fransen et al. (2017) Belgium players' results, since they found a putative decelerated development from 16 yrs onwards. However, care must be taken in these comparisons because they used a different statistical approach - a segmental linear model. We suggest that the linear improvements found in our study may be linked to different maturation rates in the first phases of adolescence (Malina et al., 2004), to systematic soccer training stimuli as well as increasing muscle and lower limb strength (Meylan et al., 2010).

Although there is no consistent evidence of the magnitude of the confounding effects of biological maturation on selection process and developing physical capabilities and technical skills of young soccer players (Kelly and Williams, 2020), there is uniformity in that it is an important facet to consider when explaining differences in young athletes' physical performances (Balyi et al., 2013). Our study showed that the maturity offset independently explained such differences in the developmental trends in 20- and 30-meters straight speed and in agility. These results are in line with previous reports from Spanish (Bidaurrazaga-Letona et al., 2015) and Portuguese (Valente-dos-Santos et al., 2014) young soccer players. These results may be related to advantages in size, strength and power linked with advancing in maturity. We therefore suggest coaches to be more aware of the maturity-related gradient of selection/deselection. Further, our data may also be in line with the bio-banding competition approach (Cumming et al., 2017).

It is well-known that during puberty, body size changes markedly with advancing chronological age and biological maturation, and its change accompanies an increase in muscle size and strength (Baxter-Jones, 2017). In our study we found that lower limb explosive strength, as a time-varying covariate on physical performance trajectories, was positively related changes in 20- and 30-meters straight speed, and agility. This is concordant with a previous report on agility (Valente-dos-Santos et al., 2014). Also, Freitas et al. (2021) and Philpott et al. (2020) suggested that training for jumps improvement may potentially enhance sprints, agility. We contend that such relationship may be associated with testosterone and insulin-like growth factors circulation hormones because of their ergogenic and muscle hypertrophy levels enhancing skeletal muscle strength as manifested during puberty (Handelsman et al., 2018). Likewise, it may also be explained by an enhancement of neuromechanical capacity and biomechanical factors (Bergeron et al., 2015, De Ste Croix, 2013).

We showed that systematic training was positively and independently related to changes in straight sprint and agility, i.e., with increasing weekly hours of a training they tend to run faster and are more agile, when the confounders of age, maturity and countermovement jump are controlled. This suggest a enhanced training response is linked to higher concentrations of anabolic hormones (Rogol, 2016). These findings extend those of Valente-dos-Santos et al. (2014) on agility, and parallels previous research about the positive effect of training on young soccer players' physical performance (Haugen et al., 2014, Nygaard Falch et al., 2019), although a recent study did not find statistical differences between speed and agility improvement and training methods with or without the ball (Padrón-Cabo et al., 2020), as well as neuromuscular training (Keiner et al., 2020, Menezes et al., 2020) in young soccer players.

In summary, considering the importance of repetitive actions and winning challenges in soccer and becoming an excellent soccer is not exclusively dependent on one standard set of skills. The "compensation phenomenon" (Bartmus et al., 1987) indicates that deficiencies in one area of performance may be compensated for by strengthening others. For example, faster and more agile players may react better in every possible game situation such as the transition from defense to attach or/and attack to defense. Recent studies showed a moderate correlation between speed and agility with technical skills in young soccer players (Forsman et al., 2016, Islam and Kundu, 2020, Lipecki, 2018). Further, longitudinal reports highlighted the fact that physically dominant (speed, agility) players at younger levels maintained this advantage into adulthood (Leyhr et al., 2018, Saward et al., 2020) due to stabilities of motor performance. Eventually, this suggests that by longstanding and intensive soccer-specific training relates to increases in cognitive function, task-related neural networks (Milton et al., 2007) and neural efficiency (Del Percio et al., 2009) in players.

Conclusions

Young soccer players unfolding in straight speed and agility showed a linear trend, i.e., as time passes, they systematically become faster and more agile. This increase in physical performance is positively associated with biological maturation, higher levels of explosive leg strength, and accumulated hours of training. Coaches need to be aware of the importance of developing players' speed and agility as key factors to improve players' soccer specific performance in training and game contexts.

In the future, we suggest researchers to consider more physical performance facets and investigate how they jointly unfold in a multivariate fashion. Further, we also suggest that this development may be linked to technical and tactical skills using larger samples and players from different competitive levels. Finally, it would also be of interest to use a broader rationale to include the putative effects of coaches and club' contexts.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the Faculty of Porto, University of Porto (CEFADE 13.2017, 25 July 2017).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Electronic Supplementary Material 1

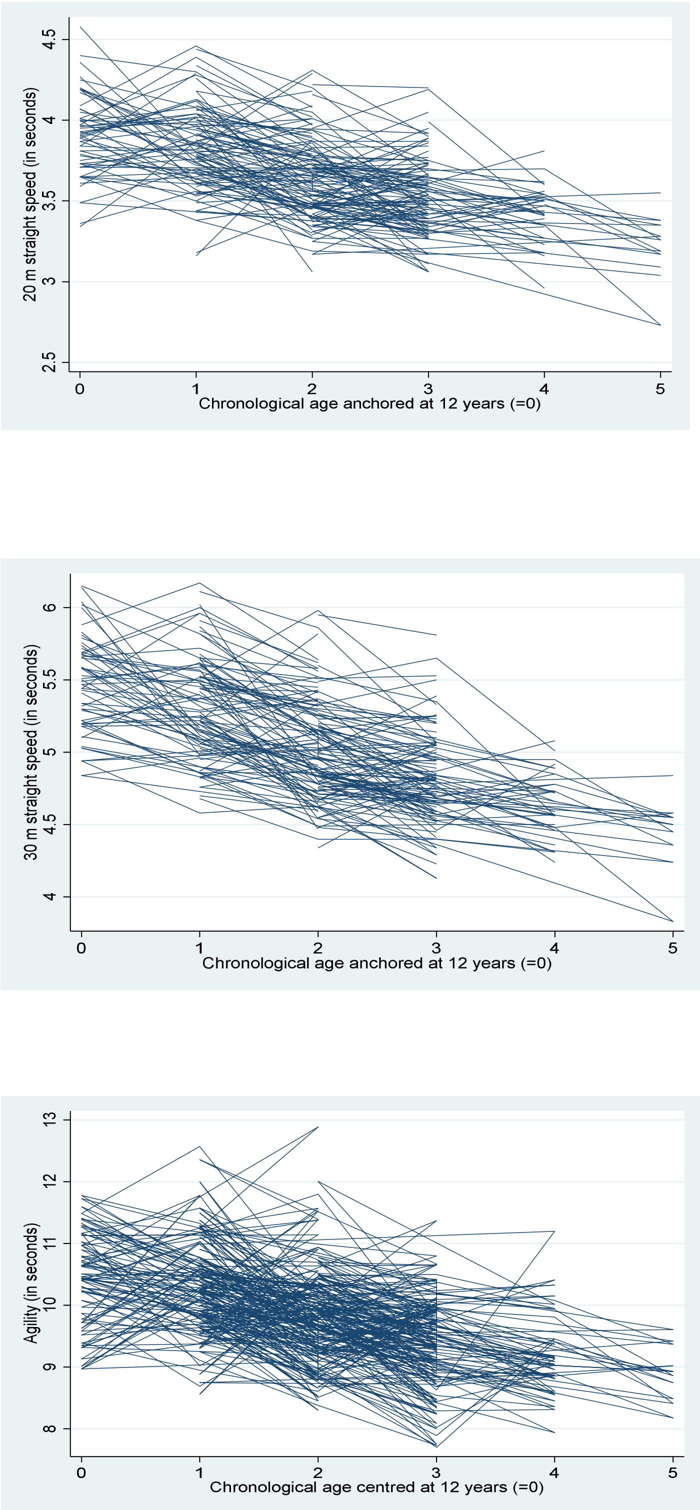

***Figure S1**: Spaghetti plots of individual trajectories for 20 m and 30 m straight sprint and agility with age centred at 12 years (CA=0)*

