TALENT IDENTIFICATION AND DEVELOPMENT IN SPORTS PERFORMANCE

EDITED BY: Nuno Leite, Alberto Lorenzo Calvo, Julio Calleja-Gonzalez, Bruno Gonçalves and Sean Cumming

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TALENT IDENTIFICATION AND DEVELOPMENT IN SPORTS PERFORMANCE

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EDITORIAL
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Editorial: Talent Identification and Development in Sports Performance

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Editorial on the Research Topic

Talent Identification and Development in Sports Performance

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Talent identification and development have become increasingly relevant in sports performance (Sarmento et al., 2018), especially in the last 20 years. A significant body of scientific research discusses longitudinal and non-linear talent identification and development processes, the qualities that underpin elite performance in sport, and how coaches could facilitate talented athletes' development through the sports system (Baker et al., 2020). Yet it can be argued that the continued interest in talent identification and development reflects the persistently low predictive value of applied and theoretical talent identification models (Till and Baker, 2020).

Finding, recruiting, and retaining talent is a global challenge, and it is especially relevant for sports clubs and national federations that often see potential assets escape due to self-system inefficiencies (Koz et al., 2012). In point of fact, original research selected for this topic confirmed that talent development programs should make conscious decisions about their selection strategies as it can affect their success (Kalén et al.; Dugdale et al.).

Globally, this Research Topic contributed to successfully collate applied research presenting some of the latest evidence of the use of technologies for measuring and analyzing talent. Other methodological advances have drawn on non-linear approaches, as well as the importance of socio-cultural determinents (Reverberi et al.; Coutinho et al.) playing out in increasingly complex and multidimensional environments (Höner et al.; Ribeiro-Junior et al.). In addition to these topics, nsightful contributions may be found on the debate about the importance of quality of the early engagement experience (Sweeney et al.), paralympic sport (Dehghansai et al.), and/or a balanced analysis of sport and health-related indicators (Bjørndal et al.).

Despite growing evidence of core influencing factors on talent ID and development, many coaches and stakeholders continue to fail to consider adequately important factors such as relative age (de la Rubia et al.), growth, maturation, training age, or to distinguish among these constructs effectively (Lloyd et al., 2014; Arede et al., 2021). The potential of unequal policy and practice implications of biased models that prioritize the athlete's current performance and therefore obviate their somatic and maturational development are also discussed (Leyhr et al.; Arede et al.; Arede et al.).

Under the vast majority of contemporary sports systems, participants are categorized into annual age groups to reduce the developmental differences during childhood and adolescence. Although age groups are ideal for matching players on attributes that follow age, they are not without their limitations. Specifically, children of the same age can vary in skeletal maturity, an established index of maturation in youth, by as much as 5–6 years (Saward et al.). Most sports federations select young athletes based on current competition results rather than development potential. This means that many of these talent selection processes fail to integrate essential indicators when assessing young talent (Romann, 2020). Given these shortcomings, several sports clubs, academies and federations have committed to adding new strategies such as bio-banding or testing indicators in talent selection, the maturational status or the peak height velocity (Arede et al., 2021). Although there is a growing map of scientific research investigating the independent effects of anthropometric, physiological, psychological (Schmid et al.; Taylor et al.) or contextual factors (Uehara et al.) among others to the talent identification process, relatively few of them, have considered the potential interactions among these variables, especially, the between contextual and socioeconomic factors on nurturing talent regardless of age-related issues or communities' size (Leite et al.).

New comprehensive research proposals are emerging (Bonney et al.) to improve overall analysis of entire processes impacting talent ID and development. Ideas like "birthday-banding" (Kelly et al., 2020), the "transfer talent" (Vaeyens et al., 2009) "process talent transfer" (Pion et al., 2020) or "specialized sampling" (Sieghartsleitner et al., 2018), will not only help to obtain better results but also lose (or retain) fewer athletes throughout the way. Very few talent development processes have an efficiency rate > 30% (e.g., see the works of Boccia et al., 2020, 2021 in athletics, or Koz et al., 2012, in professional sports). It is precisely this last point that should also capture our attention in greater depth. Most research in this area focuses on the successful athlete, ignoring that athletes will not be successful. Perhaps it is time to look the other way, better understand why some athletes fail to achieve these performance levels and consequently improve the process further and lose fewer athletes (Williams and MacNamara, 2020).

Understanding the interaction between nature and nurture is critical for better understanding talent identification and development (Williams and MacNamara, 2020). Indeed, the growing complexity of processes impacting talentID are highly unpredictable and it will never be possible to consider this phenomenon as an exact science. Furthermore, this complexity illuminates distinctly individual and personal processes contextualized to each participant's situation, and therefore not reproducible in other individuals. In this regard, progress in research, specifically in social epigenetics (Ahmetov and Fedotovskaya, 2015; Pickering et al., 2019), should offer relevant contributions in the coming years. As noted, the process of predicting which athletes are most likely to succeed (i.e., international, national or regional competition) will always encompass risks and mistakes (Born et al.). Mistakes when judging *potential* vs. *performance* must be considered the likely consequence of a process of own self-regulation that excludes talent from one sport while unconsciously taking it to another one (Collins et al., 2014).

Recognizing a certain level of scientific inconsistency that typically is associated with talent identification and development in sport (Baker et al., 2020), there is an overabundance of research employing cross-sectional designs and descriptive analysis methods on this topic (Jackson and Comber, 2020). In this sense, this issued privileged (a) longitudinal (Post et al.; Saward et al.) and prospective studies (Höner et al.), (b) non-mainstream sports (Roberts et al.), (c) inclusive approaches (Dehghansai et al.), (d) and the transference from this research to other countries and continents (Uehara et al.).

The lack of consensus in talent definition can lead to extreme positions and heterogeneous positioning among practitioners, coaches, scouts, sports scientists, athletes, and scientific community members (Kravariti and Johnston, 2019). While disagreement can foster scholarly debate and, consequently, lead to a better understanding of a particular phenomenon, it can also serve as a barrier for application. In addition, it should be noted that talent is subject to continuing evolution, via (i) future paradigms and social challenges that are transforming sport and physical activity, understood as a public health challenge and a phenomenon of socialization, (ii) of the rapidly rising diversity of media exposure of sports or, or (iii) exceptional technological advancements and the growing sophistication of methods used in the sports industry. Epstein (2004) compared former exceptional athletes like Jesse Owens or Roger Banister and their best performances with nowadays features. Changing technologies, changing genes, and a changing mindset may ultimately help explaining why the athletes are getting stronger, faster, bolder, and better than ever. As an example, focus on the recent feature by the Kenyan marathon runner Eliud Kipchoge, who made history in athletics last year by finishing for the first time, the total distance of a marathon under 2 h (Hoogkamer et al., 2019).

The recent technological and processing techniques revolution and the ongoing methodological refinement may have led to a scientific research paradigm change explored in the current Research Topic (Bedir and Erhan). To what extent all these evolving technologies have affected talent identification and development, and the selection process still requires much broader and deeper investigation. Thus, all this body of scientific knowledge may be incorporated into the performance analysis scope, instigating new questions about the dynamical parameters of performance and potentially opening new windows of opportunity. In particular, one aspect on which we clearly must work, advance, and improves the relationship between scientific research and the practical world (Stricker and Goldfried, 2019). Therefore, the criticism of this gap between science and practice is certainly understood as fair (Sandbakk, 2018; Haugen, 2019).

Globally, talentID Research Topic combined empirical research and theoretical models that contribute to advancing knowledge related to sports performance, specifically concerning its role in talent identification and proper development. The collection of these scientific articles included in the Research Topic debated and provided a holistic contribution on how this knowledge should be applied, both in organizational structures (sports clubs, youth academies, national federations, and research centers) and in strategic policies responsible for promoting and fostering long-term performance programmes, youth participation, and personal development. This is the main reason why the editors consider that this editorial article highlighted the need to understand the obligations and needs of the practitioners, to bridge the gap between science and practice (Collins et al., 2018) and provide a helpful guide to be effectively translated to daily practice in sports.

The development of human and technological resources, mostly visible in several sports sciences (from psychology to nutrition, from physiology to biomechanics, through motor learning or pedagogy), plays a key role and responds to the question posed by Epstein (2004). The evolution of each sports speciality is a consequence of all the technological, regulatory and knowledge advances, which will undoubtedly provoke the appearance or understanding of new models of successful athletes. Advances in data processing and analysis and the capacity to collect such data contribute to our understanding of what talent is and the process of identifying and developing it. In this sense, big data is playing an epicentral role in helping scientists better understand players behaviors, such as dynamic positioning in their natural environments (Gonçalves et al., 2018) and within their in-game actions (Fernandez and Bornn, 2018). Alongside, advanced processing techniques have accompanied this journey, such as machine learning and deep learning (Cust et al., 2019; Musa et al., 2020), data mining (Dubois et al., 2020), artificial intelligence (Claudino et al., 2019), or training programs based on virtual reality and virtual augmented interaction (Michalski et al., 2019).

Indeed, as the advancement of knowledge across multiple disciplines allows for greater depth of understanding about talentID, it also helps applied knowledge of impacts at a practical level in the athlete's day-to-day life. The athlete's development process can be converted into a more controlled and less random process, and we can advance in improving the efficiency of all the athlete's development processes and programs (not only at the level of performance but also the level of health—physical and mental—of the athlete). To do this, inevitably, there must first be a clear consensus among researchers to establish who is considered a talented athlete. To advance knowledge in this field, it is necessary to start from a broad consensus among the scientific community members on this topic.

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All authors contributed equally to manuscript revision, read, and approved the submitted version.

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Mechanical, Physiological, and Perceptual Demands of Repeated Power Ability Lower-Body and Upper-Body Tests in Youth Athletes: Somatic Maturation as a Factor on the Performance

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This study aims (a) to assess and compare the acute mechanical, physiological, and perceptual demands induced by a lower and upper body repeated power ability (RPA) protocols, and (b) to examine how the somatic maturation could predict training response in RPA. Thirteen young male basketball players (chronological age = 15.2 ± 1.1 years; height = 173.8 ± 9.5 cm; body mass = 71.7 ± 18.3 kg) were selected to perform the parallel Back Squat (BS), and Bench Press (BP) RPA protocols (3 blocks of 5 sets of 5 repetitions with 30 s and 3 min of passive recovery between sets and blocks, respectively). Mean propulsive power (MPP), accelerometer-based data, cardio-respiratory data, blood lactate, rate of perceived exertion (RPE) and muscle soreness were recorded. Somatic maturation was estimated according to the Khamis and Roche method. On the BS protocol, the mean oxygen uptake (VO_2), heart rate (HR), and RPE were 1006.33 ± 481.85 ml/min., 133.8 ± 12.5 bpm, and 6.14 ± 0.98 A.U., while on the BP protocol, were 684.6 ± 246.3 ml/min., 96.1 ± 10.4 bpm, and 5.08 ± 1.44 A.U., respectively. Significant between-blocks differences were found for MPP, RPE, and blood lactate for both exercises. The BS implies higher cardio-respiratory and perceptual demands, though lower power production fluctuation and movement variability than the BP. The somatic maturation was a strong predictor of RPA-derived variables in BS. The MPP during all protocol, and the MPP during the Best Set were significant predictable by somatic maturation in both exercises. Mechanical, physiological and perceptual training demands are exercise and maturation dependent.

Keywords: technology, performance analysis, maximal power output, strength, high-intensity efforts

INTRODUCTION

During team-sports matches, players are required to perform repeated bouts of high-intensity actions (HIA), such as sprinting, jumping, accelerations, decelerations, turns, and cutting interspersed with periods of low-to-moderate intensity actions (e.g., standing and walking) (Stojanović et al., 2018). Substantial decrements in HIA, mainly at the latter stages of matches (e.g., second half), have been typically reported in basketball (Stojanović et al., 2018) and other team-sports (Póvoas et al., 2012). As such, it is suggested that the ability to maintain HIA for the entire duration of a match is an important physical-fitness component in team-sports (Gabbett and Mulvey, 2008) particularly in basketball (Castagna et al., 2007). Thus, any strength and power training program with basketball players should aim to enhance the performance of HIA, and execute them efficiently throughout a match (Schelling and Torres-Ronda, 2016). Several training strategies have been recommended to optimize athletes' ability to perform lower-body and upper-body actions in team-sports athletes (Gonzalo-Skok et al., 2016, 2017; Arede et al., 2019b). In this regard, the repeated-power ability (RPA) training consists of several blocks of sets of lower or upper-body maximal power with incomplete recovery periods between sets, that can concurrently target a wide variety of adaptations (e.g., cardio-respiratory, mechanical, neuromuscular) (Gonzalo-Skok et al., 2014, 2016, 2018). Besides being considered particularly effective to improve sprinting (1.6%), cutting (2.1%), and jumping (7.2–7.5%) in team-sport athletes (Gonzalo-Skok et al., 2016), this method has been recently proposed as an effective training modality to improve upper-body fatigue resistance (Gonzalo-Skok et al., 2018). The RPA training is largely explored in young and/or moderately resistance-trained basketball players during in-season (Gonzalo-Skok et al., 2016, 2018), nevertheless, additional evidence are required to clarify its perceptual and physiological demands to help practitioners to properly design training plans that include both in-court training sessions and the RPA training.

The effects of the RPA training are typically monitored and assessed through a linear transducer, and the variables often used include mechanical variables, such as the average power (Gonzalo-Skok et al., 2014, 2018), power fluctuations and the percentage of decrement in average power (Gonzalo-Skok et al., 2018). However, a previous study revealed most accurate information for strength and power assessment (Sánchez-Medina et al., 2010). The load that maximized the mechanical power output in bench press exercise was similar between mean propulsive power (MPP) (36.5% 1RM), and peak power (37.5% 1RM), but also lower comparing to the mean power (54.2%). Nevertheless, analyzing the load-power relationships according to three different measures (mean, peak, and MPP), the MPP was the most stable variable (R^2 = 0.95), comparing to the mean power (R^2 = 0.91), and peak power (R^2 = 0.82) through the range of loads (10–100% 1RM) (Sánchez-Medina et al., 2010). Consequently, the mean propulsive power provided a better indicative of an individual's true neuromuscular potential, comparing to mean and peak power (Sánchez-Medina et al., 2010). However, more studies are needed to confirm these findings. Previous studies showed that power production gradually decreases across the RPA protocol (Gonzalo-Skok et al., 2014), which suggest that the athletes experienced fatigue toward the end of the training sessions, which influenced muscle performance and, therefore, the ability to generate maximal power (Cormie et al., 2011a). Alterations at muscle properties and hormonal level due to fatigability mechanisms (Cormie et al., 2011a), could affect technical execution, however, this issue has been scarcely explored within strength and conditioning field. Recently, multiscale entropy measures, including the sample entropy (SampEn) have been explored to analyze the variability in accelerometer-based data derived of resistance training tasks (Moras et al., 2018). According to the findings, increments in movement variability resulted in higher values of SampEn (Moras et al., 2018), extending the understanding of the athlete's movement during resistance training tasks. However, as far as we know, there is no study analyzing the movement variability through SampEn on upper-body nor lower-body repeated HIA.

A better understanding on how growth and maturational development interact with different training stimulus is essential for effective programming and, consequently, to improve athletic performance, throughout childhood and adolescence (Lloyd and Oliver, 2014). Adolescence is typically characterized by significant structural and functional modifications in the body, including the cardio-vascular response, expressed as the peak oxygen uptake, lactate production, carbon dioxide output, and minute ventilation (Armstrong et al., 2015). One of the best ways to know how these modifications occur requires the estimation of somatic maturation (Arede et al., 2019a). Previous studies analyzed how somatic maturation determined using both predicted age of peak height velocity, and percentage of predicted adult height (% PAH), affects strength-related parameters (Meylan C.M. et al., 2014; Meylan C.M.P. et al., 2014). Authors concluded as somatic maturation progresses athletes demonstrated higher values of maximum strength, maximal power output, and maximal force in concentric leg-press squat (Meylan C.M. et al., 2014; Meylan C.M.P. et al., 2014). Thus, somatic maturation helps practitioners to establish a better understanding of maturational status and therefore is beneficial to (i) design the appropriate training strategies, (ii) to optimize training adaptations and, consequently, and (iii) to achieve higher performance (Lloyd and Oliver, 2014; Haff and Triplett, 2016). However, scarce information is known about how somatic maturation is related with cardio-respiratory, mechanical, and neuromuscular parameters among both upper and lower-body repeated high-intensity protocols.

The aims of this study were (a) to assess and compare the mechanical, physiological, and perceptual demands induced by a lower and upper-body RPA, and (b) to examine how the somatic maturation could predict training response in RPA. We hypothesized that (i) training response differs according to the exercise, and (ii) somatic maturation predicts exercise response in RPA.

MATERIALS AND METHODS

Procedures

All data were gathered in a single group using a descriptive design. It was taken by the same investigator to ensure testing accuracy and reliability. Data collection took place in the second month of the competitive season (November) after a 4-weeks pre-season period. Data collection included 6 consecutive sessions: first, subjects were recorded in anthropometrical data and assessed individual maximal heart rate (HR_{max}) performing the

Yo-Yo intermittent recovery test – Level 1 (Berkelmans et al., 2018). Second, an incremental load test to determine the load that maximized power output (Loadopt) in both BS and BP exercises was performed (two independent sessions). Then, one familiarization session with testing procedures (RPA protocol) was carried out. Finally, subjects undertook the RPA protocol (two independent sessions). The subjects had 48–72 h of rest between each session.

Subjects

Twenty-two young male (U-14 to U-17) basketball players from a basketball academy were selected to participate in this study. Due to lack of interest (n = 6) or incomplete full protocol (n = 3), thirteen (chronological age = 15.2 ± 1.1 years; height = 173.8 ± 9.5 cm; body mass = 71.7 ± 18.3 kg; percentage of predicted adult height = 96.9 ± 3.9%) of the initial subjects completed the protocol. All participants had a minimum experience of 1 year in strength and power training, including parallel Back Squat (BS) and Bench Press (BP) exercises (training experience = 1.5 ± 0.5 years, range = 1–2 years). All players participated on an average of 6 h of basketball training, 2 strength/power sessions, and 1–2 competitive matches (regional level) per week. Each subject signed the approved assent form, while one parent or legal guardian also signed the approved consent form before the beginning of this investigation. The ethics committee of University of Trás-os-Montes and Alto Douro approved the present study, and it conformed to the recommendations of the Declaration of Helsinki (2013).

Measures

Somatic Maturation

Height was recorded using a commercial portable stadiometer (Tanita BF-522W, Japan, nearest 0.1 cm). Body mass was estimated using the body fat monitor (Tanita BF-522W, Japan, nearest 0.1 kg). All measurements were taken following the guidelines outlined by the International Society for the Advancement of Kinanthropometry (ISAK) by the same researcher, who holds an ISAK Level 1 accreditation. Players' height, body mass, chronological age and mid-parent height were used to predict the adult height of each player (Khamis and Roche, 1994). The height of the biological parents of each player were self-reported and adjusted for over-estimation using the previously established equations (Epstein et al., 1995). The current height of each player is then expressed as a percentage of adult height (% PAH), which can then be used as an index of somatic maturation (Roche et al., 2013). In these last years, the prediction of adult height using Khamis and Roche method is the most commonly used indicator of somatic maturation in sports field (Cumming et al., 2017; Malina et al., 2019). Moreover, this method is the most accurate to estimate age at peak height velocity, comparing to estimation based on generic age from longitudinal measures, and on the maturity offset equation (Parr et al., 2020). Individual maximal heart rate (HRmax). The HR_{max} was estimated trough the Yo-Yo intermittent recovery test – Level 1, considering the highest number of beats per minute recorded during the test. The test consists of consecutive series of 20-m shuttle runs at progressive velocities controlled by an audio beep interspersed by regular short rest periods of 10-s (Berkelmans et al., 2018). The test was finished when a subject failed to keep up with the audio beep in reaching the finish line on two separate or consecutive occasions.

Incremental Load Test

Incremental free parallel BS and BP load tests were used to determine the load that maximized mean propulsive power output (Loadopt) (Sánchez-Medina et al., 2010). The parallel BS was performed with plantar flexion to finish the movement, but jumping was not allowed. Subjects were instructed to squat down until the top of the thighs were parallel to the ground in a controlled manner and to perform the concentric phase of each repetition as fast as possible. The BP started with the bar at arm's length and lowered the bar until the chest was touched lightly without bounding the bar. Subjects were instructed to perform the concentric phase of each repetition as fast as possible, without a pause between eccentric and concentric phases, and the eccentric phase in a controlled manner (i.e., approximately 2 s). Initial load was set at 20 kg for all subjects and was progressively increased in 10 kg until the attained mean propulsive velocity (MPV) was lower than 0.99 $m \cdot s^{-1}$ in parallel BS, and lower than 0.50 $m \cdot s^{-1}$ in BP (Sánchez-Medina et al., 2010). Thereafter, load was adjusted with smaller increments (2.5–5 kg), individually for each subject. For the lighter loads (BS = MPV > 1.0 $m \cdot s^{-1}$; BP = MPV > 0.97 $m \cdot s^{-1}$) three attempts were executed at each load; two for the medium (BS = 0.57 $m \cdot s^{-1}$ ≤ MPV ≤ 0.99 $m \cdot s^{-1}$; BP = 0.50 $m \cdot s^{-1}$ ≤ MPV ≤ 0.97 $m \cdot s^{-1}$); and only one for the heaviest loads (BS = MPV < 0.57 $m \cdot s^{-1}$; BP = MPV < 0.50 $m \cdot s^{-1}$) (Sánchez-Medina et al., 2010). A 3-min rest was established for lighter and medium loads, and 5-min for the heaviest loads (Sánchez-Medina et al., 2010). Only the best repetition at each load, according to the criteria of the highest mean propulsive power output (MPP), was considered for analysis (Sánchez-Medina et al., 2010). The MPP showed an almost perfect individual load-power relationship (R^2 = 0.95), which allowed to determine the power output at each percentage of one maximum repetition (% 1RM) for each subject were observed (Sánchez-Medina et al., 2010). The test was performed using barbell standard 20-kg (BOXPT Equipment, Póvoa de Varzim, Portugal) and the barbell velocity was recorded with a SmartCoach Power Encoder linear transducer (SmartCoach Europe AB, Stockholm, Sweden), and computed in SmartCoach software into a personal computer (ASUS, model A541U).

Repeated-Power-Ability (RPA) Training Protocol

The RPA protocol consisted of 3 blocks of 5 sets of 5 repetitions with 30-s of passive recovery between sets and 3-min of passive recovery between blocks in both free parallel BS and BP exercises using Loadopt. The concentric phase was executed as fast as possible, and the eccentric phase was performed at slower velocity (i.e., self-selected and never exceeding 3-s) than the concentric phase, neither bouncing on the chest nor jumping. The protocol was performed using barbell standard 20-kg (BOXPT Equipment, Póvoa do Varzim, Portugal) and the barbell velocity was recorded with a SmartCoach Power Encoder linear transducer (SmartCoach Europe AB, Stockholm, Sweden), and computed in the SmartCoach software into a personal computer (ASUS, model A541U). Percentage of MPP decrement was calculated using the following formula: % Dec = 100 − (MPP_{mean}/MPP_{best}) × 100). Intraset power fluctuation (FLUC), was considered and calculated as follows: FLUC = (SD of MPP in each set/mean of each set) × 100, for the best set, the last set, and all protocol (i.e., mean of 3 blocks).