PAPER IV

Modelling trajectories of young soccer players' technical skills: The INEX study

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Under submition

ABSTRACT

We investigated the longitudinal developmental trends in young soccer players' dribbling speed, shooting accuracy, and short passing-rebound while considering the independent effects of height, body fat, biological maturation, level of athleticism, years of formal soccer training and hours of soccer specific training. A total of 314 male players were recruited from six clubs clustered into three age cohorts (12, 13 and 14 years) that were followed consecutively over 4-years using a mixed-longitudinal design. Multilevel hierarchical linear models were used. Results showed positive linear trends in the three soccer skills. Further, on average, players stature, fat mass and biological age did not independently explain differences in players' trajectories in dribbling speed and short passing-rebound development ($p>0.05$), yet level of athleticism were significantly associated with dribbling and passing skills ($p<0.05$). Furthermore, players with more accumulated years of official soccer training dribbled faster ($p<0.05$), and those with higher accumulated hours in weekly soccer training performed best in short passing-rebound cycle ($p<0.05$), when confounders were controlled. No significant associations were found in shooting accuracy with any predictor. Technical skills developmental profiles shown in this study may help experts and coaches in identifying and developing players across puberty, while considering the influence of training stimuli in improving their task-related neural networks and levels of athleticism.

Keywords: Youth soccer, technical skills, training, athleticism, maturity, longitudinal.

INTRODUCTION

For soccer teams to succeed at different competitive levels i.e., to function as a coherent and efficient tactical unit, it is acknowledged that players have to display appropriate physical attributes and aptitudes, as well as technical abilities (Bradly et al., 2016). Dribbling, passing, and shooting have been described as the dominant skills in the game of soccer (Barron et al., 2020; Saward et al., 2019), as well as the most relevant technical skills in strategic terms (Liu et al., 2015).

Today's increased match speeds and complex play patterns have become more physically demanding for players at all competitive levels and age-groupings (Wallace & Norton, 2014) Further, Malina et al. (2017) highlighted that youth soccer players have become both taller and heavier in age groupings. Both these attributes also tend to be associated with higher physical performance and technical skills' levels (Nevill et al., 2019). Recently the Canadian Dietitians and the American College of Sports Medicine position statements (Thomas et al., 2016) endorsed the fact that sports performance is directly related to athletes' body composition, and how it (i.e., body fat) can influence and impact soccer performance (Mills et al., 2017). For example, longitudinal studies on Danish and Portuguese youth soccer players showed dribbling changes to be positively related to their height and fat free mass, and not associated with their fat mass (Huijgen et al., 2010; Valente-dos-Santos et al., 2014a).

It has been suggested that a high level of athleticism is a key element to enhance the level of soccer performance (Dolci et al., 2020). Although dribbling and short pass rebound require players to control the ball at speed, with a quick change of direction to evade an opponent, Forsman et al. (2016) could only find moderate positive associations between dribbling and passing skills with speed and agility in Finnish players. Similarly, a study with Portuguese youth soccer players suggested that dribbling speed changes were related to the players aerobic endurance and explosive strength (Valente-dos-Santos et al., 2014b). In contrast, a recent cross-sectional study with English players of the Youth

Alliance League found no significant correlations between dribbling, passing, shooting skills and players' physical performance levels (Wing et al., 2020).

Notwithstanding the hypothesized influences of anthropometry, body composition and physical performance on youth players' technical skill performance (Kelly & Williams, 2020; Slimani & Nikolaidis, 2017) it is reasonable to assume that biological maturation may also impact different levels of technical skill (Malina et al., 2005). For example, skeletal maturity status was significantly associated with inter-individual variability in dribbling skills test of Portuguese players (Valente-dos-Santos et al., 2014b). Yet, no such trend was evident in dribbling performance during match plays in youth English players (Saward et al., 2019). Additionally, Ford et al. (2012) highlighted the putative effects of adequate training stimuli on the development of young players soccer specific skills. For example, two serial data reports showed that dribbling improvement was also driven by training stimuli (Huijgen et al., 2010; Valente-dos-Santos et al., 2014a). In contrast, a study with Italian players (U14 age categories) revealed that seasonal improvement of skills was independent of training exposure (Francioni et al., 2018).

A recent systematic review of longitudinal studies of youth soccer players highlighted the fact that technical skills trajectories were influenced by the additive effects of predictors and that their effects sizes varied, with some apparently having no significant effect (Abarghoueinejad et al., 2021b). However, it is still being debated as to how the joint, and time independent, effects of physical performance, body composition, biological maturation, years of official soccer training and hours of soccer training impact trajectories of dribbling speed, short passing-rebound, and shooting accuracy-technique development. This study aims are two-fold: (1) to model youth soccer players' technical skills' developmental trajectories, and (2) to investigate the effects of independent time dependent predictors on trajectories development, namely: height, body fat, biological maturation, physical performance, and training.

METHODS

Study design and sample

Participants for this study were recruited a part of the In Search of Excellence in Sport – A Mixed-Longitudinal Study in Young Athletes (INEX) study, conducted in the Porto metropolitan area, northern Portugal. In brief, this research project is grounded on the bio-ecological systems theory (Bronfenbrenner, 2005) and uses a hierarchical multilevel model (Snijders & Bosker, 2012) analytical template to probe into the relationships between physical growth and performance, specific-skills, game knowledge and psychological characteristics of Portuguese youth basketball, handball, soccer, volleyball, and water polo athletes within the contexts of their sports' clubs. Data was collected from 3 to 4 years based on a mixed-longitudinal design. Given the flexibility of the multilevel model and the assumption of missing at random there is no need to have complete data on every subject at every visit occasion (Hedeker & Gibbons, 2006; Laird & Ware, 1982).

In total, 314 young male soccer players (from 3 age-cohorts) were measured annually during the same time-window (in December of each year within a 2-3 weeks' time window) over four consecutive years (Abarghoueinejad et al., 2021a). Participants were randomly selected to participate by their coaches and/or club team managers. To be included in the present analysis complete valid data was required from a minimum of two-time points to a maximum four-time points, and 185 players fulfilled this criterium. Three age cohorts (12, 13, 14) were identified at study entry (Table 1). Using a mixed-longitudinal study design these cohorts overlapped and it was possible to identify 5 years of development from 12 to 16 years of age. Legal authorization was obtained from coaches and clubs' directors, parents gave their informed consent and players informed ascent. The Ethics Committee of the Faculty of Sport, University of Porto (FADEUP) approved the project, and the Porto Football Association provided permission for data collection.

Table1. Chronological age across cohorts and number of observations, in *italics*, as well as overlapping years during the study

Cohorts	Ages of follow-up (*number of observations*)					Total
Cohort 1	12¥ (*52*)	13 (*51*)	14 (*31*)	15 (*12*)		*146*
Cohort 2		13 (*55*)	14 (*49*)	15 (*31*)	16 (*8*)	*143*
Cohort 3			14 (*60*)	15 (*59*)	16 (*28*)	*147*
Total						*436*

¥ 12 years old players are those aged 12:00-12:99, till 16 (16:00-16:99).