Total Acceleration (AcelT)

The acceleration in the anteroposterior axis (Z), in the transverse or lateral axis (X), and vertical axis (Y) for the overall movement was measured using an inertial measurement unit (WIMU, Realtrack Systems, Almeria, Spain) attached to the barbell. The WIMU unit integrates accelerometer, gyroscope, and magnetometer with sampling frequency for 3-axis of 100 Hz (Muyor et al., 2018). The main variable used was the acceleration magnitude or resultant vector of acceleration which is called total acceleration (AcelT) (García-Rubio et al., 2018). AcelT was computed using the following formula: AcelT = $\sqrt{x^2 + y^2 + z^2}$. Coefficient of variation (CV), and Sample Entropy (SampEn) for AcelT (Moras et al., 2018) were computed using SPRO Software v1.0.0 (Realtrack Systems, Almeria, Spain). CV was calculated using the following formula: CV = $\frac{\sigma}{\mu}$. SampEn (m,r,n) is defined as the negative natural logarithm of the conditional probability that two sequences, similar form points (length of the vector to be compared), remain similar at the next point m + 1 (Silva et al., 2017). The values used to calculate SampEn were 2 to vector length (m) and 0.2 ± SD to the tolerance (r) (Silva et al., 2017). Values of SampEn range from zero toward infinity, where values close to zero were indicative of higher regularity in AcelT, while the higher the SampEn, the more unpredictable the AcelT (Silva et al., 2017).

Cardio-Respiratory Variables

Cardio-respiratory measures were collected continuously with breath-by-breath method using a reliable and valid automated open-circuit gas analysis system (K5, Cosmed Srl, Rome, Italy), during the RPA protocol (Perez-Suarez et al., 2018). Pulmonary ventilation (VE), oxygen uptake (VO_2) and carbon dioxide production (VCO_2) were assessed. Careful calibrations of flow sensors and gas analyzers were performed before each measurement according to the manufacturer's instructions. Thus, immediately before each test session, gas analyzers were calibrated using ambient air (20.93% oxygen and 0.03% carbon dioxide) and with a standard gas mixture (containing 16.00% oxygen and 5.02% carbon dioxide). The turbine flow meter, a bidirectional turbine with an optoelectronic reader, was calibrated with a 3-L syringe (Cosmed Srl, Rome, Italy) and used for the determination of minute ventilation. The wearable equipment was positioned on the subjects and the bidirectional turbine was attached to a facemask (Hans Rudolph Inc., Shawnee, KS, United States) covering both the mouth and the nose.

Blood Lactate

Before and after the RPA testing protocol (1-, 3-, 5-, and 7-min.), capillary blood samples were obtained from the earlobe of participants and analyzed using a reliable and valid handheld lactate analyzer (Accutrend Plus; Boehringer; Mannheim, Germany) (Bonavolontà et al., 2009). The responsible researcher carefully cleaned, disinfected and dried the subjects' ear lobe before the blood collection. Subjects' skin was punctured with a lancet and the first drop of blood was placed straight on the strip. The highest value was considered for further analysis.

Perceptual Response (RPE)

After the completion of each block of RPA testing protocol, all participants were requested to quantify the RPE through the Borg CR10 scale (Borg and Kaijser, 2006).

Muscle Soreness

Muscle soreness was determined in quadriceps muscle during a body-weight parallel BS after the lower-body exercise, and in pectoralis major muscle (on the BP), when the muscle was palpated using the Visual Analogue Scale (0: no pain at all, 10: worst pain ever), immediately after the completion of the testing protocol.

Statistical Analyses

Data are presented as mean ± SD. Normality of data distribution and sphericity were confirmed using the Shapiro-Wilk statistic and Levene's Test for equality of variances. Repeated measures univariate analysis of variance (ANOVA) were conducted for differences in different variables between all blocks. Independent *t*-tests were used to compare dependent variables between the training conditions (BS vs. BP). Effect Sizes (ES) analysis was also computed using a published spreadsheet in Microsoft Excel (Hopkins, 2007). Threshold values for Cohen's d for ES statistics were 0–0.2 trivial, >0.2–0.6 small, >0.6–1.2 moderate, >1.2–2.0 large, and >2.0 very large (Hopkins et al., 2009). A stepwise multiple regression was used to determine a predictive equation to estimate RPA-derived variables from % PAH alone. The level of statistical significance was set at $p < 0.05$. All statistical analyses were performed using SPSS software (version 24 for Windows; SPSS Inc., Chicago, IL, United States).

RESULTS

The results obtained in BS were 46.3 ± 12.2 l/min., 1006.3 ± 481.8 ml/min., 133.8 ± 12.5 bpm, and 3.36 ± 1.78 mmol/l for VE, VO_2, HR and Lactate, respectively (**Table 1**). Also, the mean RPE and muscle soreness were 6.14 ± 0.98 A.U., and 6.83 ± 0.94 A.U., respectively (**Table 1**). Regarding the BP, the mean VE, VO_2, HR, Lactate were 25.7 ± 7.2 l/min., 684.6 ± 246.3 ml/min., 96.11 ± 10.4 bpm, and 4.11 ± 1.43 mmol/l, respectively (**Table 2**). Also, the mean RPE and muscle soreness were 5.08 ± 1.44 A.U., and 6.25 ± 0.75 A.U., respectively (**Table 2**).

Results of the inferential analysis between exercises is displayed in **Table 3**. FLUCL ($p < 0.05$), FLUCM ($p < 0.05$), ACELT CV ($p < 0.0001$), and ACELT SampEn ($p < 0.05$), were significantly higher in BP than BS. Furthermore, VE ($p < 0.0001$), VO_2 ($p < 0.05$), VO_2 rel ($p < 0.05$), HR ($p < 0.0001$), and RPE ($p < 0.05$) were significantly higher in BS than BP.

TABLE 1 | Overall results from the Parallel Back-Squat RPA protocol.

Variables			
1RM (kg)	88.71 ± 18.16	VO_2 (ml/min.)	1006.33 ± 481.85
% 1RM	65.53 ± 9.47	VO_2 rel (ml/kg/min.)	13.78 ± 5.49
MPO (W)	467.83 ± 118.03	VCO_2 (ml/min.)	603.77 ± 562.90
Loadopt (kg)	55.92 ± 13.73	VCO_2 rel (ml/kg/min.)	8.13 ± 6.75
Best Set (W)	414.32 ± 100.26	HR (bpm)	133.77 ± 12.49
Last Set (W)	334.68 ± 72.96	HRmáx (%)	68.22 ± 7.91
MPP (W)	359.24 ± 84.76	Lactate (mmol/l)	3.36 ± 1.78
Dec (%)	13.16 ± 5.68	ACELT CV (a.u.)	0.22 ± 0.03
FLUCB (a.u.)	7.85 ± 2.53	ACELT SampEn (a.u.)	0.48 ± 0.14
FLUCL (a.u.)	8.35 ± 2.25	RPE (a.u.)	6.14 ± 0.98
FLUCM (a.u.)	7.89 ± 1.52	Muscle Soreness (a.u.)	6.83 ± 0.94
VE (l/min.)	46.29 ± 12.20		

1RM, one maximum repetition; % 1RM, percentage of one maximum repetition; MPO, maximal power output; Loadopt, load which maximized propulsive power; MPP, mean propulsive power; Dec, decrement in mean propulsive power; FLUCB, power fluctuation in the best set; FLUCL, power fluctuation in the last set; FLUCM, mean power fluctuation; VE, minute ventilation; VO_2, oxygen uptake; VCO_2, carbon dioxide output; HR, heart rate; HRmáx, percentage of maximum heart rate; ACELT, total acceleration; CV, coefficient of variation; SampEn, sample entropy; RPE, rate of perceived exertion.

TABLE 2 | Overall results from the Bench-Press RPA protocol.

Variables			
1RM (kg)	57.05 ± 14.50	VO_2 (ml/min.)	684.60 ± 246.32
% 1RM	44.80 ± 9.06	VO_2 rel (ml/kg/min.)	9.25 ± 2.33
MPO (W)	312.24 ± 90.10	VCO_2 (ml/min.)	525.39 ± 327.62
Loadopt (kg)	25.83 ± 9.00	VCO_2 rel (ml/kg/min.)	6.86 ± 3.42
Best Set (W)	281.91 ± 76.20	HR (bpm)	96.11 ± 10.40
Last Set (W)	211.17 ± 65.87	HRmáx (%)	48.89 ± 5.45
MPP (W)	243.32 ± 69.40	Lactate (mmol/l)	4.11 ± 1.43
Dec (%)	13.75 ± 5.60	ACELT CV (a.u.)	0.40 ± 0.11
FLUCB (a.u.)	7.60 ± 3.46	ACELT SampEn (a.u.)	0.72 ± 0.26
FLUCL (a.u.)	10.40 ± 2.96	RPE (a.u.)	5.08 ± 1.44
FLUCM (a.u.)	9.81 ± 3.54	Muscle Soreness (a.u.)	6.25 ± 0.75
VE (l/min.)	25.75 ± 7.16		

1RM, one maximum repetition; % 1RM, percentage of one maximum repetition; MPO, maximal power output; Loadopt, load which maximized propulsive power; MPP, mean propulsive power; Dec, decrement in mean propulsive power; FLUCB, power fluctuation in the best set; FLUCL, power fluctuation in the last set; FLUCM, mean power fluctuation; VE, minute ventilation; VO_2, oxygen uptake; VCO_2, carbon dioxide output; HR, heart rate; HRmáx, percentage of maximum heart rate; ACELT, total acceleration; CV, coefficient of variation; SampEn, sample entropy; RPE, rate of perceived exertion.

Significant between-block differences were found for MPP ($p < 0.0001$), ACELT CV ($p < 0.05$), RPE ($p < 0.0001$), and blood lactate ($p < 0.05$), on the BS (**Table 4**). Also, significant between-block differences were found for MPP ($p < 0.01$), RPE ($p < 0.0001$), and blood lactate ($p < 0.0001$), on the BP (**Table 5**).

Multiple regression analysis revealed% PAH as significant predictor of MPP ($p < 0.05$; $R^2 = 0.50$), Best set ($p < 0.05$; $R^2 = 0.35$), Last set ($p < 0.01$; $R^2 = 0.48$), % Dec ($p < 0.01$; $R^2 = 0.47$), and oxygen uptake ($p < 0.05$; $R^2 = 0.38$), on the BS (**Figure 1**). Also, on the BP, % PAH as significant predictor of MPP ($p < 0.05$; $R^2 = 0.32$), and Best set ($p < 0.05$; $R^2 = 0.33$) (**Figure 2**).

DISCUSSION

The aims of this study were (a) to assess and compare the acute mechanical, physiological, and perceptual demands induced by a lower and upper-body repeated power ability (RPA) bouts, and (b) to examine how the somatic maturation could predict training response in RPA. We found that lower-body RPA training protocol requires higher cardio-respiratory and perceptual demands, and lower power production fluctuation and movement variability than the upper-body training strategy. It was also observed that some lower- and upper body RPA-derived variables were predicted using somatic maturation, i.e., the present findings support our hypothesis that training response differs according to the exercise, and somatic maturation predicts exercise response in RPA, particularly in lower-body RPA.

Maximal muscular power is associated with enhanced athletic performance and the improvement of this capacity requires the use of complex movements performed with loads ranging from 50 to 90% of 1RM, for lower-body exercises, and with loads ranging from 30 to 45% of 1RM, for upper-body exercises (Cormie et al., 2011b). The RPA includes repeated bouts of short high-intensity efforts with sub-maximal loads (45–66% of 1RM). The short and maximal sustained efforts (i.e., 5–10 s at 90–100% of maximum power output) are associated with a lower contribution of aerobic mechanisms (4%) and a higher contribution of anaerobic mechanisms (96%) (Haff and Triplett, 2016). The total duration of the whole RPA protocol (≈15 min.) suggests that the oxidative system also contributes to the energy production, with light stress of cardiorespiratory (48.89–68.2%$HR_{máx}$) and glycolytic systems (3.31–4.11 mmol/l) (Haff and Triplett, 2016). Previous studies in basketball-match showed that heart rate ranged from 66.7 to 89.1% of $HR_{máx}$, and the blood lactate concentration from 2.7 to 6.8 mmol/l (Stojanović et al., 2018).

The onset of blood lactate accumulation (OBLA) which represents the concentration of blood lactate at 4 mmol/L is a well-established indicator of exercise intensity (Bompa and Haff, 2009; Haff and Triplett, 2016). Training at intensities near or above the OBLA promotes that the lactate accumulation occurs later at a higher exercise intensity, due to reduced catecholamine release at high exercise intensities, and increased mitochondrial content (Haff and Triplett, 2016). Because of this, occurs greater production of adenosine triphosphate (ATP) through aerobic mechanisms, and greater%VO_{2max} with lower blood lactate accumulation (Haff and Triplett, 2016). It seems that RPA shows some physiological correspondence with basketball-match demands, i.e., periods of high-intensity activity are interspersed with periods of low- to moderate-intensity activities. Performing RPA efforts, athletes could experience similar blood lactate accumulation to a basketball-match in a shorter period of exposure (≈15 min. vs. 40 min.), generating

TABLE 3 | Comparison between parallel Back Squat and Bench Press protocols.

Variables	p	η2	Differences	Variables	p	η2	Differences
Dec (%)	0.801	0.01 *No effect*		VCO_2 (ml/min.)	0.661	0.02 *No effect*	
FLUCB (a.u.)	0.854	0.00 *No effect*		VCO_2 rel (ml/kg/min.)	0.595	0.03 *No effect*	
FLUCL (a.u.)	0.037	0.34 *Moderate*	BP > BS	HR (bpm)	0.000	0.93 *Strong*	BS > BP
FLUCM (a.u.)	0.046	0.32 *Moderate*	BP > BS	Lactate (mmol/l)	0.315	0.09 *Minimum*	
VE (l/min.)	0.000	0.89 *Strong*	BS > BP	ACELT CV (a.u.)	0.000	0.79 *Strong*	BP > BS
VO_2 (ml/min.)	0.024	0.38 *Moderate*	BS > BP	ACELT SampEn (a.u.)	0.032	0.35 *Moderate*	BP > BS
VO_2 rel (ml/kg/min.)	0.021	0.40 *Moderate*	BS > BP	RPE (a.u.)	0.017	0.42 *Moderate*	BS > BP

Dec, decrement in mean propulsive power; FLUCB, power fluctuation in the best set; FLUCL, power fluctuation in the last set; FLUCM, mean power fluctuation; VE, minute ventilation; VO_2, oxygen uptake; VCO_2, carbon dioxide output; HR, heart rate; ACELT, total acceleration; CV, coefficient of variation; SampEn, sample entropy; RPE, rate of perceived exertion; BS, parallel back squat; BP, parallel bench press.

TABLE 4 | Between-blocks comparisons in the mechanical and perceptual variables – Parallel Back Squat.

Variable	Block 1	Block 2	Block 3	Repeated measures ANOVA		Effect Size (ES) 95% Confidence Interval		
				p	η2	Block 1 vs. Block 2	Block 1 vs. Block 3	Block 2 vs. Block 3
MPP (W)	384.87 ± 94.33	354.37 ± 85.96	338.48 ± 77.13	0.000*#$	0.64 *Moderate*	0.27 [0.13; 0.41] *Small*	0.44 [0.30; 0.57] *Small*	0.15 [0.05; 0.25] *Trivial*
FLUCM (a.u.)	7.57 ± 2.21	7.79 ± 1.56	8.31 ± 2.53	0.517	0.04 *No effect*	−0.22 [−0.84; 0.40] *Small*	−0.29 [−1.10; 0.52] *Small*	−0.13 [−0.76; 0.50] *Trivial*
ACELT CV (a.u.)	0.23 ± 0.04	0.22 ± 0.04	0.21 ± 0.04	0.032*#	0.45 *Moderate*	0.49 [0.11; 0.87] *Small*	0.71 [0.26; 1.16] *Moderate*	0.23 [−0.06; 0.51] *Small*
ACELT SampEn (a.u.)	0.46 ± 0.25	0.52 ± 0.18	0.45 ± 0.18	0.632	0.04 *No effect*	−0.38 [−1.07; 0.31] *Small*	0.02 [−0.82; 0.87] *Trivial*	0.36 [−0.23; 0.94] *Small*
RPE (a.u.)	4.83 ± 1.34	6.17 ± 0.94	7.42 ± 1.00	0.000*#$	0.82 *Strong*	−1.62 [−2.28; −0.96] *Very Large*	−3.11 [−3.96; −2.27] *Very Large*	−1.30 [−1.81; −0.78] *Very Large*
Variable	**Before**	**After**		p	**η2**	**Before vs. After**		
Lactate (mmol/l)	1.63 ± 0.63	3.36 ± 1.76		0.013	0.44 *Moderate*	−1.43 [−2.29; −0.58] *Very Large*		

** Significant difference ($p < 0.05$) between Block 1 and 2; # Significant difference ($p < 0.05$) between Block 1 and 3; $ Significant difference ($p < 0.05$) between Block 2 and 3; MPP, mean propulsive power; FLUCM, mean power fluctuation; ACELT, total acceleration; CV, coefficient of variation; ApEn, aproximate entropy; SampEn, sample entropy; RPE, rate of perceived exertion.*

metabolic adaptations which may be determinant for on-court performance.

The present results indicate that lower-body RPA training protocol implies higher cardio-respiratory (VE, VO2, VO2 rel, and HR) and perceptual demands (RPE), and also lower power production fluctuation (FLUCL and FLUCM) and movement variability (ACELT CV and SampEn) than the upper-body training strategy. The physiological demands are directly related to the amount of muscle tissue activated by the exercise (Haff and Triplett, 2016). The parallel BS involving a larger muscle mass or a greater work level than BP is likely to be associated with a higher VE, VO2, VO2 rel, and HR (Haff and Triplett, 2016). Maximal muscular power is accompanied by fast-twitch muscle fibers involvement (Cormie et al., 2011a). However, these type of muscle fibers are particularly fatigable, because they contain a low content of myoglobin, relatively few mitochondria, and relatively few blood capillaries (Cormie et al., 2011a). In addition, the rest interval affects the restoration of ATP and phosphocreatine, the clearance of fatigue-inducing substrates, and the restoration of force production capacity (Bompa and Haff, 2009). Thus, to completely restore the force- and power-generating capacity, the between-sets recovery should be within

TABLE 5 | Between-blocks comparisons in the mechanical and perceptual variables – Parallel Bench Press.

Variable	Block 1	Block 2	Block 3	Repeated measures ANOVA		Effect Size (ES) 95% Confidence Interval		
				p	η2	Block 1 vs. Block 2	Block 1 vs. Block 3	Block 2 vs. Block 3
MPP (W)	257.85 ± 75.19	244.52 ± 69.12	227.60 ± 67.42	0.001*$	0.49 *Moderate*	0.13 [0.03; 0.24] *Trivial*	0.33 [0.12; 0.53] *Small*	0.20 [0.09; 0.31] *Small*
FLUCM (a.u.)	9.25 ± 3.20	10.14 ± 4.61	10.05 ± 3.85	0.528	0.06 *Minimum*	−0.11 [−0.42; 0.20] *Trivial*	−0.18 [−0.59; 0.23] *Small*	−0.05 [−0.55; 0.45] *Trivial*
ACELT CV (a.u.)	0.40 ± 0.10	0.41 ± 0.12	0.40 ± 0.11	0.516	0.06 *Minimum*	−0.06 [−0.22; 0.10] *Trivial*	0.02 [−0.20; 0.25] *Trivial*	0.08 [−0.11; 0.27] *Trivial*
ACELT SampEn (a.u.)	0.73 ± 0.36	0.74 ± 0.35	0.69 ± 0.20	0.813	0.02 *No effect*	−0.05 [−0.48; 0.39] *Trivial*	0.00 [−0.91; 0.91] *Trivial*	0.07 [−0.81; 0.96] *Trivial*
RPE (a.u.)	3.83 ± 1.59	5.08 ± 1.56	6.33 ± 1.61	0.000*#$	0.72 *Strong*	−0.92 [−1.38; −0.46] *Moderate*	−1.65 [−2.36; −0.94] *Large*	−0.69 [−1.02; −0.37] *Moderate*
Variable	**Before**	**After**		***p***	**η2**	**Before vs. After**		
Lactate (mmol/l)	1.84 ± 0.80	4.11 ± 1.43		0.000	0.70 *Strong*	−2.38 [−3.25; −1.52] *Very Large*		

** Significant difference (p < 0.05) between Block 1 and 2; # Significant difference (p < 0.05) between Block 1 and 3; $ Significant difference (p < 0.05) between Block 2 and 3; MPP, mean propulsive power; FLUCM, mean power fluctuation; ACELT, total acceleration; CV, coefficient of variation; ApEn, aproximate entropy; SampEn, sample entropy; RPE, rate of perceived exertion.*

2 to 5 min. (Bompa and Haff, 2009). In the present protocol, subjects rested 30 s between sets, and 3 min between each block of 5 sets, affecting power-generating capacity, particularly in that exercise which involves a smaller amount of muscle mass (i.e., BP) as there is not enough between-blocks recovery to be fully recovered. In fact, altered muscle properties (i.e., release and pump back of calcium in skeletal muscle) could negatively affect maximal muscular power (Cormie et al., 2011a) and, consequently, increase power fluctuations (i.e., FLUCL and FLUCM) or movement variability (i.e., ACELT CV and SampEn). The present study failed to demonstrate any differences in blood lactate values between RPA protocols. In RPA greater emphasis is placed on mechanical stress due to the use of a lower number of repetitions per set (i.e., lower time under tension) with a short inter-set rest interval (Zatsiorsky and Kraemer, 2006). In contrast, resistance exercise protocols which include higher number of repetitions per set (i.e., higher time under tension) generate higher metabolic stress, resulting of the accumulation of metabolites, particularly lactate (Schoenfeld, 2013). In this regard, previous study revealed that higher values of blood lactate and significant between-exercises differences (BS and BP) occurred in resistance exercise protocols including higher number of repetitions per set (i.e., 10–12) at higher intensity (i.e., close of maximum predicted number of repetitions per set) (Sánchez-Medina and González-Badillo, 2011). However, in resistance exercise protocols including lower number of repetitions per set at lower intensity, lower values of blood lactate and no significant between exercises were reported (Sánchez-Medina and González-Badillo, 2011). Thus, we can claim that RPA involves mainly stress of the phosphagen system, and decreased carbohydrate metabolism, based on decreased accumulation of blood lactate, irrespective of resistance exercise. This hypothesis seems to be reinforced by the fact that adolescents have reduced capacity to utilize carbohydrate during submaximal exercise compared to young adult counterparts (Stephens et al., 2006). In fact, less mature subjects have lower number of key enzymes in the glycolytic pathways, attenuated sympathetic activity, and lower muscle glycogen content which result in lesser capacity to utilize carbohydrate, and consequently lower accumulation of blood lactate (Stephens et al., 2006). In both exercises, the MPP decreased across the RPA, with significant differences between blocks 1, 2, and 3. These results are in accordance with previous studies using a RPA training protocol (Gonzalo-Skok et al., 2014). During the first set, subjects performed higher concentric average power, while average power gradually decreases in the subsequent sets (412.5 > 391.7 > 378.8 > 367 > 358.2 W) (Gonzalo-Skok et al., 2014). The RPA training protocol consists of maximal power training with incomplete recovery periods (Gonzalo-Skok et al., 2016). The rest interval affect the restoration of adenosine triphosphate and phosphocreatine, the clearance of fatigue-inducing substrates, and the restoration of force production capacity (Bompa and Haff, 2009). However, short rest intervals coupled with high volumes of training generate physiological adaptations, such as capillary density, mitochondrial density, and buffer capacity which results in an endurance performance increased (Bompa and Haff, 2009). In fact, the enhanced ability to tolerate repeated sprints after RPA training might be associated to these kind of adaptations (Gonzalo-Skok et al.,

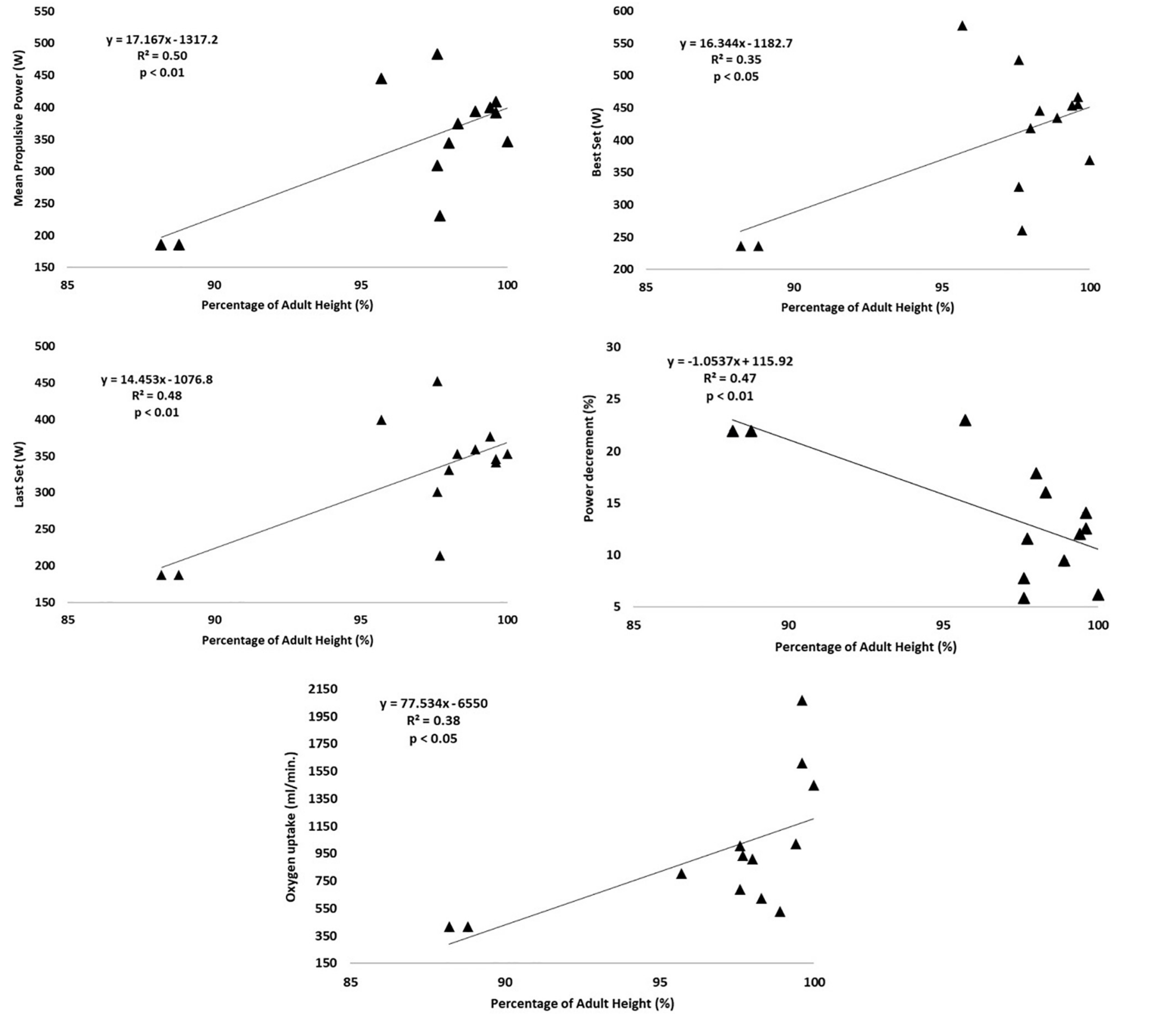

FIGURE 1 | Linear relationship between **(A)** Mean Propulsive Power and% PAH, **(B)** Best Set and% PAH, **(C)** Last Set and% PAH, **(D)** Power decrement and% PAH, and **(E)** Oxygen uptake and% PAH.

2016). Considering the MPP decrements, we can claim that the present training protocol reproduces in controlled setting the substantial decrements in HIA at the latter stages of a match.

The multiple regression analysis confirmed somatic maturation (expressed as% PAH) as a significant predictor of MPP and Best set for both exercises and for Last set, % Dec, and oxygen uptake only in the BS exercise. Thus, more advanced somatic maturation corresponds to higher values of the above-mentioned variables, with the exception of% Dec. Growth and maturation are characterized by significant changes in muscle structure, size, and metabolism, but also in neuromuscular system (Van Praagh and Doré, 2002; Lloyd and Oliver, 2014; Armstrong et al., 2015; Cumming et al., 2017). More matured subjects have a concomitant higher muscle fiber size, type II fiber distribution, and also higher levels of testosterone secretion (Van Praagh and Doré, 2002). Increased testosterone induces selective hypertrophy of type II fibers which could confer an advantage in power activities (Van Praagh and Doré, 2002; Cormie et al., 2011a), expressing by higher MPP and Best Set, as occurred in the present study.

Furthermore, a combination of changes in anatomical, metabolic and hematological factors underpin the ability of cardiopulmonary system to cope with increased exercise intensities, in later stages of maturation (Lloyd and Oliver, 2014). In fact, increased lungs size, heart size and number of alveoli results in higher values of VO_2 during exercise (Lloyd and Oliver, 2014). The present results support the hypothesis that somatic maturation could promote different responses to the RPA training, due to metabolic, muscular and neuromuscular factors.

Training methods which can concurrently stimulate different capacities are most efficient to catalyze improvements in HIA,

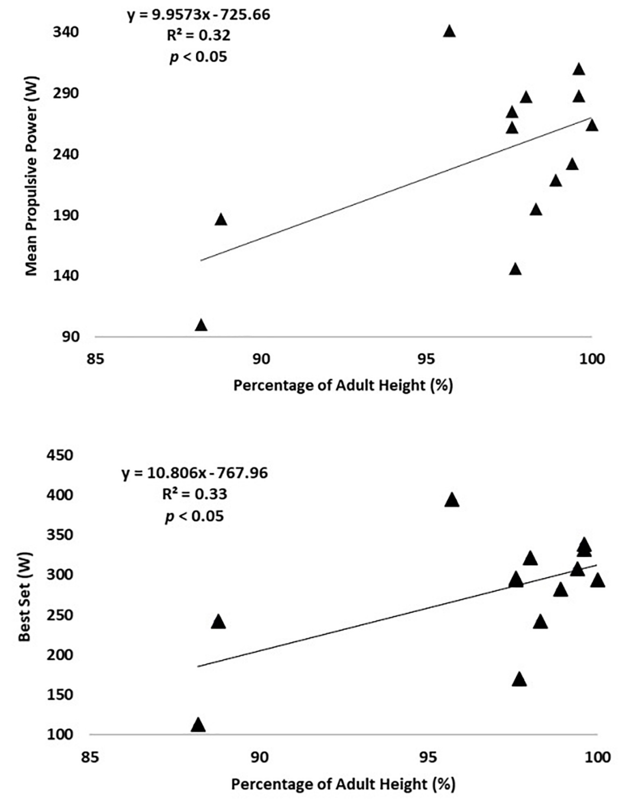

FIGURE 2 | Linear relationship between **(A)** Mean Propulsive Power and %PAH, and **(B)** Best Set and %PAH.

in more mature athletes (Lloyd and Oliver, 2014; Gonzalo-Skok et al., 2016, 2018). In this regard, a previous study with U-18 elite basketball players (Gonzalo-Skok et al., 2016), showed considerable improvements in repeated sprint ability (ES = 0.49) and repeated change of direction (ES = 0.60) after a low-volume and frequency lower-limbs RPA training. In the same line, another study made with U-17 elite basketball players (Gonzalo-Skok et al., 2018) showed meaningful improvements in BP performance at 1RM (ES = 0.26) and light to submaximal loads (20–80% 1RM, ES = 0.37–0.89). Improved lower and -upper body HIA performance might offer important competitive advantage to youth basketball players. Thus, RPA training protocol should be a suitable strategy to improve both upper- and lower-body HIA in youth athletes, particularly among more matured athletes. Limitations for interpreting the data of this study include the relatively small sample size (n = 13). Despite the small sample size, gold-standard technology was used to analyze key variables, biological maturation was assessed (in previous studies it was not taken into account (Gonzalo-Skok et al., 2014, 2016, 2018), and significant inferences were observed. However, given the current lack of knowledge regarding the physiological, and perceptual demands of RPA, this this study provides support for future investigations to clarify RPA training effects in the setting of the team-sports. Additional research with larger sample, players of different sport, age, gender, and playing standards should be conducted before the applicability of the current results can be generalized. Future studies should be conducted to analyze the short- and medium-term effects in lower-body (jumping, sprinting, and cutting) and upper-body (throwing and shooting) HIA following the RPA protocol. Finally, it would be interesting to analyze other performance variables, such as surface electromyography or biochemical markers (e.g., creatine kinase, and testosterone: cortisol).

CONCLUSION

The RPA focuses on maximal repeated power training with incomplete recovery periods in between sets, using multiple joint exercises, provides a high neuromuscular, and lower metabolic and perceptual stimulus. It has practical applicability due to the existence of many sports that include strength and power expressions under predominantly aerobic requirements (e.g., soccer, basketball). So, training together both qualities would optimize athletic performance similarly to traditional training in a more time-efficiently manner. Considering the present findings, it would be expected that the RPA is a time effective way of generating positive neuromuscular and physiological adaptations in youth athletes. However, somatic maturation explains more aspects of exercise response during lower body RPA protocol than during upper body RPA protocol. Higher levels of testosterone secretion during adolescence, promotes the growth of contractile tissue and the skeletal development, and consequently increased strength (Round et al., 1999; Van Praagh and Doré, 2002). These effect of testosterone is particularly higher on the quadriceps muscle (Round et al., 1999), determinants on the execution of parallel BS. Whereas somatic maturation can be a confound variable in the optimization of training adaptations, practitioners should assess technical competence, but also somatic maturation, before designing and prescribe this type of training protocols for young athletes. During upper body RPA protocol occurred higher power fluctuation and movement variability may demonstrate the importance of mastering technical competency, comparing to the lower body protocol. Previous studies demonstrated that power fluctuation is independent of overall power capacity (Gonzalo-Skok et al., 2014), and muscle activation during bench press exercise at different intensities is distinct according to the experience, particularly of main stabilizer muscle (i.e., medial deltoid) (Shick et al., 2010). If practitioners intend train simultaneously distinct qualities through upper body RPA protocol should mainly consider the technical competency. Moreover, upper body RPA protocol may be especially useful to optimize athletic performance, when players are going through developmental phases in which they may be more susceptible to injury in lower limbs (i.e., the pubertal growth spurt).

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of Trás-os-Montes and Alto Douro Research Ethics Committee. Written informed consent to participate in this study was provided by the participants, and if necessary, the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

JA, NL, and OG-S: conceptualization, investigation, and methodology. JA: data curation, formal analysis, software, and writing – original draft. JA, NL, BB, MM-P, ES, and OG-S: writing – review and editing. All authors contributed to the article and approved the submitted version.

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frontiers in Psychology

SYSTEMATIC REVIEW
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Does the Relative Age Effect Influence Short-Term Performance and Sport Career in Team Sports? A Qualitative Systematic Review

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Background: The impact on athletes based on grouping methods according to the date of birth within the constituent year, known as the relative effect of age (RAE), is a factor that can influence the achievement of sports success. Many studies have examined the magnitude of this phenomenon in sport; however, the relationship between the RAE and performance in team sports competition has not been accurately evaluated so far. The purpose of this study was to conduct a systematic review on the influence of the RAE on competition performance in team sports through analysis of published peer-reviewed articles from 2000 to 2019.

Methods: According to Preferred Reporting Items for Systematic Reviews and Meta-Analysis systematic search guidelines, 19 studies were identified of the 2,093 that were found in the systematic searching process carried out in four databases: Sport Discus, PubMed, Web of Knowledge, and Scopus. The sample of the study was composed by 77,329 players, of which 92.08% were male and 7.92% were female, whereas the recorded performance measurements were 87,556. The relation between relative age effects and competition performance was registered according to constraints-based theoretical model: individual constraints (sample characteristics) and task constraints (sport context). Moreover, study quality analysis, Strengthening the Reporting of Observational Studies in Epidemiology, was carried out.

Results: The short-term individual (10.20%) and collective (18.09%) performance was influenced by the RAE, whereas the long-term individual performance (49.71%) was affected by the RAE reverse. However, in 16.99% of the measurements, no relationship was found between the RAE and competition performance. In the analysis by subcategory, the influence of the RAE was higher in men, in adulthood (senior category), in invasion games, and in national contexts.

Discussion: The findings clearly demonstrated that the RAE has a great influence on the performance in team sport. Possible implications for policy and practice should be discussed in order to prevent unequal practice based on biased models that prioritize the athlete's current performance and therefore obviate their maturational development. The heterogeneity and variability of the identified results require a relativization of the findings of this study.

Keywords: relative age effect, birthdate, performance, competition, sport talent, statistics, sport success, team sport

INTRODUCTION

In sport, especially at the highest competitive level, there has always been a constant search to achieve excellence at the individual level. In a team sports context, this fact can also extend to the collective field (Vaeyens et al., 2008). However, one of the issues of sports talent identification programs is the attempt to recognize, through transversal measurement models, a future "talent" according to the athlete's current performance characteristics (physiological, physical, and/or anthropometric) and the current characteristics of their own sport and its evolution (Bailey and Collins, 2013). This approach seems not to take into consideration the maturational status of the athlete, which is omitted when analyzing the player's development process, or other factors connected to the effects produced by training (Abbott and Collins, 2002). Therefore, this situation could produce an imbalance, in terms of sport development, between the athlete's maturity level and his/her chronological age (Torres-Unda et al., 2013).

The grouping of athletes by age group is very common in sport. In particular, the categories in team sports usually correspond to annual or biannual competitive cycles, getting into competition groups according to the athlete's chronological age and according to a previously established cutoff date (January 1 is globally accepted as the beginning of the selection year). This normally applied strategy sharpens the differences between athletes because of their maturation status, which does not necessarily correspond to their chronological age (Wattie et al., 2008). This phenomenon is known by the name of "relative age," and the consequences are referred to as the relative age effect (RAE) (Musch and Grondin, 2001).

This situation is usually reflected in youth sports contexts and is understood as an overrepresentation of athletes born in the first months of the year because of a greater maturational development (Barnsley et al., 1985). Therefore, it seems that the relatively older athletes have more opportunities to achieve a higher sports level, in terms of selection and competition performance, than their relatively younger peers (Till et al., 2010). Most of the explanations that have been provided in this regard have highlighted biological factors as the origin of the imbalance between athletes, focusing attention on anthropometric, physical, and physiological parameters (Baker et al., 2010). This "maturation-selection hypothesis" is the most argued and commonly cited theory (Helsen et al., 1998; Cobley et al., 2009), especially in team sports of a predominantly physical nature, to explain the advantages of relatively older players with regard to relatively young players. Other arguments displayed, primarily in team sports, are connected to the specific interactive factors of each sport exposed in the RAE constraints-based theoretical model (Wattie et al., 2015), so we could consider sociocultural factors (Wattie et al., 2008), geographic (Steingröver et al., 2017) and psychological criteria (Hancock et al., 2013), or linked to the competition itself (Yagüe et al., 2018), are some of the key factors that could modulate the impact of the RAE.

However, as the athlete ascends to higher performance levels (senior category), it does not seem so clear that relatively older athletes enjoy certain sport and competitive advantages over their younger peers (McCarthy and Collins, 2014). Thus, as the sports transition process progresses and especially in team sports such as football, it seems that the impact of the RAE tends to decrease but not disappear (Brustio et al., 2018; Gil et al., 2019). Furthermore, Gibbs et al. (2012) revealed how being an athlete born at the end of the year could be an advantage for the long-term sport development due to overcoming adversities and demands derived from the RAE— "underdog effect." This possible circumstance, based on an overrepresentation of athletes who are relatively young or born in the last months of the year, is called RAE reversal (Cobley et al., 2009). Recently, there have been several investigations in team sports regarding this phenomenon, finding different explanations about its presence and magnitude. From a psychological perspective, it was found that relatively younger athletes presented, in the early stages of development, a psychological profile with a high degree of resilience (Collins and MacNamara, 2012; Sarkar et al., 2015). Other explanations were as follows: lower dropout rate by relatively young players due to a lower number of injuries than relatively older players (Bjørndal et al., 2018a), self-improvement experiences associated with adversity in selection processes (Collins and MacNamara, 2017), high levels of challenge in competition (McCarthy et al., 2016), or player recruitment systems (Sims and Addona, 2016). However, it should be clarified that the influence of the birthdate in professional sports (RAE vs. RAE reversal) does not yield results in the same direction, depending on factors connected to the sport context (Delorme et al., 2009; Lupo et al., 2019).

The RAE has been studied from a variety of approaches and with different purposes: to examine its presence in collective and individual sports contexts (Papadopoulou et al., 2019; Steidl-Müller et al., 2019; Mon-López et al., 2020), evaluate their influence on a fixed competition (Saavedra-García et al., 2019), check the degree of impact of gender and/or of age/competition categories in clubs or federal organizations (Bjørndal et al., 2018b; Romann et al., 2018), or even through intervention proposals the intention of which was to reduce the possible consequences (Mann and van Ginneken, 2017; Hill et al., 2019). Currently, it seems that the objective of the research is focused on studies whose aim is to analyze the relationship between the RAE and competition performance in order to know in-depth how the latter can be influenced by this phenomenon.

According to this approach, Singer and Janelle (1999) considered that the performance yielded in competition could serve as a useful tool to recognize sports excellence quantitatively. Although competition performance can be measured based on indicators of a different nature (i.e., biomechanical, technical, tactical, physiological, etc.), it is very common for team sports to often use clear, unequivocal, and useful indicators in relation to the successful result or not of the actions done and/or the matches played (Hughes and Bartlett, 2002). Analyzing these types of parameters, either in isolation or by comparison with other athletes or teams, an accurate measure of sport success could be obtained through indexing performance in team sports.

In the field of team sports, the analysis of sports success could be carried out on two levels: short-term and long-term performance. In the first kind of performance, it has normally been measured by weighing the collective results, using the final team position in the competition (McGarry, 2009); or through observation of individual statistical parameters (i.e., minutes played, goals scored, average performance indexes, etc.) that synthesize officially the participation, intervention, and performance of the players in competition (de la Rubia et al., 2020). Both indicators represent valuable information to accurately interpret the performance and interaction of the athlete with the environment, peers, and adversaries (Sampaio et al., 2015). At the same time, the growing interest in team sports to recognize the worth of the athletes individually has led to an increase in studies based on performance analysis through different personal attainments (salary, rankings, recognition, longevity, etc.) achieved throughout the athlete's sports career (Fumarco et al., 2017; Gil et al., 2019). This is the long-term consideration of competition performance.

The scientific literature presents, usually, the relationship between "RAE" and "performance" from a causal approach, that is, providing explanations why the birthdate could affect sport performance. Thus, the length of the performance period examined becomes a key factor. On the one hand, studies have been carried out with the aim to evaluate performance through a "cross-sectional analysis" based on determining sports success at a specific point in time. One of the main studies in this field (Vaeyens et al., 2005a,b) examined the performance variables "number of games played" and "time played," that is, short-term statistical parameters. In this kind of studies, the impact and magnitude of the RAE can be accurately evaluated, but they have the inconvenience of assuming an equal distribution of the athletes by grouping method throughout the year (Dixon et al., 2020). On the other hand, studies based on the "longitudinal performance analysis" have proliferated with the aim of verifying the consequences derived from the RAE throughout the sport careers (Steingröver et al., 2016; Fumarco et al., 2017; Jones et al., 2018). The indicators most used to assess long-term performance have been individual or collective cumulative statistics, position in the ranking, victory rates, or number of national/international appearances. Through these investigations, it is possible to observe in depth the dissonances between the talent detection systems (clubs vs. federations), the influence of the RAE depending on the competition level (professional vs. amateur), or the dropout rate in a particular sporting context. However, these approaches often require differentiating overlapping parallel talent development processes that hinder a conclusion about the impact of RAE on long-term performance (Dixon et al., 2020).

The purpose of this study was to conduct a systematic review of the influence of RAE on competition performance in team sports at the national and international levels. Although the RAE has been studied in-depth in team sports, to the best of our knowledge, its influence on competition performance in team sports, measured both individually and collectively as well as in the short term and in the long term, is not exactly known. The literature published in this regard between January 2000 and December 2019 was examined with one main objective: (i) to analyze the influence of the RAE on competition performance according to the performance measurement indicators employed in each sample (type of result in competition and performance production period) based on the sample characteristics (gender and age group) and the sport context (type of sport, competition category, competition level, and competition period). Therefore, the importance of this study lies in the need to determine the impact of the RAE on the total sample of athletes and to synthesize the results derived from the relationship between RAE and competition performance in team sports, with the aim of questioning the convenience of talent detection models based on performance parameters in competition.

METHODS

Study Design

The study design employed in this research was a systematic review with the aim of synthesizing the available scientific evidence through a qualitative review of the primary studies and summarizing the existing information (Manterola et al., 2013), in this case with regard to the influence of the RAE on competition performance in team sports. The stages of the systematic review procedure and subsequent qualitative and quantitative analysis of the scientific evidence adhered to the guidelines set out in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) checklist and the PICOS (Population, Interventions, Comparisons, Outcomes, and Study Design) question model for the definition of inclusion criteria.

Participants—Inclusion and Exclusion Criteria

Original studies aimed at examining the relationship between the RAE and competition performance in team sports were included. Moreover, these studies could be published in peer-reviewed journals with an impact factor included in the Journal Citation Reports of the Web of Science (JCR of WoS) that were in English or Spanish language and in the period between the years 2000 and 2019 (previously, no significant relevant studies were found).