Anthropometry

Anthropometric measurements were performed by trained staff of the Kinanthropometry Lab (FADEUP) following standard protocols (Ross & Ward, 1986) with all players in their soccer kits without shoes. Stretch standing height (Harpenden portable stadiometer; Holtain Ltd., Crymych, UK) and sitting height (Harpenden sitting table; Holtain Ltd., Crymych, UK) were measured to the nearest 0.1 cm, with subjects' heads positioned to the Frankfurt plane. Leg length (accuracy=0.1 cm) was computed as the difference between standing height and sitting height (trunk length). Weight was measured using a bioelectrical impedance scale (Tanita® model BC-418MA, Tokyo, Japan) with a 0.1 kg precision.

Body Composition

Fat-free mass (kg) was estimated from the bio-electric impedance scale (Tanita® model BC-418MA, Tokyo, Japan) using a two-compartment model and according to the manufacturer's formula. Prior to testing players were instructed as follows: (1) evening meals prior to testing should be taken as usual following players' daily routines in terms of their nutritional habits; (2) prior to arrival at the Lab players were requested to empty their bladder, and (3) they were told to stay quietly seated in the device as per the manufacturer instructions.

Biological Maturation

Biological age (termed maturity offset - years from peak height velocity) was estimated from anthropometrics using the Mirwald et al. (2002) equation for boys:

Maturity offset = -9.236 + (0.0002708 * (Leg Length *Sitting Height)) + (-0.001663 *(Age * Leg Length)) + (0.007216*(Age*Sitting Height)) + (0.02292 * (Weight/Height*100)).

The maturity offset estimates the temporal distance (in decimal years) from age-at-peak height velocity (PHV) at the time of measurement. The error is within ±1.14 years in 95% of cases. A positive (+) maturity offset represents the number of years the participant is post attainment of PHV, whereas a negative (-) maturity offset indicates the number of years the participant is prior to attainment PHV.

Physical performance

Physical performance was assessed by trained staff of the FADEUP Football study group in an indoor stadium with subjects in their soccer kits and running shoes:

- *Straight speed* was assessed using: (i) 5meters and (ii) 20-meters tests: players ran in a straight line at full speed. Time (s) was recorded using a photoelectric cells system Speed Trap II (Brower Timing Systems LLC., USA) Participants performed two maximal trials with 2-minute rest intervals. The best time performance (seconds) at each distance was considered as the test result (Kirkendall et al., 1987).
- *Agility* was measured using the T-Test (Semenick, 1990). Players ran and changed direction in a T shape. Time (s) was recorded using a photoelectric cells system Speed Trap II (Brower Timing Systems LLC., USA). Each player performed two trials with ~2 minutes rest intervals and the best time (seconds) was used as the test result.
- *Explosive strength* was estimated from: (i) countermovement jumps (Bosco et al., 1983). During each trial, players started in a standing position on an AMTI OR6-WP force plate (Advanced Mechanical Technology Inc., Watertown, MA, USA) operating in 2000 Hz.); and (ii) the standing long jump test. The player resets to the starting position after each jump, and the procedure was completed for a total of three

jumps, with approximately 2 minutes rest intervals. The best jump (cm) was considered as the best performance and used for further analysis.

A Total Score of Athleticism (TSA) was used after transforming individual test results into z-scores and computing an unweighted sum of all z-scores as advocated (Turner et al., 2019). Care was taken to reverse signs in 5-meters, 20-meters tests and T-Test since in both tests less time represents better performance.

Technical skills

Soccer specific technical skills were assessed by trained staff of the Football study group using the University of Queensland's Football Skill Assessment Protocol (Wilson et al., 2016).

- *Dribbling* speed ($m \cdot s^{-1}$) was assessed by recording the total time taken for an individual to dribble (i.e., kick) the ball through a 61.2 m agility circuit course. This test mimics the situation when players looking to break open the defence by running with the ball controlling at opponents through tight spaces with change of direction. Participants performed two maximal trials with 2.5-minute rest intervals. The best time performance (seconds) at each distance was considered as the test result. The time taken to complete the circuit was recorded with a stopwatch and then converted to average speed over the 61.2 m.
- *Shooting accuracy-technique (points/kick)* was measured by 14 attempts to shoot a ball with power, accuracy, and technique using in-step (top of the foot) towards scoring zone 20-meters away. A score of zero applied if they did not use the correct technique. A player's individual performance for this task was calculated by adding up accumulated points and dividing it by 14, which corresponded to the average points per kick.
- *Short-passing rebound (cycles/min).* Two techniques were employed and tested in this task, together mirroring the condition when player receive a ball and plays a consequent pass at 135º whilst under pressure from an opponent to the angle of ball reception. For each

attempt, penalties were awarded as extra time added to the final score: (i) +1 s for each extra touch on the ball while setting up a pass; (ii) +1 s for every touch on the ball with the wrong foot; and (iii) +1 s for each time the ball misses the rebound board. we divide 60 by the total time taken (in seconds) to complete cycles to convert this number into a measure of number of circuits per minute.

Training information

Players' training experience, expressed as years of formal soccer training, was obtained from self-report questionnaires filled-out by players and cross-checked with registration histories available from Portuguese Football Federation (FPF) official website: https://www.fpf.pt/Jogadores (22 June 2020). For example, a player registered for one competitive season in FPF indicates one year of formal soccer experience, for two competitive seasons, two years of experience, and so on. The weekly number of training as well as the minutes of the soccer-specific training sessions were also gathered from self-report questionnaires and completed by the managers/coordinators of the academies.

Statistical Analyses

Descriptive statistics, means and standard deviations were computed in SPSS version 27.0 (SPSS, Chicago, IL, USA). The statistical parametric mapping analysis for the countermovement jump (CMJ) was performed in MATLAB, and the force plate data were post-processed using a custom Matlab2019a routine (MATLAB, MathWorks Inc., Natick, MA, USA). The CMJ phases were identified as suggested (Linthorne, 2001), as were the jump height calculation methods.

Given the nested hierarchical structure of the data, a multilevel regression linear model was used to predict technical skills' developmental trajectories (Hedeker & Gibbons, 2006). For each technical skill (dribble, shoot, pass), a two-level hierarchical structure was defined with repeated measures within individuals as level 1 of the model, and between individuals' soccer players as level 2. Given the cohorts' sequential data waves we centre the time (age) metric as the age of the youngest cohort, i.e., 12 years such that 0, 1, 2, 3, 4 corresponds to 12, 13, 14, 15, 16 years of age. Given the relatively small data set, we used the (Kenward & Roger, 1997, 2009) methodology for small samples inferences in fixed effects, as well as its restricted maximum likelihood parameter estimates implemented in STATA 16 software (StataCorp, 2020). The following modelling strategy was used: firstly, we investigated which trend (linear versus nonlinear) best fitted the data; secondly, we fitted a new model including time-varying covariates, namely height, body fat mass, biological maturation, TSA, years of formal soccer training, and weekly hours of soccer specific training. Comparisons between models were done as suggested (Kenward & Roger, 1997, 2009), and the level of significance was set at 5%.

RESULTS

Descriptive statistics for anthropometry, body composition, biological maturation, TSA, training information and technical skills of players by age group are shown in Table 2. Generally, and as expected, all variables improved with increasing age.

Table 2. Descriptive statistic [means and standard deviations (SD)], of players across study by age group.