The inclusion criteria established for the systematic search, according to the PICOS question model, were as follows: (1) population: athletes with highest standard of performance in team sports belonging to the 1st competition level (top-tier professional leagues or tours—international level), 2nd level (2nd tier professional leagues or tours—national level), or 3rd level (athletes involved in talent development processes) and whose minimum level of sport success has taken place in a 2nd- or 3rd-level competition (Swann et al., 2015); (2) intervention: national and international official high-performance competitions with information about individual and/or collective performance; (3) comparison: relationship between individual and/or collective competition performance and athlete's birthdate within the same constituent year; (4) outcomes: competition performance according to two specific indicators, "type of result" (individual and/or collective) and "performance period" (short term and/or long term); (5) study design: observational-descriptive research based on establishing a relationship between the RAE and competition performance.

The following exclusion criteria were set: (1) studied the RAE in educational contexts (physical education or sport in the educational center); (2) evaluated the RAE in individual sports, in pairs or connected to refereeing; (3) showed a sample with competition levels below national and/or international; (4) carried out interventions on the ways of grouping the sample; (5) not provided data connected to the distribution of the participants according to the RAE; (6) exclusively examined other different results (acquisition skills, fitness, psychological, physical, and/or anthropometric tests); (7) examined cognitive performance; (8) exclusively determined a relationship between the RAE and performance in other terms (salary, market value, etc.); (9) examined relationships with other developmental and/or behavioral processes (leadership, anxiety, suicide, etc.); (10) analyzed, as a priority objective, interventions to solve the consequences derived from the RAE; (11) analyzed combined competition levels in the same sample (i.e., regional and national). In addition, those studies in editorial format, letter to the editor, comment, abstract, conference, or opinion article were excluded. Previously published systematic reviews about RAE in sport were only considered in order to find potentially valid studies for this scientific research.

Search Strategy—Data Sources

The scientific studies compilation process was carried out through an exhaustive and systematic search in four electronic databases: Sport Discus, PubMed, Web of Science, and Scopus. The search terms used were grouped into three search strings: (1) "RAE" or "relative age" or "relative age effect*" or "influence of age" or "birthdate" or "birthdate effect*" or "age effect*" or "season of birth"; and (2) "American football" or "Australian football" or "baseball" or "basketball" or "cricket" or "football" or "futsal" or "handball" or "hockey" or "ice hockey" or "netball" or "rugby" or "soccer" or "softball" or "volleyball" or "team sport*" or "associative sport*"; and (3) "performance" or "minute* played" or "game* played" or "goal*" or "ranking" or "classification" or "place*" or "medal*" or "success" or "attainment" or "statistics." Moreover, studies were incorporated through additional sources (bibliography of systematic reviews and alerts received by e-mail during the process).

Systematic Review Protocol

To ensure the reliability of the search process and the suitable eligibility of scientific studies, the authors worked separately and independently. The process was carried out in the months of December 2019 and January 2020, and it was composed of the following phases (**Figure 1**), according to the criteria for preparing systematic reviews (PRISMA) (Liberati et al., 2009): (1) identification: the first author (A.R.) found 2,087 studies through the digital query of four databases (Sport Discus, PubMed, Web of Science, and Scopus) with the aim of increasing control over the reliability of the data associated with the existing scientific bibliography; (2) screening: the first author (A.R.) eliminated duplicate files (n = 249) and excluded those studied based on topics considered not relevant according to a previous reading of the title, abstract and keywords (n = 1,529). In addition, together with the second author (A.L.) and third author (J.L.), the first author (A.R.) rejected the studies about RAE contextualized in one of the following fields (n = 266): educational contexts, individual sports, refereeing, amateur, or local or regional competitions, with no link to sport performance and with no sample distribution by quartiles (Q1–Q4), semesters (S1–S2), or months of the year (M1–M12) as a function of the participants' birthdates. At the end of this stage, 43 studies were admitted by the authors; (3) eligibility: the first (A.R.), second (A.L.), and third authors (J.L.) eliminated full-text studies from the selection process by the following reasons: type of publication (n = 7), indexing of the journal (n = 9), or systematic review (n = 8); (4) inclusion: the remaining studies (n = 19) were finally considered for inclusion in the systematic review in order to analyze them, quantitatively and qualitatively, and synthesize the main results on the relationship between the RAE and competition performance.

Data Collection and Extraction

All studies analyzed, read, and reviewed by the authors were published in English. In the data extraction process, the information was categorized according to the following items: (A) year of publication, (B) authors, (C) sample characteristics (number of athletes, gender, age, and age group), (D) sport context (type of sport, competition category, competition level, and competition period), (E) grouping method based on birthdate (month [M], quartile [Q], semester [S]), (F) competition performance indicators (in terms of result: individual and/or collective; in terms of performance production period: short term and/or long term), and (G) the relationship between the RAE and the competition performance (influence of the RAE, influence of the RAE reversal, or lack of influence).

Analysis by Subcategories

In order to conduct an in-depth analysis of the impact of the RAE on competition performance according to established performance indicators, the sample of the studies under review was distributed into different subcategories according constraints-based theoretical model (Wattie et al., 2015). From each study, the data connected to the samples or set of athletes according personal characteristics and sport context ("n" and "%"), the athletes ("n" and "%"), and the relationship between the RAE and competition performance ("n" and "%") were provided (absolute and relative frequency).

Sample Characteristics (Individual Constraints)

Regarding the characteristics of the sample (C), athletes were grouped according to (C1) "gender": men and women, (C2) "age group": adolescence (12–14 years), postadolescence (15–19 years), and adults (>19 years) (Baxter-Jones, 1995; World Health Organization, 2015; Smith et al., 2018). Samples composed of athletes from two different stages of human development (adolescence and postadolescence or postadolescence and adult) were registered as "not encodable."

Sport Context (Task Constraints)

Based on the sport context (D), the athletes were assigned to the corresponding subcategory according to four items: (D1) "type of sport": "invasion games" (American football, basketball, football/soccer, futsal, handball, ice hockey, rugby, and water polo) or "striking and fielding games" (baseball and cricket) (Read and Edwards, 1992); (D2) "competition category": U-14, U-15, U-16, U-17, U-18, U-19, U-20, U-21, U-22, or senior; (D3) "competition level": national or international [the samples composed of athletes who participated in several competition levels at the same year or season (i.e., regional and national level) were excluded].; (D4) "competition period": prior to 2000, after 2000, or combined (beginning before 2000 and ending after 2000).

Grouping Method (Environmental Constraints)

Regarding the sample distribution and grouping method (E), the athletes were categorized according to the birthdate and cutoff date established for each sport and international and national federation So, the athletes were divided into annual or biannual competition cycle by (E1) "semesters": semester 1/semester 3 (S1/S3) and semester 2/semester 4 (S2/S4); (E2) "quartiles": quartile 1/quartile 5 (Q1/Q5), quartile 2/quartile 6 (Q2/Q6), quartile 3/quartile 7 (Q3/Q7), quartile 4/quartile 8 (Q4/Q8); (E3)

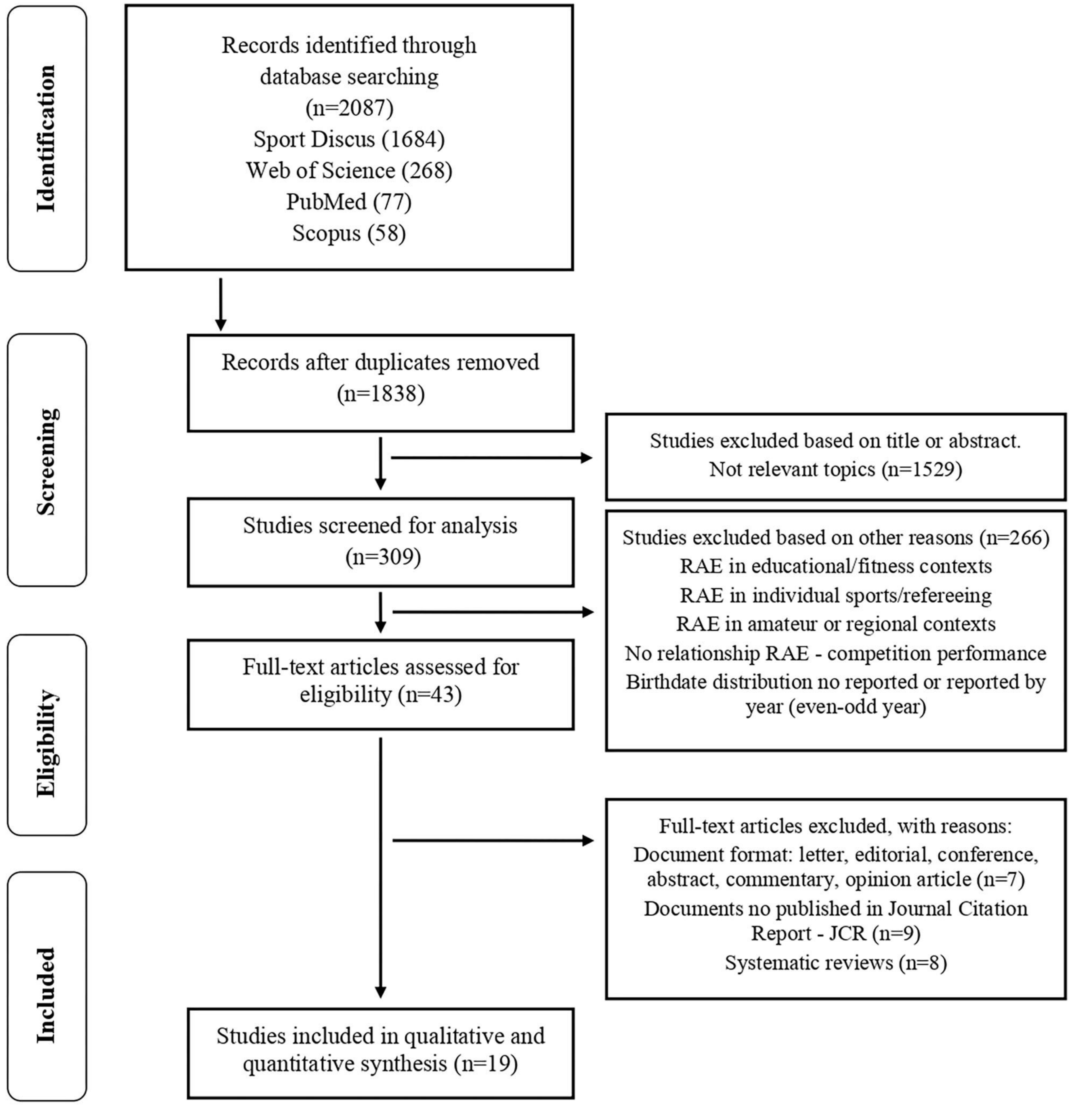

FIGURE 1 | Flow diagram for screening and selection of studies according to Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA).

"months": month 1 (M1), month 2 (M2), month 3 (M3), month 4 (M4), month 5 (M5), month 6 (M6), month 7 (M7), month 8 (M8), month 9 (M9), month 10 (M10), month 11 (M11), month 12 (M12).

Sport Performance Indicators

Regarding the competition performance (F), the scientific evidence of the studies analyzed was registered according to two kinds of measurement indicators: (F1) "type of result" (individual or collective); (F2) performance production period (short term or long term). While the short-term performance refers to the statistical parameters associated with short competitions or regular seasons due to a presumable non-variation of the players of a team roster, the long term focuses on the evaluation of performance beyond a sport season or, even, throughout a sport career according to the statistical parameters accumulated individually and/or collectively. Combining both measurement criteria, the sample was categorized into four groups: short-term individual performance (individual statistics in competition), short-term collective performance (final team classification in competition), long-term individual performance (attainments throughout the sport career), and long-term collective performance (team rankings and maintenance period).

Influence of the RAE on Competition Performance

The samples were grouped by the influence of the RAE on competition performance (G). Thus, the athletes were included in one of the following groups: (G1) samples in which the RAE showed an impact on performance; (G2) samples in which the influence of RAE reversal on performance was detected; (G3) samples in which no relationship between the RAE and competition performance was identified.

Study Quality Assessment

An adapted version according to "RAE–performance" Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist (Vandenbroucke et al., 2014;

TABLE 1 | Study quality assessment according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE).

References	*1	*2	*3	*4	*5	*6	*7	*8	*9	*10	*11	*12	*13	*14	*15	*16	*17	*18	*19	*20	Score
Vaeyens et al. (2005a)	0	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	0	15
Vaeyens et al. (2005b)	0	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	0	15
Williams (2010)	0	0	0	1	0	1	1	1	0	1	1	0	0	0	1	1	1	1	0	0	10
Deaner et al. (2013)	0	1	0	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	0	0	14
García et al. (2014)	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	17
Karcher et al. (2014)	1	1	1	1	0	1	0	1	1	0	1	1	1	1	1	1	1	1	1	0	16
González-Víllora et al. (2015)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	18
Arrieta et al. (2016)	0	0	1	1	0	1	1	1	1	0	1	1	0	0	1	1	0	0	1	1	12
Sims and Addona (2016)	0	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	0	0	1	1	15
Steingröver et al. (2016)	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	17
Torres-Unda et al. (2016)	0	1	1	1	1	0	0	1	1	1	1	0	0	0	1	1	1	1	0	1	13
Fumarco et al. (2017)	0	1	1	1	0	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	14
Rubajczyk et al. (2017)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	19
Bjørndal et al. (2018a)	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	18
Ibañez et al. (2018)	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	19
Jones et al. (2018)	0	1	1	1	0	0	0	1	0	1	1	1	0	1	1	1	0	1	1	1	13
Yagüe et al. (2018)	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	15
Barrenetxea-Garcia et al. (2019)	0	0	0	1	0	1	1	1	0	0	1	1	1	1	1	0	1	1	0	1	12
Lago-Fuentes et al. (2019)	0	0	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	15

*"0" = item with absence or lack of information; "1" = item with complete and explicit information; In title and abstract, *1 (title/abstract) = informative and balanced summary of what was done and what was found is provided. In introduction, *2 (background) = scientific background and rationale for the investigation being reported is explained; *3 (objectives) = state specific objectives and/or any pre-specified hypothesis. In Methods, *4 (setting) = setting, locations, and relevant dates for data collection are described. This must include information on study period (specific dates), sport context (type of sport, competition level, and competition category) and competition year(s) for all data collected; *5 (participants) = give characteristics of the sample (overall number, age, gender); *6 (participants) = procedure for selecting and grouping athletes in the sport context under evaluation (i.e., through cutoff date based on birthdate) and the way grouping according study purposes (i.e., by quartiles) are described; *7 (data source) = source and procedure for obtaining the birthdate and performance characteristics of the sample (RAE and individual and collective performance statistics) are described; *8 (data source) = procedure for determining performance measurement (individual and/or collective) is described; *9 (statistical methods) = statistical methods, including specific analytical methods used to examine subgroups and interactions (relationship between RAE and performance), are described; *10 (statistical methods) = how duplicates and missing data were addressed or incomplete data were handled (if applicable) is explained in results, *11 (descriptive results) = the number (absolute frequency) or percentage (relative frequency) of participants found in each grouping category and subcategory are reported; *12 (main results) = statistical estimate and precision (i.e., 95% CI) for each sample or subgroup group examined is provided; *13 (main results) = post hoc comparisons (OR) between grouping category (i.e., Q1 vs. Q4) are provided when appropriate; *14 (main results) = a measure of effect size is provided (i.e., Cramer's V, phi coefficient, Cohen's); *15 (main results) = a coefficient of correlation between RAE and performance measures is provided. In Discussion, *16 (key results) = a summary of key results with reference to study objectives is provided; *17 (limitations) = limitations of the study, taking into account sources of potential bias or imprecision are discussed; *18 (interpretation) = a cautious overall interpretation of results considering objectives and relevant evidence is provided; *19 (generalizability) = the generalizability of the study results to similar or other contexts is provided. In Funding, *20 (funding) = the funding source of the study is cited or the absence of funding, if applicable.*

Smith et al., 2018) was employed to determine the quality of the studies object of the review (**Table 1**). The checklist constituted of 20 items grouped into six categories corresponding to the different sections of the study: "title-abstract" (item 1), "introduction" (items 2 and 3), "methods" (items 4–10), "results" (items 11–15), "discussion" (items 16–19), and "funding" (item 20). A score of 0 was awarded to the items with lack of information, and 1 to the items accurately described. The total score resulted from the addition of the item values, considering the following levels: "very low quality" (0–4 points), "low quality" (5–8 points), "medium quality" (9–12 points), "high quality" (13–16 points), and "very high quality" (17–20 points). Two independent reviewers (A.R. and A.L.) conducted study quality assessment. Rating disagreements were resolved by J.L., and interrater reliability calculated.

RESULTS

Qualitative Analysis—Study Selection and Characteristics

The quality analysis (RAE–performance STROBE checklist) yielded the following results (**Table 1**, Annex 1). Of the 19 included investigations, 15.79% ($n = 3$) were considered to "medium quality" (9–12 points); 52.63% ($n = 10$) were categorized as "high quality" (13–16 points); and 31.58% ($n = 6$) were considered to "very high quality" (17–20 points). The quality scores of the studies were found between the values 10 (lower limit) and 19 (upper limit), so that no article was classified as "very low quality" (0–4 points) or "low quality" (5–8 points). The average score of the studies analyzed was 15.11 points.

According to the analysis by sections, it was observed that the highest scores were located in "Introduction" (78.95%), "Methods" (80.45%), "Results" (75.79%), and "Discussion" (80.26%). Among the highest quality studies, item 8 ("Data source—procedure for determining performance measurement") and item 15 ("Main results—a coefficient of correlation between RAE and performance measures") were considered complete in all cases (100%), whereas the most commonly absent or incomplete items (0 points) were found in item 5 ["Participants—sample characteristics" (47.37%)], item 14 ("Main results—a measure of effect size" (52.63%)], and item 13 ["Main results—*post-hoc* comparisons between the different categories/groups" (57.89%)]. The lowest scores were found in "Abstract" (68.42%) and "Funding" (42.11%) sections.

Quantitative Analysis

The quantitative analysis was based on the examination and evaluation of the RAE on the sample universe registered in the different studies of the review, according to the main characteristics of the athletes (individual constraints) and the sport context provided for each group of athletes (task constraints), as well as the relationship that the RAE presents with competition performance, depending on the different performance indicators used. Scientific evidence and detailed summary were included.

Sample Characteristics (Individual Constraints) and Sport Context (Task Constraints)

Scientific Evidence

Scientific evidence of the analyzed and reviewed studies on the characteristics of the sample (C) and the sport context (D) is shown in **Table 2**. Format and design, including the title, the author, and the year of publication; the sample characteristics (overall number, gender, age); and the characteristics of the sport context (type of sport, competition category, competition level, and competition period) were included. The studies are arranged chronologically to favor an interpretation and longitudinal evaluation of the findings.

Summary

Table 3 shows a synthesis of the scientific evidence of the sample according to constraints-based theoretical model based on the main characteristics of the participants (gender, age, and age group) and the sport context (type of sport, competition category, competition level, and competition period). Through the analysis of the 19 scientific studies (C), 77 independent samples composed of 77,329 athletes were identified. Examining the sample characteristics (individual constraints): (1) depending on the "gender," the sample distribution was biased because of 92.08% of the athletes being men ($n = 71{,}202$), whereas only 7.92% were women ($n = 6{,}117$); (2) regarding the "age" of the athletes, the sample set was identified as between 13 (lower limit) and 41 years old (upper limit). However, no data were found connected to the age of the participants in 24 samples (31.17%), recording 17,457 athletes with no identification by age. Thus, the athletes were unevenly distributed according to the "age group": adolescence [$n = 2{,}523$ (3.26%)], postadolescence [$n = 18{,}446$ (23.85%)], and adults [$n = 46{,}026$ (59.52%)]. Of the total number of players, 13.35% ($n = 10{,}324$) could not be categorized because the sample crossed two or more different age groups without determining the exact age.

According to the sport context (task constraints) (D), the following results by subcategory were observed: (1) based on the "type of sport," most of the samples analyzed ($n = 75$) corresponded to sports called "invasion games," adding a total of 46,867 athletes (60.61%), whereas only two samples (baseball and cricket) belonged to the so-called "striking and fielding games" with 30,462 athletes (39.39%). (2) In relation to the "competition category," the most evaluated development stage was "senior" with 54,479 athletes (70.45%) distributed in 40 samples. In the other categories, the remaining 37 samples were recorded, collecting the following values in terms of number of athletes: U-14 ($n = 2{,}523$), U-16 ($n = 2{,}700$), U-17 ($n = 2{,}416$), U-18 ($n = 3{,}505$), U-19 ($n = 828$), U-20 ($n = 1{,}665$), U-21 ($n = 8{,}834$), and U-22 ($n = 369$). (3) According to the "competition level," the performance of 13.58% of the athletes was examined in international competitions ($n = 10{,}491$), such as World Championships or Olympic Games, whereas the performance evaluation of 86.42% of the athletes was carried out in national contexts of competition ($n = 66{,}828$), such as Leagues or Cups of the respective countries. (4) Finally, regarding the "competition

TABLE 2 | Distribution of the sample according to the characteristics of the athletes (*n*, age and gender), sport context (type, competition category, competition level and competition period), grouping method (months [M], quartiles [Q], semesters [S]) and its impact on the set of birthdates (relative age effect).