	12 yrs	13 yrs	14 yrs	15 yrs	16 yrs
Variable	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Decimal age (yrs)	12.55±0.28	13.57±0.27	14.52±0.26	15.51±0.26	16.47±0.26
Anthropometry					
Stature (cm)	155.36±7.57	162.20±7.60	168.34±7.30	172.25±6.62	172.57±5.62
Body composition					
Body fat mass (kg)	7.98±2.61	9.10±3.45	9.70±3.23	10.40±3.21	9.91±2.17
Biological maturation					
Maturity offset (yrs-to-PHV)	-1.21±0.53	-0.26±0.63	0.62±0.66	1.50±0.60	2.11±0.48
Physical performance					
TSA (z-score)	-3.33±2.70	-2.38±3.15	0.45±3.00	2.04±3.00	3.68±3.02
Technical skills					
Dribbling speed ($m \cdot s^{-1}$)	2.25±0.14	2.35±0.18	2.48±0.18	2.61±0.14	2.65±0.15
Shooting accuracy-technique (pts/kick)	3.23±1.10	3.54±1.14	3.46±1.17	3.78±1.00	3.66± 1.19
Short-passing-rebound (cycles/min)	1.07±0.10	1.16±0.17	1.28±0.16	1.36±0.15	1.46±0.25
Training information					
Years of training (years)	3.85±1.55	4.60±1.53	5.74±1.43	6.71±1.43	7.70±1.48
Weekly hours of training ($h \cdot w^{-1}$)	3.54±0.55	4.06±0.70	4.53±0.73	5.10±0.81	5.20±0.84

TSA= *total score of athleticism*

In results not shown, we found that a linear trend model fitted the data better than a nonlinear one, and in the Table 3 we present results for model 1 (without any time-varying predictor, and plotted in Figures 1, 2 and 3), as well as for model 2 (full model with all covariates) which fitted the data better but shooting accuracy.

Dribbling speed

On average, 12-year-old soccer players (see intercept) have a dribbling speed of 2.311±0.030 m·s-1, and this estimate is statistically significant ($p<0.001$). With increasing age, the dribbling speed increased linearly ($\beta=0.098\pm0.018$ m·s-1 per year, $p<0.01$). Increases in height, body fat mass and biological maturation did not independently affect players differences in dribbling speed trajectories ($p>0.05$) when the confounders of Total Score of Athleticism (TSA) and soccer training markers are held constant. In contrast, higher levels of athleticism were positively related to dribbling speed ($\beta=0.014\pm0.003$, $p<0.001$), when the other covariates were held constant. Players with more formal years of soccer training experience were, on average, faster dribblers with increasing age ($\beta=0.022\pm0.006$, $p<0.001$), but hours of weekly training did not explain players developmental trends ($p>0.05$). Further, we could only identify a random intercept ($\sigma^2=0.009\pm0.002$).

Shooting accuracy-technique

In model 1 the estimated shooting accuracy of a random 12-years old player was 3.300±0.113 pts/kick, $p<0.001$, and the rate of change was also significant ($\beta=0.134\pm0.054$, $p<0.05$). Yet, in model 2 with the inclusion if the time-varying predictors not only no improvement in model fit was noticed (p-values for covariates effect sizes are greater than 0.05) but the rate of change was now non-significant ($p>0.123$). Finally, there appears that there was no significant random intercept ($p>0.05$).

Short-passing rebound

On average, 12-years old players perform the pass-rebound with 1.099±0.031 cycles/min ($p<0.001$), and there was a significant linear trend with increasing age ($\beta=0.090\pm0.020$ cycles/min, per year; $p<0.001$). Stature, body fat mass and biological maturation did not significantly associate with the developmental trend in short-passing rebound ($p>0.05$) even when all other covariates were held constant. Yet, players with increasing athleticism across time performed more cycles in the short-passing rebound ($\beta=0.009\pm0.003$, $p<0.01$) with the rest of the covariates held constant. Further, players who accumulated more weekly hours of soccer specific training with age, also increase their cycling performance ($\beta=0.050\pm0.014$, $p<0.01$); however, formal years of soccer training did not significantly ($p>0.05$) associate with short-passing rebound developmental trends. Finally, we could only identify a random intercept ($\sigma^2=0.005\pm0.002$).

Table 3. The multilevel regression models for technical skills development: parameter estimates (± standard-errors) for fixed and random effects.

Variables	Dribbling speed		Shooting accuracy-technique		Short-passing rebound	
	$Model_1$	$Model_2$	$Model_1$	$Model_2$	$Model_1$	$Model_2$
Fixed effects						
Intercept (12 years)	2.240±0.017***	2.311±0.030***	3.300±0.113***	3.302±0.190***	1.044±0.018***	1.099±0.031***
Age	0.121±0.007***	0.098±0.018**	0.134±0.054*	0.163±0.123ns	0.111±0.009***	0.090±0.020***
Stature		0.000±0.002ns		0.016±0.014ns		-0.001±0.002ns
Body fat mass		-0.003±0.003ns		-0.059±0.023ns		-0.001±0.003ns
Maturity offset (yrs-to-PHV)		-0.030±0.030ns		-0.105±0.188ns		-0.033±0.031ns
TSA (z-score)		0.014±0.003***		-0.039±0.022ns		0.009±0.003**
Formal soccer training (year)		0.022±0.006***		0.080±0.084ns		0.010±0.006 ns
Weekly soccer training ($h \cdot w^{-1}$)		0.016±0.012ns		6.113±1.792ns		0.050±0.014 **
Random effects						
Player	0.0145±0.002	0.009±0.002	0.062±0.085	0. 032±0.082	0.009±0.002	0.005±0.002
Residual	0.013±0.001	0.014±0.001	1.197±0.118	1.185±0.118	0.018±0.027	0.018±0.001
Model summary						
Log restricted-likelihood	167.146	156.804	-571.870	-571.174	131.077	121.515
Number of estimated parameters	4	10	4	10	4	10

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, ns= not significant, TSA= total score of athleticism

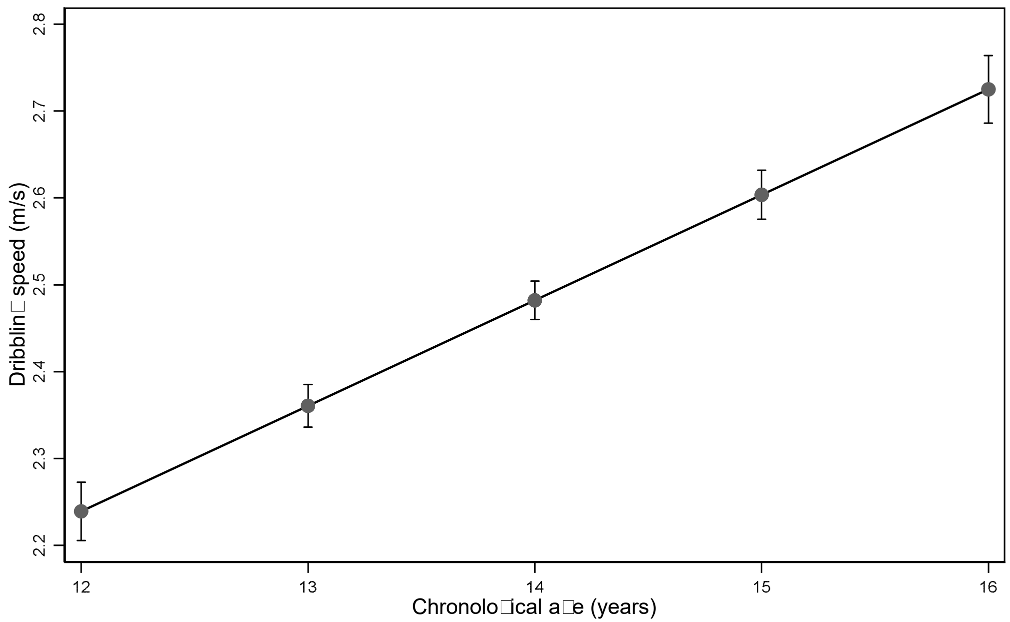

Figure 1. Dribbling speed linear trend line with 95% confidence intervals.

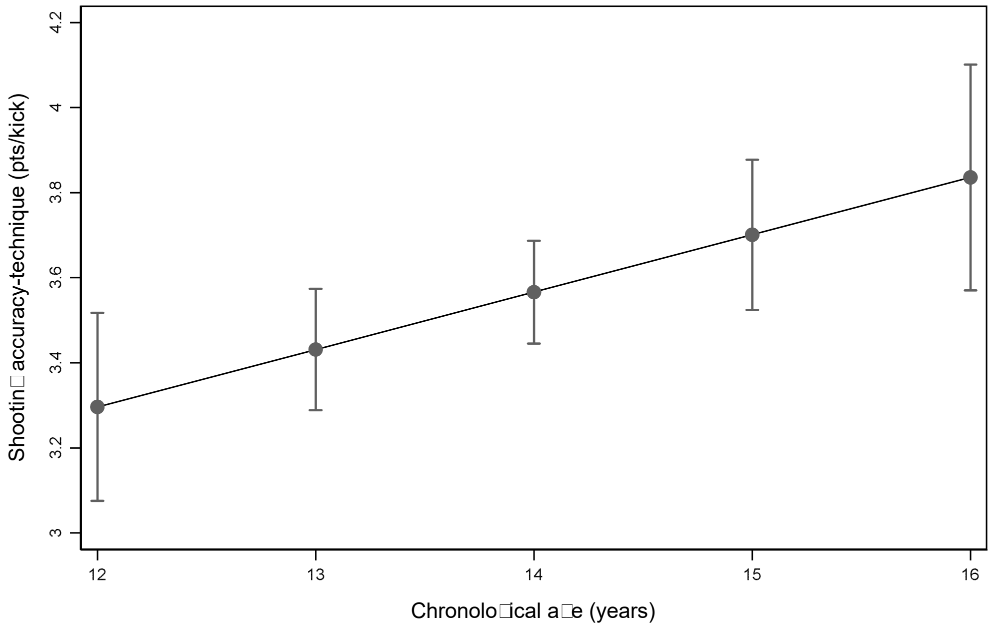

Figure 2. Shooting accuracy-technique linear trend line with 95% confidence intervals.

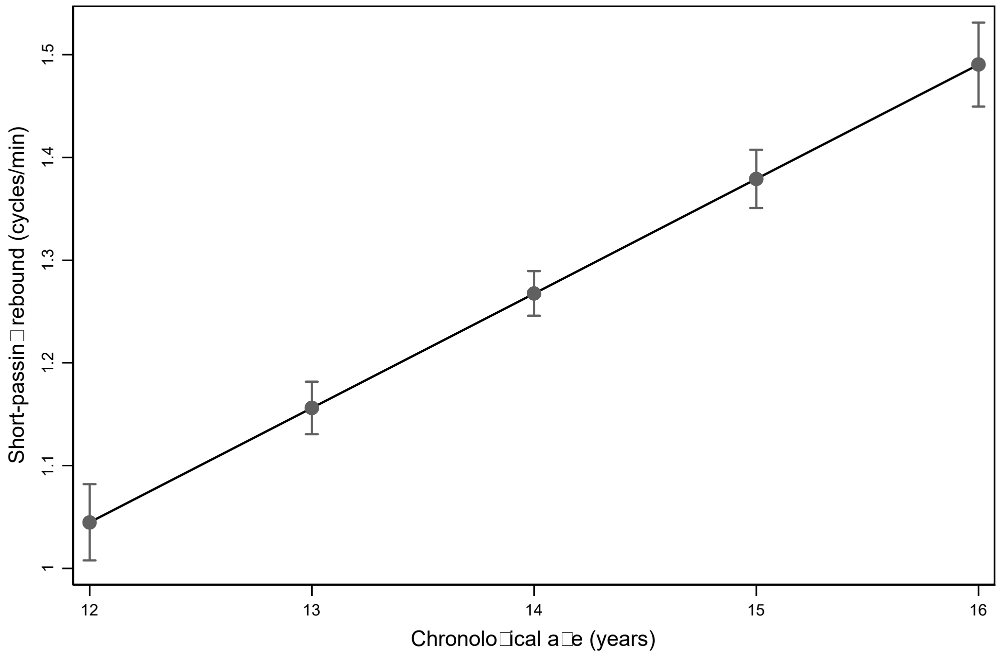

Figure 3. Short-passing rebound linear trend line with 95% confidence intervals.

DISCUSSION

In this study, age-related changes in technical skills (dribbling speed, shooting accuracy-technique, and short pass-rebound) were examined as well as their relationships with stature, body fat mass, Total Score of Athleticism (TSA), years of formal soccer training and weekly hours of soccer training. The main findings were that: (1) these skills increased in a linear fashion with increasing age; and (2) throughout their development, specific technical skills (dribbling speed and short pass rebound) were influenced by different predictors. The discussion will be sequentially approached and based on our predictors (age-related changes, anthropometry and body composition, biological maturation, physical performance and finally training information) in order of dribbling speed and short-pass rebound, and then shooting accuracy-technique.

Age-related changes

Dribbling speed improved linearly with age from 12 to 16 years which is similar to trends found in other mixed-longitudinal/pure-longitudinal studies with different time durations in: Dutch (Huijgen et al., 2010), Portuguese (Valente-dos-Santos et al., 2014a), and German (Leyhr et al., 2018) youth players. This suggests a systematic improvement in players' ability to maintain/control the ball and sudden changes of pace and direction probably explains why they may throw off the opponent in game situations as they grow and develop. This may also be related to increased links with their motor proficiency development (Voyer & Jansen, 2017) as well as with neuromotor development (Kakebeeke et al., 2018). In a study with Polish soccer players (Kokstejn et al., 2019) it has been suggested that with the mastering of fundamental motor skills with increasing age, there is the expectation of improvements in the developmental process of dribbling speed skill.

Short passing rebound consistently unfolds with age which is like findings reported in Dutch players (Huijgen et al., 2013). In this task, a putative match situation is simulated, assessing player´s ability to receive a pass by bringing ball under rapid control while under pressure from opponent. They then execute a subsequent pass with accuracy and speed with attention on body position and use of the appropriate foot should be changed by some expression that refer to the foot that the rule of the test requires. As players grow older, they modify their sensory-cognitive skills, for example anticipatory skill and reaction time (Turk & Shattuck-Hufnagel, 2020) which together with increasing neuromotor development (Kakebeeke et al., 2018) may help improve their anticipation of a ball timing tasks (Nuri et al., 2013).