Author(s)	Sample characteristics			Sport context				Grouping method	Relative age effect
	N	Age	Gender	Type of sport	Competition category	Competition level	Competition period		
Vaeyens et al. (2005a)	1,559	<21	M	Soccer (IG)	Senior	Belgian Football League (2nd and 3rd division) → NL	1998–2002	By quartiles (Q1–Q4)	RAE
	2,069	>21	M	Soccer (IG)	Senior		1998–2002		RAE
Vaeyens et al. (2005b)	1,640	16–39 (← 1980)	M	Soccer (IG)	Senior	Belgian Football League (2nd and 3rd division) → NL	1998–2002	By months (M1–M12)	RAE
	498	16–39 (→ 1980)	M	Soccer (IG)	Senior		1998–2002		RAE
Williams (2010)	288	16–17	M	Soccer (IG)	U-17	FIFA Football World Cup → IL	1997	By months (M1–M12)	RAE
	288	16–17	M	Soccer (IG)	U-17		1999		RAE
	288	16–17	M	Soccer (IG)	U-17		2001		RAE
	320	16–17	M	Soccer (IG)	U-17		2003		RAE
	320	16–17	M	Soccer (IG)	U-17		2005		RAE
	480	16–17	M	Soccer (IG)	U-17		2007		RAE
Deaner et al. (2013)	8186	—	M	Ice Hockey (IG)	U-21	National Hockey League (NHL) → NL	1980–2012	By quartiles (Q1–Q4)	RAE R
García et al. (2014)	143	16–17	M	Basketball (IG)	U-17	FIBA Basketball World Championship → IL	2010	By quartiles (Q1–Q4)	RAE
	191	18–19	M	Basketball (IG)	U-19		2011		RAE
	138	20–21	M	Basketball (IG)	U-21		2005		No RAE
	144	16–17	F	Basketball (IG)	U-17		2010		RAE
	194	18–19	F	Basketball (IG)	U-19		2011		RAE
	144	20–21	F	Basketball (IG)	U-21		2007		No RAE
Karcher et al. (2014)	192	20–41	M	Handball (IG)	Senior	Olympic Games London 2012	2012	By quartiles (Q1–Q8) By semesters (S1–S4)	RAE
	128	20–41	M	Handball (IG)	Senior	Handball World Championship	2013		RAE
	192	20–41	M	Handball (IG)	Senior	Handball European Championship → IL	2014		RAE
González-Víllora et al. (2015)	145	16–17	M	Soccer (IG)	U-17	UEFA European Soccer Championship → IL	2012	By quartiles (Q1–Q4) By semesters (S1–S2)	RAE
	144	18–19	M	Soccer (IG)	U-19		2012		RAE
	184	20–21	M	Soccer (IG)	U-21		2011		RAE
	368	22 →	M	Soccer (IG)	Senior		2012		No RAE
Arrieta et al. (2016)	455	15–16	M	Basketball (IG)	U-16	FIBA European Basketball Championship → IL	2013	By quartiles (Q1–Q4)	RAE
	454	17–18	M	Basketball (IG)	U-18		2013		RAE
	384	19–20	M	Basketball (IG)	U-20		2013		RAE
	396	15–16	F	Basketball (IG)	U-16		2013		RAE
	407	17–18	F	Basketball (IG)	U-18		2013		RAE
	299	19–20	F	Basketball (IG)	U-20		2013		No RAE
Sims and Addona (2016)	30,200	16–18	M	Baseball (SFG)	Senior	Major League Baseball (MLB) → NL	1987–2011	By months (M1–M12)	RAE R
Steingröver et al. (2016)	407	16–18	M	Basketball (IG)	Senior	National Basketball Association (NBA)	1980–1989	By quartiles (Q1–Q4)	No RAE
	1,028	16–18	M	Ice Hockey (IG)	Senior	National Hockey League (NHL)	1980–1989		RAE
	2,380	16–18	M	American Football (IG)	Senior	National Football League (NFL) → NL	1980–1989		No RAE
Torres-Unda et al. (2016)	72	13–14	M	Basketball (IG)	U-14	ACB—Mini Cup of Spain → NL	2010	By quartiles (Q1–Q4)	RAE
Fumarco et al. (2017)	2,363	18	M	Ice Hockey (IG)	Senior	National Hockey League (NHL) → NL	2008–2016	By quartiles (Q1–Q4)	RAE R
	1,538	19	M	Ice Hockey (IG)	Senior		2008–2016		RAE R
	546	20	M	Ice Hockey (IG)	Senior		2008–2016		RAE R

(Continued)

TABLE 2 | Continued

Author(s)	Sample characteristics			Sport context				Grouping method	Relative age effect
	N	Age	Gender	Type of sport	Competition category	Competition level	Competition period		
Rubajczyk et al. (2017)	1,223	13–14	M	Basketball (IG)	U-14	Polish Youth Basketball Championships (PZK) → NL	2013–2016	By quartiles (Q1–Q4) By semesters (S1–S2)	RAE
	927	15–16	M	Basketball (IG)	U-16		2013–2016		RAE
	907	17–18	M	Basketball (IG)	U-18		2013–2016		RAE
	792	19–20	M	Basketball (IG)	U-20		2013–2016		RAE
	1,228	13–14	F	Basketball (IG)	U-14		2013–2016		RAE
	922	15–16	F	Basketball (IG)	U-16		2013–2016		RAE
	900	17–18	F	Basketball (IG)	U-18		2013–2016		RAE
	369	19–22	F	Basketball (IG)	U-22		2013–2016		RAE
Bjørndal et al. (2018a)	299	18–19	M	Handball (IG)	U-19	Norwegian Handball Federation (NHF) → NL	2016–2017	By quartiles (Q1–Q8)	RAE
	182	20–21	M	Handball (IG)	U-21		2016–2017		RAE
	55	21 →	M	Handball (IG)	Senior		2016–2017		No RAE
	256	17–18	F	Handball (IG)	U-18		2016–2017		RAE
	190	19–20	F	Handball (IG)	U-20		2016–2017		RAE
	45	20 →	F	Handball (IG)	Senior		2016–2017		No RAE
Ibañez et al. (2018)	334 247	17–18 17–18	M M	Basketball (IG) Basketball (IG)	U-18 U-18	Adidas N. Generation Tournament → IL	2013–2014 2014–2015	By quartiles (Q1–Q4) By semesters (S1–S2)	RAE RAE
Jones et al. (2018)	262	—	M	Cricket (SFG)	Senior	International Cricket Council (ICC)	1994–2004	By quartiles (Q1–Q4)	RAE
	690	—	M	Rugby (IG)	Senior	International Rugby U. Players (IRUP) → IL	1994–2004		RAE R
Yagüe et al. (2018)	523	—	M	Soccer (IG)	Senior	L. Santander (Spain)	2016–2017	By quartiles (Q1–Q4) By semesters (S1–S2)	RAE
	596	—	M	Soccer (IG)	Senior	Ligue 1 (France)	2016–2017		RAE
	543	—	M	Soccer (IG)	Senior	Bundesliga (Germany)	2016–2017		RAE
	573	—	M	Soccer (IG)	Senior	Premier (England)	2016–2017		RAE
	632	—	M	Soccer (IG)	Senior	Serie A (Italy)	2016–2017		RAE
	450	—	M	Soccer (IG)	Senior	Eerste Klasse (Belgium)	2016–2017		No RAE
	522	—	M	Soccer (IG)	Senior	SüperLig (Turkey)	2016–2017		RAE
	297	—	M	Soccer (IG)	Senior	Bundesliga (Austria)	2016–2017		RAE
	521	—	M	Soccer (IG)	Senior	Eredivisie (Netherlands)	2016–2017		RAE
	544	—	M	Soccer (IG)	Senior	Primeira Liga (Portugal) → NL	2016–2017		RAE
Barrenetxea-Garcia et al. (2019)	622	—	M	Water polo (IG)	Senior	2011, 2013 and 2015 World Water Polo Championships → IL	2011–2015	By quartiles (Q1–Q4)	No RAE
	623	—	F	Water polo (IG)	Senior		2011–2015		No RAE
Lago-Fuentes et al. (2019)	183	—	M	Futsal (IG)	Senior	National League of Futsal (LNFS, Spain) → NL	2006–2007	By quartiles (Q1–Q4)	RAE R
	206	—	M	Futsal (IG)	Senior		2007–2008		RAE R
	201	—	M	Futsal (IG)	Senior		2008–2009		RAE R
	205	—	M	Futsal (IG)	Senior		2009–2010		RAE R
	219	—	M	Futsal (IG)	Senior		2010–2011		RAE R
	218	—	M	Futsal (IG)	Senior		2011–2012		RAE R
	203	—	M	Futsal (IG)	Senior		2012–2013		RAE R
	211	—	M	Futsal (IG)	Senior		2013–2014		RAE R
	227	—	M	Futsal (IG)	Senior		2014–2015		RAE R

N, absolute frequency of the sample; "←", before; "→", after; "—", information not provided; M, male; F, female; U-14, under 14; U-16, under 16; U-17, under 17; U-18, under 18; U-19, under 19; U-20, under 20; U-21, under 21; U-22, under 22; IG, invasion games; SFG, striking and fielding games; NL, national level; IL, international level; M1-M12, birth month; Q1-Q4/Q8, birth quarter; S1-S2/S4, birth semester; no RAE, no relative age effect; RAE, relative age effect; RAE R, relative age effect reversal.

TABLE 3 | Summary of samples (*n*) and athletes (*n* and %) by characteristics of athletes (gender and age group) and sport context (type of sport, competition category, competition level and competition period).

Category	Subgroup category	Samples (*n*)	Athletes, n (%)
Gender	Male	63	71,202 (92.08)
	Female	14	6,117 (7,92)
Age group	Adolescence (12–14)	3	2,523 (3.26)
	Postadolescence (15–19)	32	18,446 (23.86)
	Adult (>19)	39	46,026 (59.53)
	Not encodable	3	10,324 (13.35)
Type of sport	Invasion games	75	46,867 (60.61)
	Striking and fielding games	2	30,462 (39.39)
Competition category	U-14	3	2,523 (3.26)
	U-16	4	2,700 (3.49)
	U-17	9	2,416 (3.12)
	U-18	7	3,505 (4.53)
	U-19	4	828 (1.07)
	U-20	4	1,665 (2.15)
	U-21	5	8,834 (11.43)
	U-22	1	369 (0.48)
	Senior	40	54,479 (70.46)
Competition level	National	40	66,828 (86.42)
	International	37	10,491 (13.58)
Competition period	← 2000	5	5,343 (6.91)
	2000 →	61	27,824 (35.99)
	← 2000 →	11	44,152 (57.10)

n, absolute frequency; %, relative frequency; U-14, under 14; U-16, under 16; U-17, under 17; U-18, under 18; U-19, under 19; U-20, under 20; U-21, under 21; U-22, under 22; ← 2000, prior to year 2000; 2000 →, after the year 2000; ← 2000 →, prior and after to year 2000.

period," 57.10% of the athletes analyzed ($n = 44,152$) were part of longitudinal studies that combined in their analysis previous and post-2000 seasons. The studies carried out, entirely, from the year 2000 represented, in terms of the number of athletes, 35.98% ($n = 27,824$), whereas those that were carried out before the year 2000 were 6.91% ($n = 5,343$).

Sample Distribution (Environmental Constraints)

Scientific Evidence

Considering the criteria for grouping athletes (E) according to chronological age and the cutoff date, the scientific evidence of the results is shown in **Table 2**. Format and design, including the title, the author, and the year of publication; the overall number of the participants; the grouping method (months, quartiles, or quartiles/semesters); and type of distribution of the participants (RAE, RAE reversal, or no RAE) were included. The studies are arranged chronologically to favor an interpretation and longitudinal evaluation of the findings.

Summary

The sample distribution and the athletes that composed it are shown in **Figures 2**, **3**. The most used method for the grouping of athletes was, according to number of samples, the birthdate considering the year by quartiles [41 samples (28,594 athletes)]. Among these samples, the distribution by quartiles was not the same if the competition period was considered as an annual cycle made up of four quartiles and two semesters (87.5%) or a biannual cycle made up of eight quartiles and four semesters (12.5%). In another 27 samples, 14,403 athletes were categorized, in addition to quartiles, by semesters. In the other samples ($n = 9$), the grouping method according to the natural month of birth was identified, accounting, surprisingly, for 34,322 athletes.

Regarding the number of registered athletes according to the grouping method (quartiles, "Q"; semesters, "S"; months, "M"), an unequal and biased distribution was observed in 66 samples (71,788 athletes). Among them, RAE was detected in 51 samples and 26,392 athletes (34.12%), whereas the RAE reversal was found in 15 samples and 45,396 athletes (58.71%). In the remaining 10 samples, no impact of the RAE on a representation of 5,531 athletes (7.17%) was identified.

Taking as a reference the set of athletes in whom the RAE (RAE or RAE reversal) was detected [$n = 71,788$ (92.83%)], a summary based on the characteristics of the athletes (individual constraints) and the sport context (task constraints) is included in **Table 4**. With regard to the sample characteristics, the RAE did not have the same impact. Considering the sample characteristics: (1) according to "gender," an overrepresentation of relatively young athletes in male distributions was observed, accounting for 45,396 athletes (63.25%), whereas biased distributions in favor of relatively older players grouped 21,386 athletes (29.79%). On the other hand, in most of the samples analyzed in women's sports, a distribution with an overrepresentation of relatively older players was identified [$n = 5,006$ (6.97%)], with no cases of RAE reversal being recorded. (2) Assessing the "age group," the RAE reversal was identified in 60.54% of the samples, with more frequency in the adult age group (>19 years old) where 33,309 athletes were registered, whereas in the immediately lower development stage, postadolescence (15–19 years old), the number of athletes was considerably less ($n = 3,901$). No cases of RAE reversal were found in adolescent athletes (12–14 years old). With regard to the analyzed samples that showed a selection bias favorable to relatively older athletes (39.46%), the results confirmed a higher impact of the RAE in the adult age ($n = 10,272$) and postadolescence ($n = 11,459$) than in the adolescent age ($n = 2,523$).

Considering the sport context, the sample also presented an unequal and biased distribution of the athletes. (1) Based on the "type of sport," the RAE reversal was mainly detected in the "striking and fielding games," which affected 30,200 athletes, whereas in 262 of them, the presence of RAE was observed. In the "invasion games," the trend was reversed showing a greater weight of the influence of the RAE on the athletes ($n = 26,130$) than the RAE reversal ($n = 15,196$). (2) According to the "competition category," in the athlete's formative ages, a prevalence of the samples in which the selection process to participate in official competitions was biased in favor of relatively older players was observed (U-14: $n = 3$; U-16: $n = 4$;

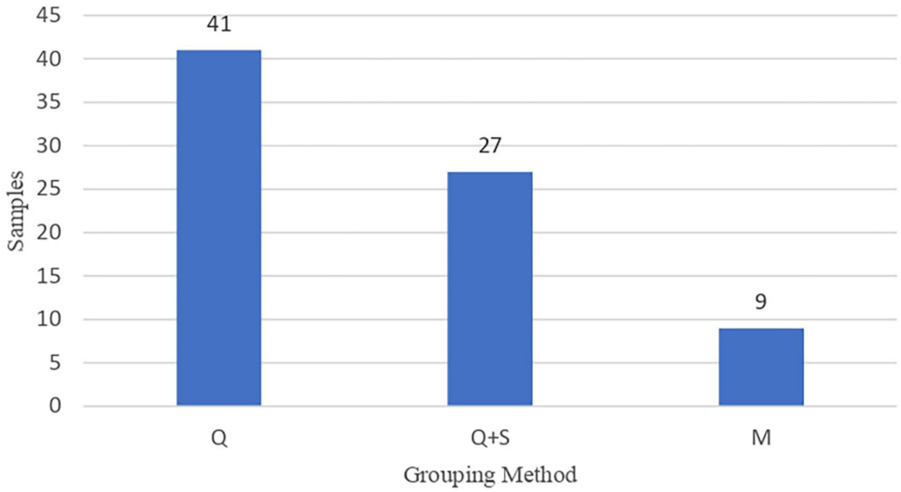

FIGURE 2 | Distribution of the samples (N) according to the grouping method (quartiles [Q]; quartiles and semesters [Q + S] and months [M]).

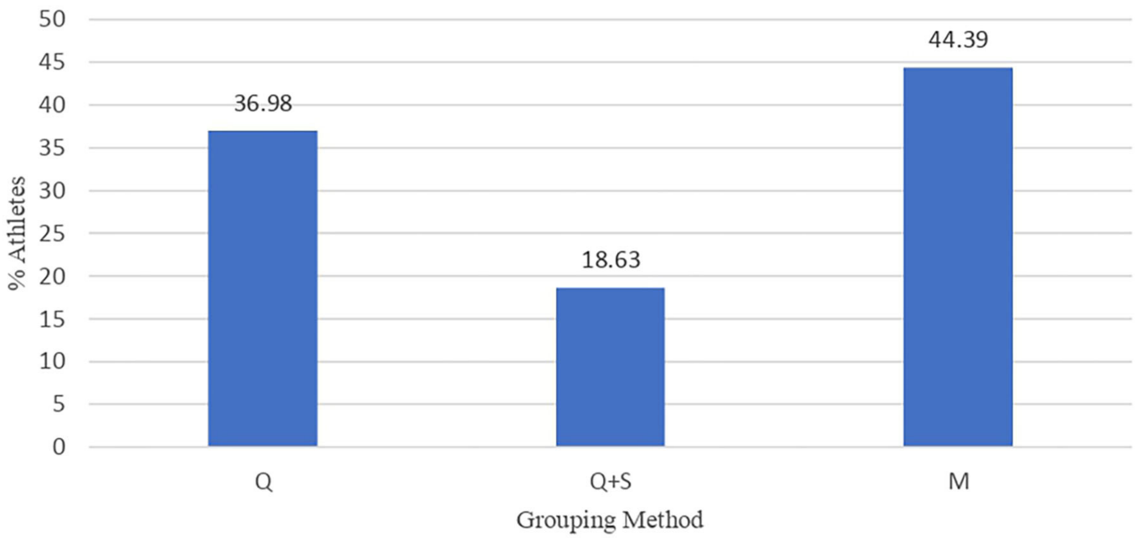

FIGURE 3 | Distribution of the athletes (%) according to the grouping method (quartiles [Q];quartiles and semesters [Q + S] and months [M]).

U-17: $n = 9$; U-18: $n = 7$; U-19: $n = 4$; U-20: $n = 3$; U-21: $n = 2$; U-22: $n = 1$). In contrast, only one biased sample was identified in favor of relatively young players (U-21: $n = 1$). Similar results were found in the senior category, where the samples in which RAE was identified ($n = 17$) continued to be larger than the samples showing an RAE reversal ($n = 14$). However, by number of athletes, the connection is reversed at a ratio of 3:1 (RAE: $n =$ 12,319; RAE reversal: $n =$ 37,210). (3) Based on the "competition level," a notable presence of the RAE reversal was observed in the samples of national competitions (62.28%) including 44,706 athletes, whereas in international competitions, this presence was minimal [$n = 690$ (0.96%)]. However, in the cases with the presence of RAE, large differences were not found because of 18,885 athletes (26.31%) being identified in national contexts, whereas 7,507 athletes (10.48%) were detected in international contexts. (4) Finally, regarding the "competition period," the RAE reversal affected more than half of the athletes in the whole sample [$n =$ 38,386 (53.47%)] whose performance was analyzed before and after the year 2000, whereas the RAE was identified in 18,760 athletes (26.13%) from samples of studies after the year 2000. In the investigations carried out before 2000, the difference did not seem to be highlighted because of a considerable number of samples not being found ($n = 5$).

Relationship Between RAE and Competition Performance

Scientific Evidence

The synthesis of the relationship between RAE and competition performance in team sports (G) based on performance indicators (F) is shown in **Table 5**. Format and design, including the

TABLE 4 | Summary of sample's distribution (*n* and %) according to the relative age effect identified (RAE or RAE reversal) by characteristics of athletes (gender and age group) and sport context (type of sport, competition category, competition level, and competition period).

Category	Subgroup category	RAE		RAE reversal	
		Samples *n*	Athletes *n* (%)	Samples *n*	Athletes *n* (%)
Sample characteristics	Gender				
	Male	41	21,386 (29.79)	15	45,396 (63.24)
	Female	10	5,006 (6.97)	0	0 (0)
	Age group*				
	Adolescence (12–14)	3	2,523 (4.11)	0	0 (0)
	Postadolescence (15–19)	27	11,459 (18.64)	2	3,901 (6.35)
	Adult (>19)	19	10,272 (16.71)	12	33,309 (54.19)
Sport context	Type of sport				
	Invasion games	50	26,130 (36.40)	14	15,196 (21.17)
	Striking-fielding games	1	262 (0.36)	1	30,200 (42.07)
	Competition category				
	U-14	3	2,523 (3.52)	0	0 (0)
	U-16	4	2,700 (3.76)	0	0 (0)
	U-17	9	2,416 (3.37)	0	0 (0)
	U-18	7	3,505 (4.88)	0	0 (0)
	U-19	4	828 (1.15)	0	0 (0)
	U-20	3	1,366 (1.90)	0	0 (0)
	U-21	2	366 (0.51)	1	8,186 (11.41)
	U-22	1	369 (0.51)	0	0 (0)
	Senior	17	12,319 (17.16)	14	37,210 (51.83)
	Competition level				
	National	23	18,885 (26.31)	14	44,706 (62.28)
	International	28	7,507 (10.46)	1	690 (0.96)
	Competition period				
	← 2000	4	1,866 (2.60)	1	690 (0.96)
	2000 →	43	18,760 (26.14)	12	6,320 (8.80)
	← 2000 →	4	5,766 (8.03)	2	38,386 (53.47)

*n, absolute frequency; %, relative frequency; U-14, under 14; U-16, under 16; U-17, under 17; U-18, under 18; U-19, under 19; U-20, under 20; U-21, under 21; U-22, under 22; ← 2000, prior to year 2000; 2000 →, after the year 2000; ← 2000 →, prior and after to year 2000. *Because of the lack of data about the age of participants in some studies, the analysis of the sample by age group was reduced to 61,464 athletes.*

title, the author, and the year of publication; the aim of the study; the indicators used for measuring the performance in competition; the main results of the investigation associated with the relationship between RAE and performance in competition; and the most relevant conclusions were included. The studies are presented in chronological order to emphasize their longitudinal interpretation.

Summary

Looking at the competition performance and taking as a reference the number of performance measurements made (**Figures 4**, **5**), individual performance indicators were utilized in 76.61% of the measurements, whereas the collective performance indicators entailed the 23.39% of the total. Among the samples analyzed using individual performance indicators ($n = 48$), an unequal distribution of athletes was observed according to the performance production period. Thus, 23,240 performance measurements were identified based on the short-term results achieved through the consideration of official statistical parameters (26.41%), whereas 44,180 performance measurements based on the attainments reached throughout the sports career were registered (50.20%). With regard to the samples that analyzed the collective performance indicators ($n = 46$), 19,634 short-term measurements associated with the final team classification/position in competition were found (22.31%), whereas only 952 long-term measurements linked to international rankings and maintenance periods (1.08%) were observed.

Table 6 shows the relationship between RAE and competition performance based on the measurement indicators used ($n = 87,556$), in terms of the result (individual and collective) and the performance production period (short term and long term). The following findings were identified: (a) the correlation between competition performance and the effect of the athlete's birthdate occurred with greater force in those

TABLE 5 | Relationship between RAE and competition performance providing aim of the study, performance indicators, main results and conclusions.

References	Aim of the study	Performance indicators	Main results (RAE–performance)	Conclusions
Vaeyens et al. (2005a)	(1) To examine whether semiprofessional and amateur soccer teams complied with the under-21 rule (S1); and (2) to determine if the under-21 rule was effective in increasing the playing opportunities of young adult (under-21) soccer players (S2)	Individual statistics: no. of games played and time played (min)	1. Relatively older amateur or semiprofessional players in the senior category (>21 years old) played a higher number of minutes and they were selected a bigger number of appearances than relatively young players 2. Relatively young players (U-21) were selected to participate with the first teams from the bench and for short periods of time	Influence of RAE on short-term individual performance
Vaeyens et al. (2005b)	The present study had two objectives: (1) to compare the relative age (RA) effect in players before and after the change in cutoff for the selection year (1997). And (2) to use match-related variables in addition to birth dates to examine the RA	Individual statistics: no. of games played and time played (min)	1. Competition performance, measured in games and minutes played, was higher in relatively older players, both in the G1B (cutoff date on August 1; born before 1980) and in the G2B (cutoff date on January 1; born after 1980)	Influence of RAE on short-term individual performance
Williams (2010)	This investigation sought to determine if a RA effect exists in the FIFA U-17 World Cup competition	Collective statistics: final team position	1. The performance, according to the final team position in each of the World Soccer Championships analyzed, was larger in those teams that had a higher percentage of relatively older players or early maturing players in their squads	Influence of RAE on short-term collective performance
Deaner et al. (2013)	(1) Our analyses of productivity included all selections from all draft rounds for a period of 27 years; (2) we tested whether birth quarter was associated with productivity once draft slot was controlled; (3) we investigated a potential mediator of selection bias, the decision to become draft eligible; (4) we tested for changes in selection bias over time; (5) we examined whether selection bias reduces relatively younger individuals' playing opportunities	Individual statistics throughout the sports career: no. of games; goals per game; assists per game; pints per game (goals + assists); offensive and defensive productivity measure	1. The relatively young players chosen in the last rounds of the draft (+101st round) achieved better competition performance, in terms of games played and points per game, than the relatively older ones. Attenuated results were observed in the drafted players between rounds 1st and 100th 2. The relatively young players, chosen within the first year of the draft (18 years old), achieved longer competition performance indicators (games played and points scored) than relatively young players chosen in the second year (19 years old) and third year (20 years old) respectively 3. Relatively young players performed better, throughout their sports careers, than relatively older players	Influence of RAE reversal on long-term individual performance
García et al. (2014)	To check whether the RA effect does exist in the World Basketball Championship U-17, U-19, and U-21 male and female categories, to investigate if the RA effect exists in the different specific positions and also try to find differences in height and in performance between players depending on their birthdate	Individual statistics: games played; minutes played; converted field goals (% effectiveness); 2-point field goals (% effectiveness); 3-point field goals (% effectiveness); free goals scored (% effectiveness); def. rebounds; off. Rebounds; assistances; personal faults; stolen; recuperations; blocked; points; points per game	1. Relatively older players performed better on the following statistical parameters: 3-point % (male U-17); points per game (male U-19); assists and assists per game (female U-19) 2. In contrast, relatively young players performed better on the following statistical parameters: 2-point % and free-throw % (female U-19) 3. However, could be not affirmed, in general, that the competition performance in basketball, measured in statistical terms, was affected by the RAE	No relationship between RAE and short-term individual performance
Karcher et al. (2014)	To examine the effects of month and year of birth on playing time during international competitions with respect to playing positions	Individual statistics: time played (min)	1. The probability of playing more than 50% of the time competition tended to be higher in relatively older players than relatively young players. However, no significant impact of the RAE, expressed in quartile (Q) and/or semester (S), was observed on playing time	No relationship between RAE and short-term individual performance
González-Víllora et al. (2015)	To examine the birthdates of the international players, together with other variables in the 2012 European Soccer Championship at a senior level and in U-21, U-19, and U-17 from the previous European Soccer Championship	Collective statistics: final team position	1. An overrepresentation of relatively older players was detected in those teams (U-17, U-19, and U-21 category) that achieved high performance in competition according to their classification (quarterfinals, semifinalists, finalists, and champion) 2. No such phenomenon was observed in the senior category	Influence of RAE on short-term collective performance (U-17, U-19 y U-21) No relationship RAE -performance (senior)

(Continued)

TABLE 5 | Continued

References	Aim of the study	Performance indicators	Main results (RAE–performance)	Conclusions
Arrieta et al. (2016)	To analyze the presence of the RAE and the possible relation of RA with performance in male and female European Youth Basketball Championships	Individual statistics: minutes, points, assists, steals, blocked shots, rebounds, personal fouls, missed shots, turnovers, personal, PIR Collective statistics: final team position	1. Relatively older players obtained higher individual performance indicators, in absolute and weighted terms, and collective performance according to final team position in competition than relatively young players in the U-20 category. The impact was less in U-16 and U-18 2. In women, the relationship between RAE and performance lost significance when the results were weighted for minutes played	Influence of RAE on short-term individual and collective performance (men) No relationship RAE -performance (women)
Sims and Addona (2016)	We explore the relationships of age and RA for players drafted out of HS with baseball career performance, using four different performance metrics (whether or not the player reached the major leagues, games played in MLB, career wins above a replacement player (WAR), and career on-base plus slugging percentage (OPS) for non-pitchers	Individual statistics throughout the sports career: time played (min); measure the additional number of wins that the player's team accumulates over a replacement-level player; running average	1. Relatively young drafted players achieved higher levels of competition performance (Baseball Professional Leagues—MLB) than their relatively older peers, according to the total number of drafted players 2. No influence of the RAE on long-term individual performance was observed, once the player reached high levels of competition (Major League Baseball—MLB)	Influence of RAE reversal on long-term individual performance
Steingröver et al. (2016)	To replicate previous findings on RAEs among NHL ice hockey players, NBA basketball players, and NFL football players and in a second step to investigate the influence of RA on career length in all three sports	Individual statistics throughout the sports career: no. of games	1. Relatively young players played more games throughout their professional NHL career. However, in the NBA and in the NFL, there was no such performance phenomenon 2. Considering the individual ranking, the relatively young NHL players with a medium/high individual ranking (positions 25–125th of 201) and relatively young NBA players with a medium/high individual ranking (positions 25–125th of 141), played more games than the relatively older players. No relationship was appreciated in the NFL players.	Influence of RAE reversal on long-term individual performance (NHL and NBA) No relationship between RAE and long-term individual performance (NFL)
Torres-Unda et al. (2016)	To compare anthropometric, maturational, and physical performance variables regarding the performance of the teams in a championship. In addition, another objective was to explore the relationship between maturity-related parameters, anthropometric variables, and physical performance variables of boys enrolled in elite basketball teams and the relationship between these parameters and their performance in basketball	Individual statistics: points per minute; points per game; index performance rating (PIR) and time played per game (min) Collective statistics: final team position	1. A relationship between chronological age/RA, when the player reached the maximum peak height velocity (YAPHV), and competition performance was observed, in terms of points scored and performance index rating (PIR). This relationship decreased when the results were weighted by the minutes played 2. The combination between an early maturation (years from age at peak height velocity) and advanced maturity status (relatively older age) was identified as a key factor to reach the highest levels of competition performance in basketball. Thus, relatively older players performed better than relatively young peers 3. Relatively older players were overrepresented in those basketball teams that performed better in competition based on the final position	Influence of RAE on short-term individual and collective performance
Fumarco et al. (2017)	First, we test for the presence of the RAE on points and on salaries with quantile regressions, which allow us to explore how the RAE varies along the distribution of points scored and salary. Second, we investigate the RAE on the quarter of birth distribution by draft age (i.e., 17, 18, 19), which is established by NHL drafting rules; this is the first time such analysis is conducted	Individual statistics: points (goals + assists)	1. The relatively young drafted players scored more points (goals + assists) in competition than their relatively older peers. The difference increased when it was considering those players with the best score ranking (>90%).	Influence of RAE reversal on long-term individual performance

(Continued)

TABLE 5 | Continued

References	Aim of the study	Performance indicators	Main results (RAE–performance)	Conclusions
Rubajczyk et al. (2017)	To identify the RAE in youth basketball games in Poland while taking into consideration the age, sex, and the players' match statistics. Additionally, the aim of this study is to determine whether differences in the body height of players are associated with the success of the team	Individual statistics: points per game; assists per game; rebounds per game; steals per game; blocks per game; turnovers per game; PIR Collective statistics: final team position	1. Relatively older players achieved higher individual performance parameters than relatively young players in U-14 men category. No impact of the RAE on competition performance was observed in the remaining male categories (U-16, U-18, and U-20) and in women 2. Relatively older players (with higher height) scored more points per game than relatively young players in male and female U-14 category 3. The teams with the worst classification in the men's competitions showed roster made up mainly of players with a bigger height differential between the relatively older players (Q1) and the relatively young peers (Q4) than the teams that performed better (final position)	Influence of RAE on short-term individual performance (male U-14) No relationship RAE and short-term individual performance (male U-16, U-18, and U-20 and female) Influence of RAE on short-term collective performance
Bjørndal et al. (2018a)	(a) To evaluate the prevalence of the RAE in international youth, junior, and senior Norwegian male and female handball players; and (b) explore the relationship between RA and the number of international youth, junior, and senior level appearances	Individual statistics: number of international appearances	1. The relatively older female players in the U-18 category were called up more times by the Norwegian national team than the relatively young peers. No impact of the RAE on the remaining female categories (U-20 and senior) or on male categories (U-19, U-21, and senior) was observed 2. Considering the long-term performance (number of international appearances) no impact of the RAE was found in those players who had already been previously selected at least once	Influence of RAE on long-term individual performance (female U-18) No relationship RAE and performance (male and female U-20 and senior)
Ibañez et al. (2018)	(i) To examine the distribution of birth dates in competitive basketball in the U-18 category, differentiating by playing position and (ii) to analyze the effect of the RAE on performance according to playing position using performance indicators	Individual statistics: points scored, tried and successful two- and three- point shots, tried and successful free throws, total rebounds, defensive and offensive rebounds, assists, steals, turnovers, blocks committed and received, dunks, personal fouls committed and received, PIR, and minutes played	1. Relatively older players, who occupied the "guard" position obtained higher competition performance in points scored, % effectiveness in 2-point shots and value of the PIR than their relatively young peers 2. Relatively older players, who occupied the "guard-forward" position performed better on blocks made than their relatively young peers 3. Relatively older players who occupied the "center" position reached higher competition performance in points scored, 2-point shots, and value of the PIR than their relatively young peers	Influence of RAE on short-term individual performance
Jones et al. (2018)	First, to test whether RAEs highlighted thus far extend beyond youth sport and elite sport into the world's "super elite" performers, whilst controlling for a significant limitation of previous research by considering intra sport differences through assessing RAE prevalence across the different positions. Second, to determine whether comparing RAE across different sports at the super-elite level will allow exploration of intersport differences	Study 1 Individual statistics: ranking among the 30-20-10 best players in the world, maintenance period (1 month to 5 years) in those positions for the last 10–20 years Collective statistics: international team ranking	Study 1: 1. Relatively older cricketers showed better individual performance indicators than their relatively young peers 2. Regarding the analysis by position, the relatively older cricketers, who occupied the "batsmen," "spin bowler," and "bowler combined" positions, were able to performance better (no. ranking and maintenance period in the ranking) than their relatively young peers. There was no impact of the RAE on performance in the players who occupied the "pace bowler" position	Study 1: Influence of RAE on long-term individual and collective performance

(Continued)

TABLE 5 | Continued

References	Aim of the study	Performance indicators	Main results (RAE–performance)	Conclusions
		Study 2 Individual statistics: number of international appearances; player career longevity and victory rate Collective statistics: international team ranking	Study 2: 1. Relatively young rugby players showed better competition performance than their relatively older peers 2. Regarding the analysis by position, relatively young rugby players, who occupied the "forward" position performed better than their relatively older peers. The impact was not found in the players who occupied the "back" position	Study 2: Influence of RAE reversal on long-term individual and collective performance
Yagüe et al. (2018)	To verify the RAE in the professional male soccer of the ten best national leagues of the UEFA Confederation during the 2016/2017 season, as well as to verify the possible differences and correlations between the RAE and the players' position, and the final classification	Collective statistics: final team position	1. The teams with the best (1st−4th position) and worst (last four positions) qualifying results showed a roster team with an overrepresentation of relatively older players. In the teams in the middle of the classification, the impact of the RAE on performance was weaker. The exception to this fact occurred in the Belgian Football League (Eerste Klasse) where no impact of the RAE on competition performance was identified	Influence of RAE on short-term collective performance (except Eerste Klasse)
Barrenetxea-Garcia et al. (2019)	(i) There would be an overrepresentation of players born in the first months of the year in elite water polo, (ii) there would be a larger percentage of left-handed players on the wing positions than in the general population, and (iii) RAE would be present in right-handed and not in left-handed water polo players	Individual statistics: played minutes, number of shots, number of goals, number of shots per minute, number of goals per minute, shots endured per minute, and blocks per minute	1. The RAE did not have a significant impact on any statistical performance parameter in water-polo players, both in men and women	No relationship between RAE and short-term individual performance
Lago-Fuentes et al. (2019)	To verify the occurrence and effect size of the RA in professional futsal players of the Spanish First Division, by observing how its presence and impact changed according to the season, the team level, and the player position	Collective statistics: final team position	1. The teams with the best qualifying results (play-off) or intermediate results (outside the play-off zone and the relegation zone) were made up of an overrepresentation of relatively young players. No impact of the RAE was observed in the teams at the bottom of the classification (promotion or relegation zone) 2. In the "goalkeeper" and "pivot" positions, an overrepresentation of relatively young players was confirmed	Influence of RAE on short-term collective performance (better classification) No relationship between RAE and short-term individual performance (worst classification)

PIR (performance index rating) = a statistical formula also used by the FIBA, the Euroleague and the Eurocup, and various European national domestic leagues to determine the performance of each player in match (Arrieta et al., 2016).

cases where RAE reversal was detected (52.64% measurements), whereas it was not so decisive in cases with presence of the RAE (30.36%). No relationship between RAE and competition performance was found (17%); (b) this connection, RAE and performance, was observed, to a greater degree, in the short-term collective performance measurements [30 samples (15,841 measurements)]; (c) regarding the relationship between RAE reversal and competition performance, the birthdate had a noticeable influence on individual performance over large periods of time [6 samples (43,523 measurements)]; (d) RAE had no clear impact on immediate or short-term individual performance (12 samples, 8,392 measurements); (e) measurements that yielded results on RAE reversal and the short-term individual performance were not found; (f) the impact of the RAE and RAE reversal was greater on long-term performance (52.57% of measurements) than on short-term performance (30.43% of measurements).

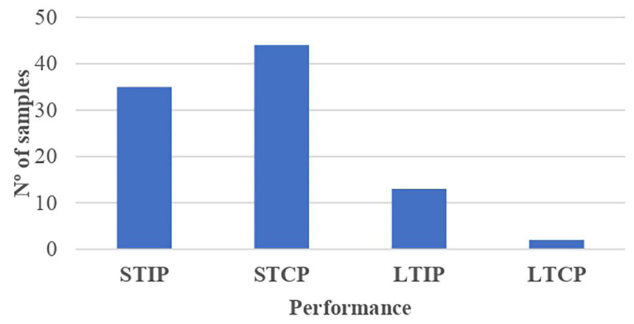

FIGURE 4 | Performance indicators by samples based on the result in competition and the performance production period. STIP, short-term individual performance; STCP, short-term collective performance; LTIP, long-term individual performance; LTCP, long-term collective performance.

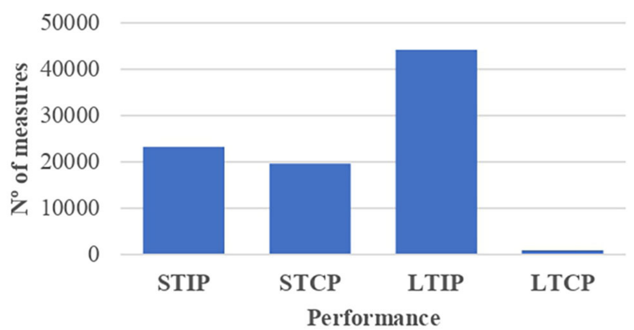

FIGURE 5 | Performance indicators by measurements based on the result in competition and the performance production period. STIP, short-term individual performance; STCP, short-term collective performance; LTIP, long-term individual performance; LTCP, long-term collective performance.

Further evaluating this relationship, based on constraints-based theoretical model, the most outstanding findings are shown in **Table 7**. In relation to sample characteristics (individual constraints): (1) according to "gender," the short-term individual performance in male sports was the most affected by the RAE reversal (49.71% measurements), whereas the RAE had no impact on the competition performance in female sports, with regard to 16 samples (7.96% measurements); (2) considering the "age group," the greatest influence of the RAE on competition performance was observed in the adult development stage, with 47,281 measurements (54.00%), whereas in adolescence only 5.76% of measurements were identified. The higher impact of the RAE (RAE reversal) on performance was found at the long-term individual level in adulthood [31,436 measurements (35.90%)]. Furthermore, this impact amplified as the chronological age of the athletes increased (adolescence, 0%; postadolescence, 4.46%; adult, 38.83%). On the other hand, the influence of the RAE was identified, mainly, on the short-term collective performance measurements (adolescence, 2.88%; postadolescence, 8.71%; adult, 6.50%).

Examining the sport context (task constraints), the findings were the following: (1) with regard to the "type of sport," the RAE showed a longer influence on long-term collective performance in the "invasion games" [15,841 measurements (18.09%)], whereas the RAE reversal had a higher impact on long-term individual performance [13,323 measurements (15.22%)]. However, a considerable number of samples (n = 32) with no relationship between the RAE and competition performance were identified. In this set of samples, 8,392 short-term individual performance measurements were registered (9.58%). In the "striking and fielding games," according to 30,200 measurements (34.49%), the performance most affected by the RAE reversal was the long-term individual performance;

TABLE 6 | Summary of samples (*n*) and performance measures (PM) [*n* and (%)] according to the relationship between relative age effect (RAE or RAE reversal) and competition performance (influence or no influence).

Performance		Influence—RAE		Influence—RAE reversal		No influence	
		Samples	PM	Samples	PM	Samples	PM
		n	*n (%)*	*n*	*n (%)*	*n*	*n (%)*
Performance (St)	IPI	11	8,935 (10.20)	0	0 (0)	12	8,392 (9.58)
	CPI	30	15,841 (18.09)	9	1,873 (2.14)	13	2,936 (3.35)
Performance (Lt)	IPI	3	1,546 (1.77)	6	43,523 (49.71)	7	3,558 (4.07)
	CPI	1	262 (0.30)	1	690 (0.79)	0	0 (0)

n, absolute frequency; %, relative frequency; PM, performance measures; St, short-term; Lt, long-term; IPI, individual performance indicators; CPI = collective performance indicators.

TABLE 7 | Summary of samples (*n*) and performance measures (PM) [*n* (%)] within the relationship between RAE and competition performance by characteristics of athletes (gender and age group) and sport context (type of sport, competition category and competition level).

Performance		Influence—RAE		Influence—RAE reversal		No influence	
		Samples	PM	Samples	PM	Samples	PM
		n	*n (%)*	*n*	*n (%)*	*n*	*n (%)*
GENDER							
			Men				
Performance (St)	IPI	11	8,935 (10.20)	0	0 (0)	4	3,248 (3.71)
	CPI	26	12,422 (14.19)	9	1,873 (2.14)	7	1,352 (1.54)
Performance (Lt)	IPI	2	1,290 (1.47)	6	43,523 (49.71)	5	3,323 (3.80)
	CPI	1	262 (0.30)	1	690 (0.79)	0	0 (0)
			Women				
Performance (St)	IPI	0	0 (0)	0	0 (0)	8	5,144 (5.88)
	CPI	4	3,419 (3.90)	0	0 (0)	6	1,584 (1.81)
Performance (Lt)	IPI	1	256 (0.29)	0	0 (0)	2	235 (0.27)
	CPI	0	0 (0)	0	0 (0)	0	0 (0)
AGE GROUP*							
			Adolescence (12–14 years)				
Performance (St)	IPI	2	1,295 (1.68)	0	0 (0)	1	1,228 (1.59)
	CPI	3	2,523 (3.27)	0	0 (0)	0	0 (0)
Performance (Lt)	IPI	0	0 (0)	0	0 (0)	0	0 (0)
	CPI	0	0 (0)	0	0 (0)	0	0 (0)
			Postadolescence (14–19 years)				
Performance (St)	IPI	4	1,490 (1.93)	0	0 (0)	8	5,550 (7.19)
	CPI	15	7,630 (9.88)	0	0 (0)	7	1,774 (2.30)
Performance (Lt)	IPI	2	1,284 (1.66)	2	3,901 (5.05)	4	3,276 (4.24)
	CPI	0	0 (0)	0	0 (0)	0	0 (0)
			Adult (>19 years)				
Performance (St)	IPI	3	4,012 (5.19)	0	0 (0)	3	1,614 (2.09)
	CPI	12	5,688 (7.36)	9	1,873 (2.43)	6	1,162 (1.50)
Performance (Lt)	IPI	1	262 (0.34)	3	31,436 (40.70)	3	282 (0.37)
	CPI	1	262 (0.34)	1	690 (0.89)	0	0 (0)
TYPE OF SPORT							
			Invasion games				
Performance (St)	IPI	11	8,935 (10.20)	0	0 (0)	12	8,392 (9.58)
	CPI	30	15,841 (18.09)	9	1,873 (2.14)	13	2,936 (3.36)
Performance (Lt)	IPI	2	1,284 (1.47)	5	13,323 (15.22)	7	3,558 (4.06)
	CPI	1	262 (0.30)	1	690 (0.79)	0	0 (0)
			Striking and fielding games				
Performance (St)	IPI	0	0 (0)	0	0 (0)	0	0 (0)
	CPI	0	0 (0)	0	0 (0)	0	0 (0)
Performance (Lt)	IPI	1	262 (0.30)	1	30,200 (34.49)	0	0 (0)
	CPI	0	0 (0)	0	0 (0)	0	0 (0)
COMPETITION CATEGORY							
			U-14 to U-18 (youth categories)				
Performance (St)	IPI	6	2,785 (3.18)	0	0 (0)	7	5,687 (6.50)

(Continued)

TABLE 7 | Continued

Performance		Influence—RAE		Influence—RAE reversal		No influence	
		Samples *n*	PM *n (%)*	Samples *n*	PM *n (%)*	Samples *n*	PM *n (%)*
	CPI	17	9,361 (10.69)	0	0 (0)	6	1,475 (1.68)
Performance (Lt)	IPI	1	256 (0.29)	0	0 (0)	1	299 (0.34)
	CPI	0	0 (0)	0	0 (0)	0	0 (0)
U-20 to U-22 (junior categories)							
Performance (St)	IPI	1	384 (0.44)	0	0 (0)	3	1,460 (1.67)
	CPI	4	1,729 (1.97)	0	0 (0)	3	581 (0.66)
Performance (Lt)	IPI	0	0 (0)	1	8,186 (9.35)	2	372 (0.42)
	CPI	0	0 (0)	0	0 (0)	0	0 (0)
Senior category							
Performance (St)	IPI	4	5,766 (6.59)	0	0 (0)	2	1,245 (1.42)
	CPI	9	4,751 (5.43)	9	1,873 (2.14)	4	880 (1.01)
Performance (Lt)	IPI	2	1,290 (1.47)	5	35,337 (40.36)	4	2,887 (3.30)
	CPI	1	262 (0.30)	1	690 (0.79)	0	0 (0)
COMPETITION LEVEL							
National							
Performance (St)	IPI	6	7,061 (8.06)	0	0 (0)	7	6,045 (6.90)
	CPI	18	12,091 (13.82)	9	1,873 (2.14)	0	0 (0)
Performance (Lt)	IPI	1	1,028 (1.17)	5	42,833 (48.92)	2	2,787 (3.18)
	CPI	0	0 (0)	0	0 (0)	0	0 (0)
International							
Performance (St)	IPI	5	1,874 (2.14)	0	0 (0)	5	2,347 (2.68)
	CPI	12	3,750 (4.28)	0	0 (0)	13	2,936 (3.35)
Performance (Lt)	IPI	2	518 (0.60)	1	690 (0.79)	5	771 (0.88)
	CPI	1	262 (0.30)	1	690 (0.79)	0	0 (0)

n, absolute frequency; %, relative frequency; PM, performance measure; St, short term; Lt, long term; IPI, individual performance indicators; CPI, collective performance indicators.
Because of the lack of data about the age of participants in some studies, the analysis of the sample by age group was reduced to 77,232 athletes.