Anthropometry and Body composition

Malina et al. (2017) reported that young soccer players' age-related stature and body mass have increased in the last decade. Nevill et al. (2019) suggested that body size can be considered a synergistic factor for success in modern soccer. In our study height and fat mass apparently provide no comparable independent advantage in technical skills development (dribbling speed and passing rebound) after controlling for other variables. This may indicate that coaches apparently do not rely on body size on players selection and that proficiency in these skills are size independent as suggested in other Portuguese youth soccer players' dribbling speeds (Valente-dos-Santos et al., 2014b). However, using the same data set, these previous authors claimed in another paper that stature was related to dribbling speed (Valente-dos-Santos et al., 2014a).

Biological maturation

It has been proposed that the amplitude of the confounding effects of biological maturation on youth players' selection process, as well as in developing technical skills, is apparently small or non-inexistent (Kelly & Williams, 2020). In our study, biological maturation did not independently explain differences in players' technical skills developmental trends which is consistent with reports in English players' dribbling performance during match plays (Saward et al., 2019). However, previous motor skill test research highlighted the positively related dribbling speed changes with maturity status in Portuguese players (Valente-dos-Santos et al., 2014b). In any case, it remains unclear the extent to which biological maturity may relate to technical skills enhancements.

Physical performance

Important effective attacking skills in soccer is identified in the ability to catch defences off balance by keeping the ball, dribbling in open spaces with the aim of reaching the opposite goal as quickly as possible, or/and then being able to pass it to a team-mate and shooting on target (Barreira et al., 2020). To manifest these skills players, need to combinate them with their levels of athleticism (Dolci et al., 2020). In our study we reported that players exhibiting greater overall athleticism tend also to be more successful in dribbling and passing independent of age. Similar findings were previously reported in Portuguese players (Valente-dos-Santos et al., 2014b) linking lower limb explosive strength and aerobic endurance. Moreover, moderate positive correlations were also reported in Finn players' dribbling and passing skills (Forsman et al., 2016).

Training information

Key developmental changes periods occur during adolescence (Janacsek et al., 2012), and intensive soccer-specific training (Ford et al., 2012a). within its age-ranges, are very important for skill acquisition (Fédération Internationale de Football Association, 2021) given it's correlates with task-related neural networks (Milton et al., 2007) and neural efficiency (Del Percio et al., 2009). Our results showed that systematic soccer training was positively and independently related to changes in dribbling speed and passing rebound, i.e., with increasing years of formal soccer training they tend to dribble faster and with increasing weekly hours of a training players tend to increase their short passing- rebound cycling performance. These findings parallel previous mixed-longitudinal research (Huijgen et al., 2010; Valente-dos-Santos et al., 2014b) about the positive effect of training.

Although we reported in Model 1 a significant increase in shooting accuracy mean trend with increasing age, when we included predictors of this age-related change not only did the trend vanished but also none of the predictors was statistically significant. We think that this may be due to the scoring system that demanded the examiner to give a zero score when players performed the shot without using the in-step technique, without considering their ability to execute a powerful and accurate shot. Despite this result, we found reports with different testing protocols nonlinear increases in shooting of German players with regard to precision and speed of it (e.g., under 12 age categories U12 scored =17.76 points; U15 scored = 14.92 points (negatively coded); further, a predictive value of relative age and adult performance level was confirmed (Leyhr et al., 2018). However, in a mixed-longitudinal study with English players that modelled match skills performance, the models predicted that on-target shots frequency linearly decreased (e.g., U12 performed= 0.5 on-target shots per hour however U18 performed = 0.3 on-target shots per hour); the models also suggested that the centre forward position explained most of the variance and that playing status and maturity status did not explain these changes (Saward et al., 2019). Thus, age-related changes in shooting skill and its predictors of young soccer players remain unclear and require further research across a wider range and duration of studies.

This study is not without limitations, and caution must be held when generalizing our results. First, although it is estimated that young soccer players from Porto Football Association are comparatively like other Portuguese players from other regions, we concede that our sample is not widely representative. Second, while we have reliable data on soccer players' training information, if we could have access to data concerning training methodologies, namely exercises' objectives, complexities and intensities, as well as their cycles would probably give more convincing evidence about their links to increased trends in players' technical skills. Third, there is no way to escape to missing data (players drop-out or no-show during testing) and this is commonly reported in other mixed-longitudinal studies with young soccer players (but see Saward et al., 2019; Leyhr et al., 2018). Although the mixed/multilevel model does not require complete data for all individuals (Hedeker & Gibbons, 2006; Laird & Ware, 1982), we relied on the Kenward and Roger (1997, 2009) methodology for small samples to have precise parameter estimates and standard errors.

CONCLUSIONS

This study imparts reliable empirical evidence of the putative prognostic value of technical skills tests of Portuguese youth soccer players. Age was a consistent predictor in all technical skills markers that increased linearly. Developmental changes in dribbling speed, as well as short passing rebound, were mostly explained by level of athleticism and years of formal soccer training. However, no such evidence was found for shooting accuracy-technique. This information may allow coaches and practitioners to enhance training methods particularly during adolescence.

In the future, we suggest researchers to consider a broader range of technical skills and investigate how they jointly unfold in a multivariate fashion. Further, we also suggest that longitudinal studies may have larger samples and players from different competitive levels, whilst considering detailed seasonal training schedules, tactical, and psychological development. It may also be of interest, to investigate the putative links between combinations of fundamental skills, levels of motor coordination and technical skills' unfolding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the Faculty of Porto, University of Porto (CEFADE 13.2017, 25 July 2017).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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CHAPTER V

GENERAL DISCUSSION

GENERAL DISCUSSION

A long-term athlete developmental program needs to be grounded in research and appropriate coaching guidance to maximising athletes' potentials, as suggested by the sage words of Franklin D. Roosevelt - "we cannot always build the future for our youth, but we can build our youth for the future". This is a long-term process relying on advanced and rigorously tested scientific management programmes and close collaborations with soccer bodies including, but not limited to federations, clubs, coaches, families, and players. A long-term athlete developmental program is multifaceted linking individual's physical growth and biological maturation with their physical performance and motor skills and psychological development, all intertwined with the environments (e.g., family, clubs) they are exposed to. Consequently, a multidisciplinary approach is required to enhance holistic data collections, as expertise in soccer is not solely dependent on one standard set of skills (Williams et al., 2020).

The goals pursued by this thesis were embedded in a larger research project, partially funded by the Instituto Português do Desporto e da Juventude and the Comité Olímpico Português, entitled "*in search of excellence in sport - a mixed-longitudinal study in young athletes (INEX)"*. The INEX research project was conceived and grounded within Bronfenbrenner's (2005) bioecological model, with its person-process-context-time intertwined processes, and a hierarchical multilevel statistical model which accommodated the network of variables underlying human development in a unified template. It is assumed that the use of such models will provide an integrated understanding of this multifaceted phenomenon. INEX mixed-longitudinal design and the relationship dynamics of change in sets of variables were organized into four domains: three within the players' orbit (biological, skill/game proficiency, psychological) and the fourth localized in specific context, i.e., the soccer club. Further, the age range of participants in this project (12-17) is a well-known window of opportunity for more sensitive responses to training and competition as well as serious engagement in young players' careers.

The current thesis provides insight into the evolving process of young soccer players' by examining their unfolding physical and technical development and other related factors. In the first study, the aim was to tackle two important concurrent issues: (1) provision of an extended overview of the soccer portion of the INEX study, namely its objectives, methodology, and design; and (2) presentation of a selected set of baseline results. In summary, and to the best of our knowledge, this first study added important information on the multi-layered characteristics that described the growth, maturation and developmental of young soccer players. Its main strengths were as follows: (1) its frame work (Bronfenbrenner′s bio-ecological theory on human development); (2) the use of a mixed-longitudinal design, with three age cohorts with overlapping years, making it possible to estimate the intricate dynamics of young footballers' development trajectories in a shorted period of time during a sensitive period of their development; (3) the use of a hierarchical multilevel statistic model that was able to link within and between individual variances to enable the identification of independent time-dependant predictors of development and at the same time being able to handle missing data. Multilevel models' have been shown to adequately control the complexities of repeated measures data within and between individual's (Hedeker & Gibbons, 2006; Raudenbush et al., 2019); (4) the consideration of a wide range of variables evolving from two main sources - the player orbit (biological, soccer specific, psychological) and the environmental context (clubs); (5) a series of coherent procedures that guarantee the quality of data acquisition during serial collection, and (6) a steering committee comprising of well-known experts in the field that are "safe guards" of the overall importance of the study. It is evident that the complexity engendered during a performance in competitive soccer requires an integrated approach that considers multiple aspects. A challenge for researchers is to align these measures with coaches' needs, to produce practical and usable information that improves player's performance (Cushion et al., 2012; Helsen et al., 2012). This will also enhance coaches' knowledge. For example, an understanding of maturational differences (biological age) within chronological age bands will assist coaches to align and match players on biological age, termed bio-banding. This approach should enhance young players' expectations and playing experiences that could be lost when using traditional chronological age bands.

In summary, in this first study, I cross-sectionally described a broad set of variables at study initiation that allowed me to describe age-associated differences in body physique, body composition, physical performance, technical and tactical skills, psychological development and club characteristics. Older players with advanced biological maturation were significantly taller, heavier and had greater lean mass, finding that are in line with previous cross-sectional studies in young soccer players (Slimani & Nikolaidis, 2019). These older boys also performed relatively higher, compared to their peers, in all physical and technical skills, which was related to their advanced maturity and longer exposure to training stimuli. However, there were no significant differences between age categories in tactical skills or any psychological domains.

Pure or mixed-longitudinal data comprises a collection of repeated observations of the same subjects across time (Goldstein, 1979). This study design permits a broader understanding of the extent and direction of change in a specific component. In doing so, allowing the identification of sequences of events that enable researchers to putatively address cause and effect relationships (Collins, 2006). Using this approach has enabled me to have a better understanding of the effects of training stimuli on young players' growth and development. Given the apparent absence of a coherent organized review of young male soccer players' motor performance, I have provided an extended rigorous summary of all existing primary research. In this systematic review I used the PRISMA protocol which allowed me to probe into the literature of longitudinal reports and enable me to present an organized view of empirical evidence during puberty. Overall, studies showed that motor performance improved non-linearly with chronological age, which was linked to biological maturity, body composition changes and training stimuli. However, there was not a comprehensive agreement between all longitudinal results studied. Moreover, I reported on putative poor quantitative evidence validating the factors and mechanisms that explained changes of straight speed, agility, dribbling, shooting, and passing in youth soccer players. Consequently, it is still cardinal to re-examine the longitudinal development on these components, as well as their stability (i.e., tracking) during players' pubertal years.

In the final two papers of my thesis, I investigated the unfolding of changes in physical and technical skills performance at the same time identifying the influences of physical growth and biological maturation, training stimuli and player' athleticism. I also describe the tracking of physical performance.

Players' orbit

Physical performance and technical skills consistently improved with age, which is in line with previous pure or/and mixed-longitudinal studies, of different time durations, from Belgium (Fransen et al., 2017), Germany (Leyhr et al., 2018a), and England (Saward et al., 2020).

It has been suggested that speed and agility are key requirements, and discriminant variables, in young soccer players (Williams et al., 2020). Also dribbling, passing, and shooting have been labeled as main skills in the game of soccer (Barron et al., 2020; Saward et al., 2019), as well as the most relevant technical skills in strategic terms (Liu et al., 2015). In the multilevel model from the third study I showed that speed and agility improved linearly with age which is similar to the segmented models findings in Belgians young soccer players between 5–20 years of age (Fransen et al., 2017). This resulting model found that in straight speed (20 and 30 m) and agility (T-test) contentious development occurred. In contrast, multilevel modelling of longitudinal data from Germany (Leyhr et al., 2018a), and England (Saward et al., 2020) showed that development occurred non-linearly , possibly due to players' different soccer level and types of field tests used.

Technical skills in young soccer players, followed from 12 to 16 years, improved linearly. This is in agreement with previous mixed-longitudinal reports on dribbling speed in Dutch players, aged 12-19 at study initiation (Huijgen et al., 2010), Portuguese players, aged 11-13 years (Valente-dos-Santos et al., 2014a) an findings from a longitudinal study on young U12 German players (Leyhr et al., 2018b). All these studies conveyed systematic improvements in dribbling ability, and (Huijgen et al., 2013) in the Dutch study, passing skills. I concur with the putative explanations from these authors as to why these changes occur. Likely, related to the mastering of fundamental motor skills with increasing age, and the concurrent neuromotor development (Kakebeeke et al., 2018), that are linked with players' motor proficiency development (Voyer & Jansen, 2017) and the augmented capabilities in anticipation of ball timing tasks (Nuri et al., 2013).

Physical growth and biological maturation data revealed no significant relationships with technical skills' development in any of INEX soccer players across all cohorts. This is consistent with reports in English players' dribbling performance during match plays (Saward et al., 2019), as well as with a recent report showing that biological maturity was not related with minutes of match play (Clemente et al., 2021). However, biological maturation did independently explain differences in players' trajectories in physical performance. This result is in line with previous mixed-longitudinal studies on agility in U11Spanish players (Bidaurrazaga-Letona et al., 2015) and 10-14 year old Portuguese players' (Valente-dos-Santos et al., 2014a). I think that these results may be related to advantages in body size, strength and power linked to advanced maturation. It is well-known that muscle mass growth occurs during adolescence, and hence the increases in muscular strength (Baxter-Jones, 2017). Further, peak rates of development in agility and speed tend to roughly occur at 13-14 years of age, an age that is equal with the timing of peak height velocity. In contrast, Philippaerts et al. (2006) highlighted that straight speed and lower limb explosive strength plateaued after age-at-peak height velocity (APHV). Further, a study of Spanish players (Carvalho et al., 2017) reported that agility reached a stable rate around

3-4 years after APHV and that sprint maximum velocity occurred around 2 years after APHV.

In our third study I found that lower limb explosive strength, as a time-varying predictor of physical performance trajectories, was positively related to changes in 20- and 30-meters straight speed and agility, this is consistent with another Portuguese study (Valente-dos-Santos et al., 2014a). Moreover, in the fourth study I reported that players with greater overall athleticism also tended to be more successful in dribbling and passing. These results are in line with previous Portuguese players' data (Valente-dos-Santos et al., 2014b). Further, Forsman et al. (2016) reported in Finnish players' that dribbling and passing skills revealed a moderate positive correlation with speed and agility.

The accumulation of soccer-specific training hours also had an impact on straight speed, agility, and short passing-rebound ability trends of Portuguese young soccer players during puberty. These findings extend those of Valente-dos-Santos et al. (2014a) on agility and dribbling ability (Huijgen et al., 2010). Consequently, this suggest that participating in greater amount of soccer training may be positively associated with higher performance (as expected), but care must be exercised when interpreting the quality and complexity of players' training histories.

In summary, my results suggest that changes in adolescent players with their implicit skill learning processes can also be considered key ingredients for the development of superior performance.