(2) with regard to the "competition category," a transition process from the youngest categories, where a greater influence of the RAE on competition performance was identified (12,402 measurements; 14.16%), to the higher categories, in which a bigger impact of the RAE reversal on the long-term competition performance was detected [junior: 8,183 measurements (9.35%); senior: 37,900 measurements (43.29 %)]; (3) from the perspective of the "competition level," at the national level, the long-term competition performance was more affected by the RAE reversal [43,861 measurements (50.09%)], whereas the results found were mixed at the international level, showing no prevailing relationship between RAE and competition performance. However, a noticeable number of samples (n = 23) revealed no relationship between the RAE and competition performance at the international level (6,054 measurements; 6.91%).

DISCUSSION

The present study represents the first attempt to synthesize and analyze the scientific evidence regarding the impact of the RAE and its relationship with competition performance in team sports. Based on the analyzed data, the results confirmed (i) a prominent influence of the RAE on competition performance in team sports in 83% of the measurements and (ii) a greater impact of the RAE/RAE reversal on short-term collective performance and on long-term individual performance (sport career). Moreover, attending to the constraints-based theoretical model, individual constraints, sample characteristics (gender and age group), and task constraints, sport context (type of sport, competition level, and competition category), were modifying factors of the impact of the RAE and its influence on competition performance (**Figure 6**).

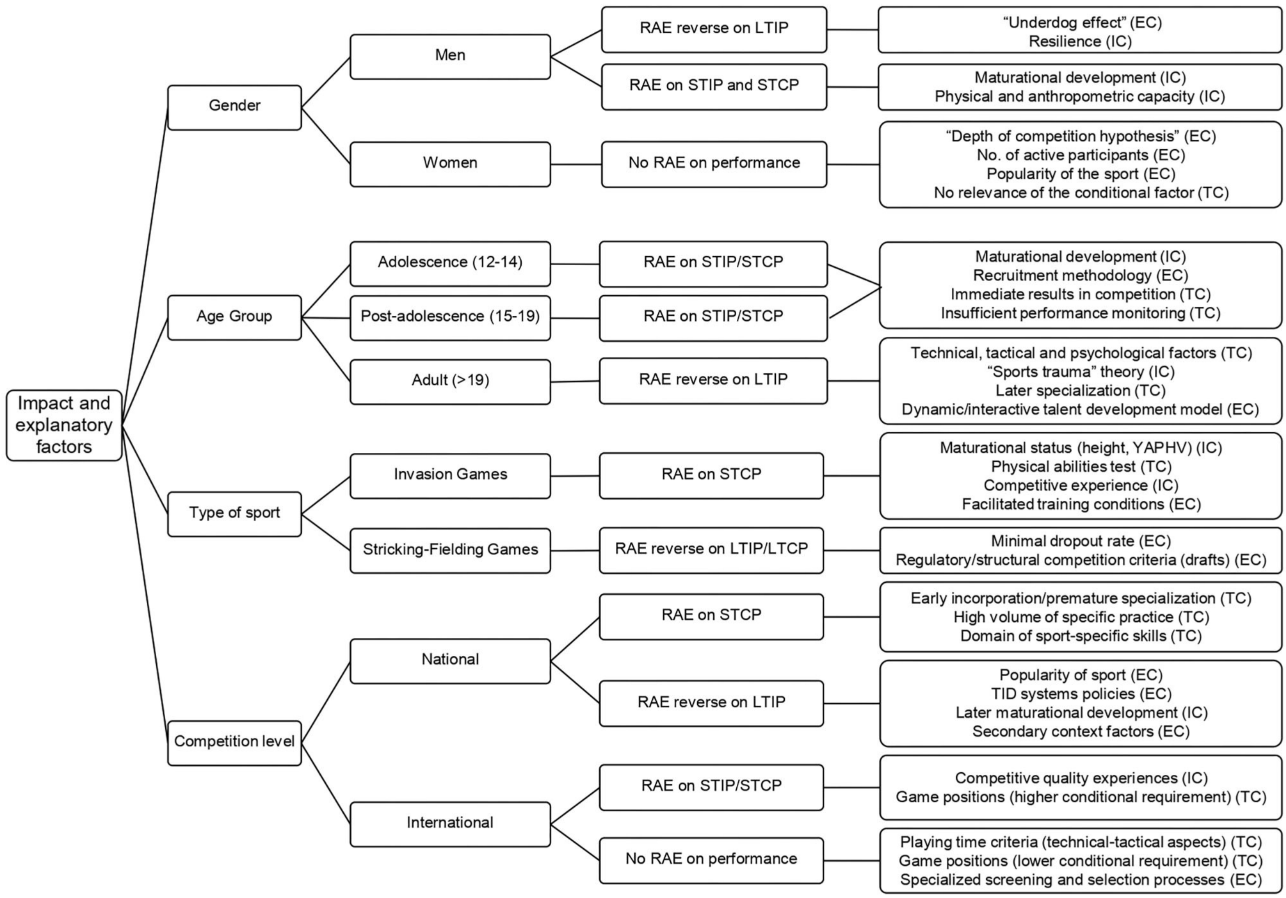

FIGURE 6 | Summary of impact and explanatory factors of the influence/non-influence of the RAE/RAE reversal on the competition performance in team sports by categories and sub-categories according to Wattle's constraints-based theorical model. STIP, short-term individual performance; STCP, short-term collective performance; LTIP, large-term individual performance; LTIC, large-term collective performance; IC, individual constraints; TC, task constraints; EC, environmental constraints.

However, it is necessary to minimize the results yielded because of the difficulty of establishing a homogeneous discussion and common conclusions, given the high degree of variability that the investigations showed in their study design. Therefore, for a correct interpretation of the existing scientific literature in this regard, characterized by a lack of homogeneity in the methodological field (very diverse study designs applied to very different samples, in terms of age/age group and competitive category), it is necessary to contextualize the investigations without advancing hasty conclusions.

RAE and Competition Performance (Study Quality Assessment)

With regard to the study quality analysis, it was identified that the investigations that yielded better quality scores, according to the adapted version of the STROBE checklist (Vandenbroucke et al., 2014; Smith et al., 2018), were associated with the analysis and evaluation, mainly, of individual short-term (statistical parameters) and long-term (attainments throughout the sport career) performance indicators. However, it could not be confirmed that a high study quality score was linked to a specific trend in terms of the impact of the RAE on competition performance, producing results with great variability and heterogeneity. These findings highlight the need to provide complete data on the characteristics of the participants and the context for a complete and in-depth analysis. The study quality evaluation list can be a valid and useful tool for subsequent works that aim to establish a connection between the relative age and competition performance.

RAE and Competition Performance by Gender

According to the gender of the athletes analyzed (individual constraints), in men, a higher impact of the RAE reversal on competition performance was observed, especially on individual long-term performance (sport career), whereas in the case of women, the presence of the RAE was detected in some samples; however it did not have, for the most part, an impact on performance.

These results, in men's sport, are in line with other studies that confirmed that relatively young players, considered as "talented," achieved more and greater attainments throughout their sport career in terms of competitive experience (Carling et al., 2009), competitive productivity (Sims and Addona, 2016), longevity of sport career (Jones et al., 2018), ranking position (Ford and Williams, 2011), or salary (Ashworth and Heyndels, 2007). These results, given the relevance of team sports in their respective sociocultural contexts, could be explained by the "underdog effect" (Gibbs et al., 2012). The fact of being born in the last months of the year would allow the development and acquisition of specific technical–tactical skills, which would help the relatively young players overcome physical and anthropometric limitations. Moreover, greater experimentation of stressful training situations under pressure in youth categories (Andronikos et al., 2016), even with some need to face potentially positive adverse experiences—"traumas" — (Collins and MacNamara, 2017), along with a great effort in the learning process (Roberts and Stott, 2015), could suppose that relatively young athletes overcome, to a greater extent, the challenges presented throughout their sport career, displaying greater resilience than relatively older players (McCarthy and Collins, 2014; McCarthy et al., 2016).

On the contrary, a strong impact of the RAE on the selection process and individual and collective competition performance was identified (Vaeyens et al., 2005a,b; Yagüe et al., 2018). This reality can be explained by the performance production period. The analysis of these studies was based on short-term performance measurements (statistical parameters in competition), determining "competitive" as meaning having a roster composed of a majority of relatively older players due to a greater maturational development, which was reflected in higher anthropometric and physical patterns (Gastin and Bennett, 2014).

In women's sport, it seems that, even with an overrepresentation of relatively older players, the relative age did not entail an influence on competition performance. Probably, as the magnitude of the RAE in female sport is less than in male sport (Smith et al., 2018; de la Rubia et al., 2020), because of factors such as the depth of the competition (Baker et al., 2009) or the number of active participants and the popularity of the sport (Sedano et al., 2015), this phenomenon is not relevant enough to affect the competition performance, either individually or collectively. Furthermore, because of the conditional component of the players seeming to be less decisive for achieving high performance in team sports (Konstantinos et al., 2018), the biological differences (physical, anthropometric, physiological, etc.) that could be derived from the RAE would be reduced, and therefore, relative age would not be a relevant factor in women's performance.

RAE and Competition Performance Throughout the Age Group—Competition Category

Considering jointly the age group and competition category (task constraints), even though the cases in which there was an influence of the RAE on competition performance were very frequent, it was detected that the impact of the RAE on competition performance decreased gradually as the chronological age of the players increased, that is, when the sport transition by age categories is taking place. Therefore, an impact of the RAE on short-term performance indicators was observed in adolescent and post-adolescent athletes (youth and junior categories), whereas in the adulthood or senior category the long-term individual competition performance was affected by the RAE reversal.

The gradual reduction of the impact of the RAE and therefore its lower weight on the performance of athletes in the higher competition levels (senior categories) seem to be explained from two perspectives: (1) by the maturational development of the athletes, that is, the physical and anthropometric advantages that relatively older players have in the early stages of sport development (adolescence) would tend to equalize in adulthood in relation to the relatively young peers (Leite et al., 2013); (2) because of the complexity of considering and measuring the performance in team sports. The possible maturational advantages would not be so decisive in advanced stages of development and superior performance categories. Thus, the lower relevance that conditional capacities exert on the competition performance, to the detriment of the technical, tactical, strategic, and even psychological qualities (Rampinini et al., 2007), could suppose a reduced impact of the RAE; and (3) because of the trauma connected to talent (Collins and MacNamara, 2012). The difficulties, derived from the RAE, that relatively young athletes would have to overcome in their early stages of development (i.e., expectations breach, the non-selection for a team, or change of training group), could cause them to develop determining psychological abilities to achieve high performance in adult age or senior stages (Collins et al., 2016; Savage et al., 2017). Even some studies (Collins and MacNamara, 2012; Sarkar and Fletcher, 2014) demonstrated the "need" for these athletes to experience trauma to reach professional sports levels. Therefore, it seems that to be born in the last months of the year would not suppose a disadvantage to progress toward high sport performance.

According to the performance production period, a higher short-term performance by relatively older players in early development stages could correspond to various reasons, apart from the maturational process. With regard to the recruitment methodology, it seems that coaches prioritize the consideration of immediate performance indicators in talent identification programs for elite levels, trying to predict, in this way, the athlete's sport development (Simonton, 2001). Therefore, the selection processes seem to be biased in favor of the relatively older players. Nevertheless, it is necessary to highlight that a large part of the scientific literature in this regard provides us with studies carried out in top-level international contexts (Rubajczyk et al., 2017; Carraco et al., 2020), so it seems logical to think that the impact of the RAE would have an exponential influence on short-term competition performance. Thus, the most employed criteria in talent identification and development (TID) systems, in stages prior to the highest competitive level (adulthood–senior category), are short-term indicators, neglecting other important ones in team sports, such as the specific criteria of the game (decision-making, leadership, cognitive skills, etc.) (Hyllegard et al., 2001).

Furthermore, insufficient and deficient monitoring of performance indicators could cause an imbalance in the athlete's sports development without considering the individual's characteristics (Hartwig et al., 2009). However, in adulthood, corresponding to the senior category, the relatively young players yielded better results in the long-term performance indicators (Gil et al., 2019). A late specialization, as happens in most team sports, and a dynamic and interactive model of sports talent development based on comprehensive learning activities seem to be factors that modulate long-term performance, favoring longevity and quality of the sport career (Güllich and Emrich, 2014). Moreover, although scientific evidence is limited, it was suggested that specialized environments based on talent detection and selection processes, in which the maturational development of the athlete is ignored, could be correlated with shorter and less successful sports careers.

RAE and Competition Performance by Type of Sport

In the analysis carried out regarding the type of sport (task constraints), the performance results in the "invasion games" were influenced by the presence of the RAE, whereas the impact of the RAE reversal was observed in the "striking and fielding games." Within the first group, in sports such as football/soccer (Williams, 2010; González-Víllora et al., 2015) and basketball (Arrieta et al., 2016; Rubajczyk et al., 2017), a clear relationship between the RAE and short-term collective performance was confirmed. The scientific literature coincides in highlighting the difference in the maturational status of athletes as a decisive factor. In that regard, Torres-Unda et al. (2016) found higher values in maturation indicators, such as height or the "years at peak of high velocity," in relatively older players than their relatively younger peers. Furthermore, relatively older players produced better results in tests associated with physical capacity, which translated into better competition performance and therefore a better final team classification (Augste and Lames, 2011). However, if the performance is discriminated as positive or negative, the relationship between RAE and competition performance does not seem to behave in the same way. In this context, Yagüe et al. (2018) verified in their study on the 10 best European football leagues that teams in the middle or lower part of the classification composed of a high percentage of relatively older players achieved a better final position. Conversely, the relationship between RAE and short-term collective performance in the top teams disappeared.

Furthermore, in "invasion games," the increased competitive experience of relatively older players seems to be another key point. Thanks to an early identification of talent in athletes born in the first months of the year due, partially, to a greater probability of selection (Helsen et al., 1998), relatively older players would tend to enjoy better training conditions (sport facilities, coaches, etc.) (Hancock et al., 2013). This would help to increase their competitive experience, both qualitatively and quantitatively, which would translate into greater individual and therefore collective performance in team sports (Williams, 2010).

On the other hand, in the "striking and fielding games" (baseball and cricket), an RAE reversal was detected. The scientific literature in this regard is not plentiful, especially in cricket, leading to a lack of depth in the analysis of this phenomenon. This could affect the impact of the results. Unlike the "invasion sports," baseball and cricket, among others, are disciplines where physical and physiological maturation and subjective performance evaluation are not considered as relevant (Zuma et al., 2017). This fact would cause the dropout rate of relatively young athletes to be low, and therefore, they could develop their potential without biased selection processes based on their birthdate (Jones et al., 2018).

Moreover, in sports such as baseball, the normative criteria of the structure of the competition (drafts) seem to favor the presence of RAE reversal. In these athlete allocation processes, the relatively young players, because of selection based on short-term and biased performance identification criteria, are not usually chosen in the first instance by the top teams. This fact would suppose that they continued playing at a lower competitive level, enjoying more "quality" time played (Thompson et al., 1992). Therefore, a late pick in the draft of these kinds of sports, in the case of relatively young players, could mean a higher long-term competition performance (Sims and Addona, 2016), reaching maximum individual levels of success, such as most valuable player (Ford and Williams, 2011).

RAE and Competition Performance by Competition Level

In the analysis regarding the competition level (task constraints), an influence of the RAE on performance in national competitions was found, whereas a lack of impact of the RAE or RAE reversal on competition performance in international contexts was observed. In the domestic sphere, in terms of the number of measurements carried out, the RAE showed a considerable influence on short-term collective performance (final team position). Although there is no clear evidence of this relationship in the scientific literature, the reasons responsible for this considerable influence could be found in the athlete's development toward high performance. With a short-term performance objective in formative categories, it seems that an early incorporation and a quick specialization in the sport, a high volume of specific practice, and a high domain of specific skills lead to the achievement of a strong long-term individual and collective performance (Weissensteiner et al., 2008). According to this research line, Augste and Lames (2011) detected that those teams from the three best U-17 development leagues in Germany, mainly composed of relatively older players, achieved a final classification 1,035 positions better than the other teams. Similar results were found in the U-17 teams of the German Bundesliga clubs in the 2010–2011 and 2011–2012 seasons (Grossmann and Lames, 2013).

In addition, the long-term individual performance at the national level was affected by the RAE reversal. The study samples, in which this phenomenon was found, were observed for the most part in professional team sports in the United States, such as baseball or ice hockey (Deaner et al., 2013; Sims and Addona, 2016; Steingröver et al., 2016; Fumarco et al., 2017). The great popularity of these sports specialties in a particular geographic context, different policies connected to TID systems, the decrease in maturational differences, and secondary factors (family) throughout the university stage seem to become key environmental factors in justifying that relatively young athletes usually enjoy more successful sports careers than their relatively older peers (Wattie et al., 2015). Furthermore, Ashworth and Heyndels (2007) demonstrated in a study with top-level German football players that relatively young athletes earned systematically higher wages than their relatively older peers.

The results regarding the relationship between RAE and performance in international competitions were mixed. Although most of the performance indicators focused on the short term due to the duration of the competition, normally reduced, a similar number of measurements was registered between samples that showed an impact of the RAE on competition performance and samples that presented a lack of connection between these variables. However, no strong evidence confirming the influence of the RAE on long-term competition performance was found. On the one hand, it seems that relatively older athletes, having lived more competitive quality experiences, could reach higher performance (Bjørndal et al., 2016). In contrast, Karcher et al. (2014) checked that the criteria used by coaches to decide the playing time of their players were based on technical–tactical considerations rather than aspects derived from RAE. Taking both realities into account, it would be important to introduce a modulating factor into the relationship between RAE and performance: the playing position. In team sports, individual performance is not achieved in the same way, but will largely depend on the playing position. For this reason, many studies made this distinction (Schorer et al., 2009b; García et al., 2014; Ibañez et al., 2018; Yagüe et al., 2018; Lago-Fuentes et al., 2019; de la Rubia et al., 2020), concluding, generally, that relatively older players showed a better performance in those positions with greater physical and anthropometric requirements (i.e., pivots in basketball, backs in handball or midfielders in football), whereas in other playing positions, less conditioned by the biological and maturational development (i.e., shooting guard in basketball; wings in handball or forwards in football), there was no difference in competition performance depending on the relative age.

Unexpected Finding

The most significant unexpected finding was found in the performance analysis by competition level. Although some samples showed an influence of the RAE on competition performance at international level (Williams, 2010; Torres-Unda et al., 2016; Ibañez et al., 2018), interestingly, a similar number of samples and athletes, in which the RAE or RAE reversal did not affect competition performance, was also found (García et al., 2014; Karcher et al., 2014; Barrenetxea-Garcia et al., 2019), especially in the short term. Nevertheless, it should be specified that most of the measurements were collected from competitions in the senior category.

It seems that the primary mechanism that transforms and promotes the RAE as a bias factor appears in the early stages of the athlete's development process (Cobley et al., 2008; Schorer et al., 2009a). So, in adulthood and senior categories, the RAE, although present, does not have as much impact on competition performance. Furthermore, the screening and selection processes at these competitive levels are more specialized, being made up of sport-specific criteria and therefore usually escaping the influence of the RAE (Schorer et al., 2009a). This could suppose, as Karcher et al. (2014) affirm, that all players had the same opportunities to play, with no differences regarding the number of minutes played. Therefore, the RAE, as occurs in some studies in this review (González-Víllora et al., 2015; Bjørndal et al., 2018a), is not considered as the key factor that can modify and modulate competition performance.

CONCLUSIONS

Competitive performance in team sports is affected by the RAE. The results highlighted, mainly, the impact of the RAE on the individual and collective athlete's performance in the short term, that is, regarding statistics parameters (individual performance) and final team classification (collective performance), particularly in youth and junior categories, which correspond to adolescence and postadolescence. On the other hand, a correlation between a higher long-term competition performance, primarily at the individual level, and being a relatively young athlete, that is, RAE reversal, was verified.

With regard to the analysis of the sample characteristics, the RAE or RAE reversal affected mainly men's competition performance, whereas this relationship was not marked in women's sport, in which a lack of influence of RAE or RAE reversal on competition performance was identified. By age group, a tendency to decrease the magnitude of the impact of the RAE or RAE reversal on competition performance as the athlete's chronological age increased was detected.

Regarding the analysis of the sport context, a greater impact of the RAE on competition performance was observed in the "invasion games," whereas in the "striking and fielding games," a greater influence of the RAE reversal was identified. By "competition category," effects similar to those detected in the subcategory of "age group" were found. In other words, the impact of the RAE on competition performance was transforming as the category was superior, appreciating an RAE, to a greater extent, in lower categories (from U-14 to U-18); and an RAE reversal predominantly in junior categories (from U-20 to U-22). A notable lack of influence of the RAE on the individual and collective performance in the short and long term was detected in youth categories, rather than in the junior and senior categories. By "competition level," the RAE showed a clear influence on short-term performance, both individual and collective, at national levels, whereas the RAE reversal affected long-term individual competition performance. At international level, the results were mixed, with no clear conclusions being established in this regard.

According to this scientific evidence, these findings should be considered by sport institutions and organizations, within the design and implementation of TID programs, so as to reduce possible selection biases of athletes caused by the RAE or RAE reversal, which, subsequently, could impact on competitive performance. A reduction in the influence of the

RAE on competition performance could mean greater equality of opportunity for the athletes regardless of their birthdate within the same year of selection. Thus, the sport development process of relatively young athletes would be optimized by aligning individual constraints (sample characteristics) and task constraints (sport context) and thereby adjusting the athlete's participation throughout the sport career, especially in formative stages or youth categories.

LIMITATIONS

First, it is possible that some published scientific evidence, especially as of January 2020, has not been identified and registered in this review despite the exhaustive systematic search process carried out. Second, the lack of some relative data, especially with regard to the age of the athletes, has meant that some samples were categorized as "not encodable" by "age group" category. Third, the present study, although not its main objective, does not provide specific data on the effect size of the RAE. Fourth, in order to carry out an in-depth analysis and because of the different methodologies employed to evaluate competition performance, the total number of participants ($n = 77{,}329$), which constituted the 77 samples, did not match with the number of measurements made on the performance of these athletes ($n = 87{,}556$). Therefore, the results must be accurately interpreted. Fifth, the great sampling and methodological diversity of the analyzed studies has entailed an increase in the degree of difficulty in extracting the main results and conclusions connected to the purpose of the systematic review. Sixth, because of the existence of some actions of the game that cannot be accounted for, but that are considered of great value by the coaches (intangibles), it would be convenient to minimize the scientific evidence identified.

PRACTICAL APPLICATIONS

Given that the athlete's training process is very complex, dependent on a multitude of factors, non-linear and even random, talent detection, development, and selection models should observe with greater caution the relationship between RAE and performance in competition. Thus, these models should try not to evaluate this problem by means of a dichotomous decision, but as a process in which time helps to make better decisions with the main objective of ensuring that athletes always remain involved in their sport discipline and assuming that their level performance can vary over time, and therefore, their participation in different competitive levels could also do so.