Context

There is no doubt that the club environment plays and important role in a young soccer player's development and responses to training and competition (Ford et al., 2020). However, given the small sample of clubs, I was not able to estimate third-level parameters (fixed and random effects) and highlight their importance in players' unfolding.

INEX clubs' data showed that they had different strategies to design and apply hours of soccer-specific training sessions which may have affected players’ physical performance and technical skills development. I think that linear changes found in speed, agility and short-passing rebound development, marked with athleticism and number of accumulated hours of training, supported the players’ overall development within the clubs. Moreover, in the first study, I showed that INEX soccer participants were highly task-oriented in both goal orientation and motivational climate psychological variables. Indeed, Ames (1992) and Nicholls (1989) argued that these two factors were major agents of internalizing contextual achievement cues and were probable sources of specializing influence, these observations align with suggestions by other researchers (Mills et al., 2012; Van-Yperen & Duda, 1999). This uncovering may reveal a putative positive effect of players´ contexts (clubs, coaches) on their development.

In summary, I call for individualized pathways to expert performance because each individual player comes to a performance context equipped with a certain set of inherent dynamics that have already been molded by genes, prior development and previous experiences (Phillips et al., 2010). Soccer players are apparently required to display a high level of athleticism (Wallace & Norton, 2014) combined with adequate motor control, perception, and cognitive skills to process an overflow of information in a short time (Herting & Sowell, 2017; Scharfen & Memmert, 2019). In order to understand the intricacy of the multifaceted expression of players’ performance, a multidimensional spectrum of possible analytical relevant components had to be considered (Williams et al., 2020).

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CHAPTER VI

GENERAL CONCLUSION, LIMITATIONS AND FUTURE RESEARCH AVENUES

GENERAL CONCLUSIONS

This final chapter summarises and concludes with what has been uncovered throughout the thesis. The main aim was to unravel change and stability of physical and technical performance in young Portuguese soccer players and to investigate the putative influence of a set of covariates on their development. The effort in responding to this aim was presented in the previous chapters and the key outcomes are summarised in Table 1. Further, limitations of the current thesis, recommendations for future research are also provided in this chapter.

Table 1. Summary of the main findings

Body Physique, Body Composition, Physical Performance, Technical and Tactical Skills, Psychological Development, and Club Characteristics of Young Male Portuguese Soccer Players: The INEX Study

- 14 years-old players were found to be more advanced in body size, shape and body composition that were in line with their advanced biological maturation.
- 14 years-olds outperformed their younger peers in all physical performance and technical skills.
- These performance components were related to both advanced maturity and increased training.
- Young soccer players' tactical skills, as well as psychological characteristics, (goal orientation and motivational climate) did not differ across age-cohorts.
- Finally, clubs offer a variety of conditions aiming to enhance players success in their response to training and competition.

Paper II – Motor Performance in Male Youth Soccer Players: A Systematic Review of Longitudinal Studies

- Puberty has been found to be a sensitive time for nourishing soccer players' future quality vocations.
- Motor performance improved with chronological age in a non-linear fashion.
- Motor performance development was linked to biological maturity, body composition changes and training stimuli.

Paper III – Change and stability in straight speed and agility in young male Portuguese soccer players: The INEX study

- Young soccer players unfolding in straight speed and agility showed a linear trend, i.e., as time passes.
- Soccer players systematically become faster and more agile during puberty.
- Physical performance development is positively associated with biological maturation, higher levels of explosive leg strength, and accumulated hours of training.

Paper IV – Modelling trajectories of young soccer players' technical skills: The INEX study

- Positive linear trends were found in dribbling speed, shooting accuracy-technique, and short-passing rebound.
- Developmental changes in dribbling speed, as well as short passing rebound, were mostly explained by level of athleticism and training stimuli.
- No significant associations were found in shooting accuracy with any predictor.

STUDY LIMITATIONS

Notwithstanding the way in which this thesis was conceived, the methods used, the empirical results obtained and its reach in scientific terms, it should be noted that the studies are not exempt from limitations. Below is a putative list:

1. Aside from the recognized value and potential of the mixed longitudinal design, if I could have a pure longitudinal study from 10 to 17 years, i.e., for 7 consecutive years, I would have an informative source of undeniable value to investigate. However, I would have to face complex logistical and financial issues that in most cases are not always easy to cope with. Further, this would not be possible to deal with the time limitations of a PhD study course, unless such data already exist.
2. The final sample size in each cohort (due to drop-outs and cases with missing information) may have limited the maping of intra-individual change and inter-individual differences within each cohort as well as tracking various aspects of players' physical and technical development. Yet, this is a problem faced by researchers across the world notwithstanding the many possibilities offered by the mixed model.
3. The soccer part of the INEX project was only able to recruit players from six soccer clubs in the Porto Metropolitan area. This fact poses serious problems in the process of estimating the parameters of the third level (i.e., clubs) since we only have 6 clubs. Subsequently, with 6 clubs it is not possible to precisely and reliably estimate the portion of club's variance even when using restricted maximum likelihood (REML) and appropriate degree of freedom with the Kenward and Roger method (Kenward & Roger, 1997, 2009).
4. I was not able to gather detailed information about players' seasonal soccer specific training schedules. I am convinced that this type of data would be of great value in the interpretation of aspects related to player's physical and technical development.

5. I did not fully explore all available information on young players' physical and technical performance. I leave this untouched data for future research, not only for their inherent value in itself, but also for the putative relationships with other INEX data.
6. Finally, it is always possible to gather other measures of players' physical and technical development. Yet, although I relied on recent methodologies, and one has to constantly bear in mind that all have shortcomings.

FUTURE RESEARCH AVENUES

One of the main aims of soccer developmental studies is to provide clear information to the practitioners, coaches and stakeholders to help them provide better sporting strategies and pathways to maximise young soccer players' potentials. It is my hope that with the mixed-longitudinal approach and appropriatie analytical analysis used in this thesis, as well as all reports sent to players, parents and coaches, will support future developmental strategies to facilitate their proper unfolding in terms of responses to training and competition.

In this thesis I only focused on fractions of young players' physical and technical performance. Thus, using also other INEX data it is recommended that, within a multidisciplinary approach, future researchers shed new light into the highly complex study of young players' unfolding.

The importance of shifting towards an integrated multidisciplinary approach to analyse young players' developmental processes has been highlighted in this thesis (Abarghoueinejad et al., 2021; Sarmento et al., 2018; Williams et al., 2020). Consequently, future inquiry requires a holistic approach embedded in a theoretical rational linked to a model of sports performance. For example, with a pure longitudinal study and with the gathering of holistic data (e.g., training data, match play, tactical, psychological, clubs, coaches and family information), it will be possible to provide a more detailed "picture" of players' developmental processes, thus identifying, and subsequently developing multidimensional pathways towards anticipated higher levels of expertise in youth soccer.

While this thesis presented relevant information on performance development from 12-17 years old soccer players from six clubs of Porto metropolitan area, northern Portugal, future research should use a broader perspective using samples from other regions from both boys and girls, as well as a greater number of clubs and participants.

Furthermore, since the developmental process may also encompass with other sporting environments (see INEX study), such as basketball, handball, and volleyball we believe that using data from these sports within a cross-comparison approach will reveal new insights in young athletes' development.

Finally, it is also essential that future studies incorporate other emerging factors adjoining the development process, namely genetics and its putative influence on talent identification and development (Rees et al., 2016).

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