According to the previously mentioned objective and findings of this systematic review, guidelines or suggestions are proposed for coaches, stakeholders, and practitioners on how to approach and carry out the identification and development talent process with the aim of reducing the bias produced by the RAE: (1) do not focus the talent detection and recruitment on short-term parameters that yield a biased vision of the future potential of athletes; (2) carry out long-term monitoring of performance indices in relation to the maturational level of the athlete, allowing an adjusted and parallel development of the sport performance and maturational status; (3) collect a comprehensive database of athletes in terms of constraints-based theoretical model (gender, age group, competition category, sport, and competition level), which allows predicting longitudinal trends in the RAE's behavior with the aim to reduce its impact with regard to the athletes' characteristics and/or sport context; (4) organize development leagues or short competitions in national sport contexts that include those relatively young players not selected so that their training and competitiveness are not greatly affected; (5) adjust the participation of relatively older athletes in youth categories so as not to cause an overload of practice that may lead to a higher injury rate. This is to ensure that the long-term performance of relatively older athletes, especially in international sport contexts, is not adversely affected; (6) include psychosocial factors in the selection tests to link and connect the training, leadership, and cognitive skills variables. Thus, a balanced development of athletes will be ensured by reducing the influence of the RAE, (7) adjustment of age categories used in youth and international junior competitions, so that the relatively older players in a group can change their category every year.

FUTURE RESEARCH

According to a more in-depth analysis, the subsequent studies should include a meta-analysis that would provide more accurate statistical information on the behavior of the RAE on competition performance, considering the heterogeneity and complexity that the different performance indicators present in their measurement. On the other hand, expanding this research to other sport contexts (elementary competitive levels, such as local, regional, etc.) could help to compile a complete map of the impact and influence of the RAE on competition performance and, in this way, be able to adjust sports talent identification policies in a greater number of team sports and competitive levels. Furthermore, an in-depth evaluation of athletes in relation to competition performance, not only taking into account their primary characteristics, but also focusing on factors that are considered as secondary (coaches, friends, family, etc.), could help to carry out a holistic evaluation of sport talent, understanding the athlete as a whole composed of unequal parts, but all of them important to achieving the high performance.

AUTHOR CONTRIBUTIONS

AR, AL, and JL-C conceptualization, formal analysis, methodology, project administration, supervision, validation, visualization, and writing—review and editing. AR: data curation, investigation, resources, software, and writing—original draft preparation. All authors contributed to the article and approved the submitted version.

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Longitudinal Physical Development of Future Professional Male Soccer Players: Implications for Talent Identification and Development?

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The present study examined if elite youth male association football (soccer) players aged 8–19 y ($n = 2,875$) from the English talent development system, who ultimately achieved professional status differed in stature, body mass, and physical performance (20-m sprint speed, slalom agility speed, vertical counter-movement jump with arm swing jump height, multistage fitness test distance) compared with their non-professional peers. The study also examined the longitudinal pattern of development of stature, body mass, and physical performance, and if this was different between future professionals and non-professionals, while considering the effects of playing position. Multilevel modeling of the 8,898 individual (player-occasion) data points suggested that from age 12.0, the future professionals performed better in a vertical counter-movement jump with arm swing test and slalom agility test than future non-professionals, and improved at a faster rate, so that by age 18.0 the differences in vertical counter-movement jump with arm swing and slalom agility performance were 1.7 cm ($p < 0.001$, $d = 0.3$) and 0.14 s ($p < 0.001$, $d = 0.5$), respectively. In addition, future professionals were faster (by 0.02–0.04 s on the 20-m sprint, $p < 0.001$, $d = 0.2$) and ran further in the multistage fitness test (by 47 m, $p = 0.014$, $d = 0.2$) than future non-professionals throughout their development, but there were no differences in stature or body mass during development between the groups. Whereas, multistage fitness test performance improved linearly with age, the development of all other physical characteristics was non-linear. There were inter-individual differences in the development of all characteristics, and there were differences between playing positions in the development of all characteristics. Thus, in summary, future professionals jump higher, are more agile, faster, and more endurance fit than future non-professionals as they age, and the pattern of development is different in professionals and non-professionals for vertical jumping and slalom agility performance.

Keywords: association football, stature, body mass, agility, sprint speed, counter-movement jump, endurance, field-tests

INTRODUCTION

Talent identification and development in association football (soccer) refers to the interlinked and ongoing processes of: recognizing young players with the potential to become elite senior players; and providing them with the most appropriate learning environment to realize their potential (Williams and Reilly, 2000). In England, elite male youth players are exposed to a talent identification and development process which is largely based on scouting and recruitment to academies affiliated with professional clubs. Once recruited, academies attempt to provide players with a systematic programme of coaching and support, and make ongoing judgements of players' potential to succeed. The nature of this academy system is governed by a recent strategic framework, The Elite Player Performance Plan (EPPP), which aims to increase the number and quality of home-grown players participating in the English professional leagues (Premier League, 2011). An integral part of the system is the testing of the physical characteristics of players (e.g., their stature and body mass, and their sprinting, agility, vertical jumping, and endurance performance) using field-based protocols, as these allow large numbers of players to be tested in a short time and the tests are reliable and valid when conducted appropriately (Hulse et al., 2013). Indeed, in England, professional academies are required to conduct physical tests on their players aged U9-U21, at least 3 times per year. The aim of testing, and the subsequent creation of a national database, is "to enable each club to measure the relative success of their own programmes and players" (Premier League, 2011, p. 65). Interestingly, debate remains regarding the utility of a physical testing programme for talent identification and development processes in football (Mendez-Villanueva and Buchheit, 2013).

A major focus of talent identification and development research in football has been on establishing whether, and if so which, physical characteristics may be associated with success, possibly due to the importance of physical attributes to excellence in match-play (Stolen et al., 2005; Faude et al., 2012). Based on a range of physical characteristics (such as stature, body mass, body composition, speed, agility, vertical jumping, power, repeated sprint ability, and endurance), researchers have differentiated more successful elite youth football players from those who were less successful (e.g., retained vs. released from an academy) at multiple age groups from U9-U21 (Visscher et al., 2006; Gil et al., 2007, 2014; Gravina et al., 2008; Lago-Penas et al., 2011, 2014; Huijgen et al., 2014; Deprez et al., 2015; Honer and Votteler, 2016; Bennett et al., 2019; Castillo et al., 2019; Patel et al., 2020). However, such studies are typically cross-sectional, and can only provide information on current, rather than future, accomplishments (Abbott and Collins, 2002; le Gall et al., 2010). As the ultimate aim is to recognize young players with the potential to become elite senior players, it is necessary to prospectively track young players into adulthood to determine their senior playing status.

Carling et al. (2012) did perform a prospective study and showed that, of 158 academy football players from France aged 13 y, those who later became senior professionals were taller, heavier, and had a higher estimated maximal oxygen uptake (from a continuous track test) than their senior non-professional counterparts. Other studies have adopted similar approaches for single (Deprez et al., 2015; Martinez-Santos et al., 2016; Honer et al., 2017; Castillo et al., 2018; Sieghartsleitner et al., 2019a,b) or several distinct age groups (le Gall et al., 2010; Gonaus and Muller, 2012; Emmonds et al., 2016). While prospective, such designs are still limited in that they do not provide insight into the changes and pattern of development of physical characteristics over the length of a player's academy career and into adulthood. Also, they fail to consider talent identification and development as an interlinked, dynamic, and non-linear process (Simonton, 1999; Williams and Reilly, 2000; Abbott et al., 2005) and perhaps implicitly suggest that talent identification and development is a short-, rather than a long-term process (Sarmento et al., 2018). Therefore, multiple observations of the same individuals across time are needed to adequately track and examine the changes and the pattern of development of dynamic variables such as physical characteristics, so that casual relationships and individual developmental trajectories can be more robustly examined (Saward et al., 2016; Fransen et al., 2017; Johnston et al., 2018). Thus, the optimal research design needs to be longitudinal and prospective. That is, longitudinally monitoring changes in elite youth players' physical characteristics over several years and subsequently determining their senior playing status would allow the changes and pattern of development of physical characteristics of the most talented players to be understood, which in turn could better support talent identification and development processes (Huijgen et al., 2009; Coutinho et al., 2016; Leyhr et al., 2019). However, to the authors' knowledge only two studies have adopted this type of design in examining the development of elite youth male football players' physical characteristics (see Roescher et al., 2010; Leyhr et al., 2018).

Leyhr et al. (2018) longitudinally examined the development of 20-m sprint and slalom agility performance in 1,134 players aged U12-U15 from a German talent center and determined their senior playing status 8 years later. Multilevel modeling revealed that development of 20-m sprint and slalom agility performance was non-linear and future senior elite players (top 5 German divisions) were quicker on a slalom agility test than future senior non-elite players throughout development, but there was no difference in the pattern of development (Leyhr et al., 2018). There were no differences in 20-m sprint times between the groups. Roescher et al. (2010) used multilevel modeling to assess the longitudinal development of interval shuttle run test performance in 130 future professional and non-professional football players aged 14–18 years from two Dutch academies. For interval shuttle run test performance there was no difference between future professionals and non-professionals between 14 and 16 y. After age 16 y, the pattern of development became different for the two groups, with future professionals outperforming future non-professionals, as the professionals continued to improve in an almost linear fashion while the non-professionals improved at a slower rate, thus the differences between groups became larger over time (Roescher et al., 2010).

TABLE 1 | Player age, stature, and body mass by future playing status (non-professional vs. professional) and age group (U9 to U19).

Age group	Age (decimal years)		Stature (cm)		Body mass (kg)	
	Non-PROF [*n*]	PROF [*n*]	Non-PROF [*n*]	PROF [*n*]	Non-PROF [*n*]	PROF [*n*]
U9	9.1 ± 0.4 [746]	9.0 ± 0.4 [144]	135.0 ± 5.5 [708]	135.0 ± 5.3 [144]	30.6 ± 3.9 [708]	30.5 ± 3.8 [144]
U10	10.1 ± 0.4 [841]	10.1 ± 0.4 [158]	140.0 ± 5.7 [802]	140.9 ± 5.6 [156]	33.9 ± 4.7 [801]	34.5 ± 4.4 [156]
U11	11.1 ± 0.3 [834]	11.1 ± 0.4 [205]	144.6 ± 6.4 [778]	146.6 ± 6.1 [195]	37.0 ± 5.6 [777]	38.5 ± 5.3 [196]
U12	12.1 ± 0.3 [892]	12.1 ± 0.4 [200]	151.6 ± 7.4 [845]	152.0 ± 7.1 [194]	41.9 ± 7.0 [845]	42.0 ± 5.6 [194]
U13	13.1 ± 0.3 [814]	13.1 ± 0.3 [231]	158.3 ± 9.1 [779]	158.5 ± 8.6 [217]	47.5 ± 8.9 [778]	47.5 ± 8.0 [217]
U14	14.1 ± 0.4 [796]	14.1 ± 0.4 [282]	167.5 ± 8.7 [755]	166.3 ± 9.4 [272]	56.5 ± 9.6 [755]	54.9 ± 9.6 [273]
U15	15.1 ± 0.4 [608]	15.1 ± 0.4 [264]	173.0 ± 7.6 [598]	173.5 ± 8.8 [262]	63.4 ± 9.1 [598]	62.8 ± 9.7 [263]
U16	16.1 ± 0.4 [402]	16.1 ± 0.4 [280]	177.0 ± 6.4 [387]	177.2 ± 6.8 [271]	68.7 ± 7.8 [394]	68.3 ± 8.2 [275]
U17	17.2 ± 0.4 [330]	17.1 ± 0.4 [280]	178.4 ± 6.5 [312]	179.8 ± 6.1 [270]	71.9 ± 7.6 [325]	72.5 ± 6.7 [276]
U18	18.0 ± 0.4 [230]	18.0 ± 0.4 [237]	178.5 ± 6.2 [224]	180.2 ± 5.8 [233]	72.5 ± 7.5 [226]	74.2 ± 7.0 [229]
U19	19.0 ± 0.3 [68]	18.9 ± 0.3 [56]	178.9 ± 5.7 [68]	179.7 ± 5.1 [55]	74.6 ± 6.4 [67]	75.7 ± 7.6 [53]

Non-PROF, players who did not make a professional league appearance; PROF, players who made at least one professional league appearance; n, number of data points in the sample.

These studies (Roescher et al., 2010; Leyhr et al., 2018) are valuable as they are the only studies in elite youth male football players which have adequately modeled longitudinal data and linked this with the future professional status of the players they investigated. However, both studies did have limitations. For example, player development was examined over a relatively short period of time (∼4 y) when compared to the full duration of a talent development programme (∼10 y). Also, neither study examined any anthropometric data, and only one or two physical performance characteristics were assessed in each study, and this may not be a broad enough representation of the physical characteristics needed to progress to professional status in football (Stolen et al., 2005). It could also be argued that the study of Roescher et al. (2010) had a relatively small sample size ($n = 130$). In addition, cross-sectional research has demonstrated differences in the physical characteristics of elite youth players based on their playing position (Deprez et al., 2015a) yet with regards to the longitudinal development of several physical characteristics in future professionals, the role of playing position remains largely unaccounted for. Finally, the studies of Leyhr et al. (2018) and Roescher et al. (2010) examined players from only one or two academies from Germany and the Netherlands, and it remains unclear whether these findings can be replicated in players from another country (such as those from the English talent development system), and replicated when player data from multiple different academies are examined.

Therefore, the purpose of the present study was to examine if elite youth male football players aged 8–19 y from the English talent development system who ultimately achieved professional status differed in stature, body mass, and physical performance (20-m sprint speed, slalom agility speed, vertical counter-movement jump with arm swing jump height, multistage fitness test distance) compared with their non-professional peers. The study also examined the longitudinal pattern of development of stature, body mass, and physical performance, and if this was different between future professionals and non-professionals, while considering the effects of playing position.

METHODS

Participants and Sample

A total of 2,875 elite male youth football players aged 8–19 y participated in the study (**Table 1**). Participants were defined as elite youth football players as they were recruited from 16 professional academies in England (Swann et al., 2015). Longitudinal anthropometric and physical performance test data were collected on players between 2002 and 2013, resulting in 8,898 individual (player-occasion) data points (Mean ± SD = 3.1 ± 2.7, Range = 1–24). Playing position was also recorded at each testing session, resulting in 686, 2,563, 3,063, 1,923, and 633 individual (player-occasion) data points for goalkeepers, defenders, midfielders, forwards, and multi-positional players, respectively.

Ethical approval for the study was obtained from the University Ethical Advisory Committees. Prior to taking part in the study, participants and parents/guardians were provided with a written and verbal summary outlining the purpose, procedures involved, possible risks and benefits, and the voluntary and confidential nature of the research. For participants aged 18 y or above, written informed consent was obtained. For participants under 18 y, written assent was obtained from players and written consent was obtained from their parents/guardians. Prior to every anthropometric and physical performance testing session, participants went through a health screening process to identify any reasons that may affect, or exclude them from, participation.

Performance Testing Procedures

Participants completed a battery of anthropometric and physical performance field-tests validated in elite youth football players (Hulse et al., 2013). Firstly, the anthropometric assessments were conducted, which included the measurement of stature and body mass. Stature was measured (to the nearest 0.1 cm) using a stadiometer (Leicester Height Measure, seca ltd., England). Body mass was measured (to the nearest 0.01 kg) using portable digital scales (seca 770, seca ltd, Birmingham, UK). Subsequently,

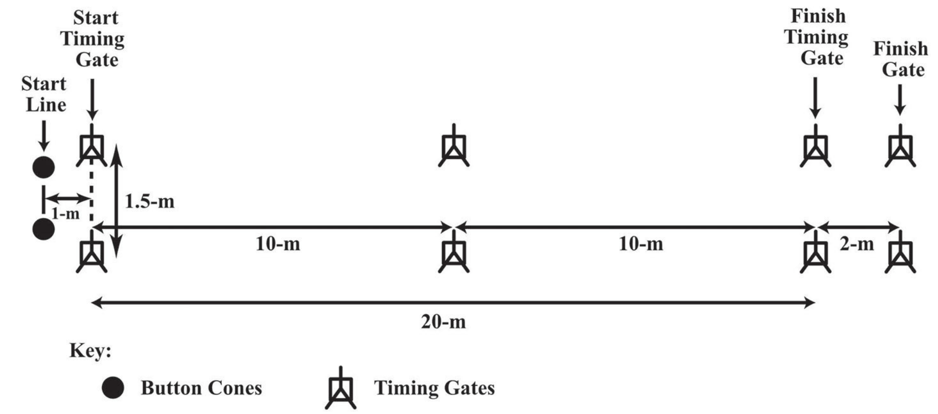

FIGURE 1 | 20-m sprint test layout and dimensions.

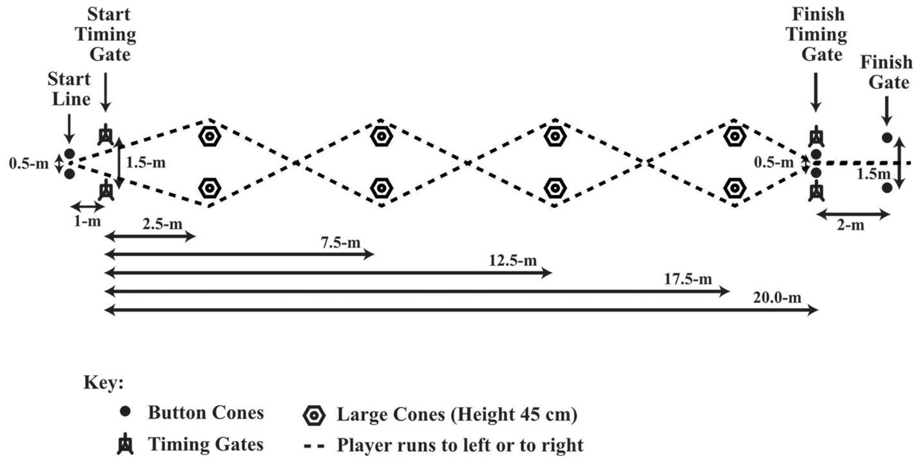

FIGURE 2 | 20.8-m slalom agility test layout and dimensions.

players completed four physical performance field-tests: 20-m sprint test, a 20.8 m slalom agility test, a vertical counter-movement jump with arm swing (CMJA), and the multistage fitness test (MSFT Ramsbottom et al., 1988). The testing battery took place on an indoor new-generation synthetic surface. The physical performance field-tests were preceded by a verbal explanation of the test, a standardized familiarization and a warm-up procedure. Each test was separated by a ∼3-min recovery.

For the 20-m sprint test (see **Figure 1**) participants completed two practice efforts, followed by two maximal sprints separated by a 3-min recovery period. Participants began the sprint in their own time, off their preferred foot, on a line 1-m behind the starting gate. The best time for 20-m was used in the current analysis. For the 20.8-m slalom agility test each participant completed four practice runs through the agility course (see **Figure 2**): two runs, where the first cone of the slalom was to their left, and two where the first cone was to their right side. Participants then performed alternate maximal efforts through each course (four in total), separated by a 3-min recovery period. Participants began their effort in their own time, off their preferred foot, on a line 1-m behind the starting gate. The agility time used in the current analysis was an aggregate (mean) of the participant's fastest left and right performance. For the 20-m sprint and slalom agility tests, times were measured to the nearest 0.01 s using infrared photoelectric cells (Newtest, Oulu, Finland, or Brower timing system, Draper, Utah, USA). Participants performed a vertical counter-movement jump with full use of their arms (Newtest Jump Mat, Oulu, Finland or SmartJump, Fusion Sport, Australia) at least 2 times, separated by a 3-min recovery period. Participants performed the multistage fitness test with an adult "pacemaker" (see **Figure 3**). The multistage fitness test involved running back and forth over a 20-m distance in time with an audio signal. Participants were required to reach the end of each 20-m shuttle and to place their foot on or over the line marking the 20-m length at the same time as the "bleep" audio signal sounded. The required speed started at 8.0 km.h^{-1}, increased to 9.0 km.h^{-1} after 63-s

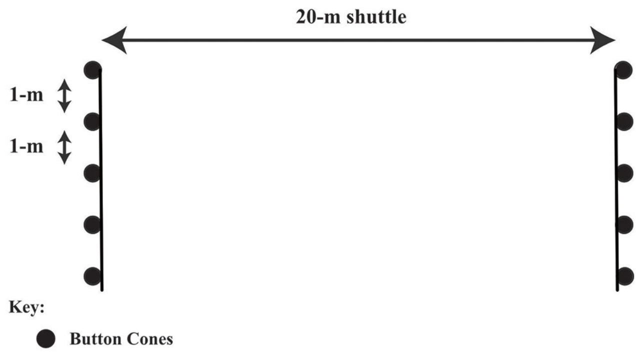

FIGURE 3 | The multistage fitness test layout and dimensions.

and then increased by 0.5 km.h^{-1} approximately every 60-s thereafter. The test ended when a participant voluntary indicated they no longer wished to continue running or they could no longer keep pace with the audio signal on three consecutive 20-m shuttles. The final level and shuttle completed by a player was recorded and then converted to a distance which was used in the current analysis. Hulse et al. (2013) reported acceptable reliability for tests completed 7 days apart for all age groups (U9-U11, U12-U14, U15-U18), with coefficients of variation of 1.5–1.7, 2.5–2.7, and 4.4–4.6%, for the 20-m sprint test, the slalom agility test and the vertical counter-movement jump with arm swing test, respectively. The coefficient of variation for the multistage fitness test has been reported to be 2–3% (Aziz et al., 2005; Cooper et al., 2005).

Establishing Professional Status

Subsequently, players were prospectively tracked, and their playing status determined as of 31st July 2019. A website containing information on professional football (Transfermarkt.com) was used to determine playing status, namely the number of professional league appearances (i.e., appearances in official league matches for a full-time senior professional football team) made by each player. The final sample consisted of 653 players who made at least one professional league appearance (23%) and 2,222 players who did not make an appearance. The group of professional players made 126 ± 123 (mean ± SD) (minimum = 1, maximum = 516) appearances across 65 professional leagues in Africa, America, Asia, Australasia, and Europe.

Data Analysis

The longitudinal sample used in the present study represents a hierarchically structured data set, with measurement occasions nested within player. As such, multilevel growth curve modeling was used to examine the development of physical characteristics (MLwiN v 3.00, Bristol, U.K.). Unlike traditional longitudinal data analysis techniques, such as the repeated measures ANOVA, multilevel modeling does not require the same number of measurement occasions per individual. Moreover, the temporal spacing of measurements may vary between players (Rasbash et al., 2017). Hence this statistical technique was suited to the current data structure. A multilevel model describes the underlying trends of a particular component in the population (fixed part), and also models the unexplained variation around the mean trend for that component (random part) (Twisk, 2003).

Following the guidelines of Rasbash et al. (2017) a two-level hierarchical structure was defined, with measurement occasion (level 1) nested within player (level 2), with a given physical characteristic as the continuous response variable. Subsequently, relevant parameters were systematically considered to observe their effect on explaining and partitioning variation in player development. Parameters were accepted or rejected based on changes in model fit, as indicated by differences in −2 loglikelihood, and the effect of explanatory variables on the response variable, as indicated by z-scores. From an empty model (i.e., the response variable and a fixed intercept), the intercept was allowed to randomly vary and a linear age term (centered at 13.0 y) was added. This forms the simplest multilevel growth model. From this simple multilevel growth model, quadratic, and cubic age terms were considered to allow for non-linearity of development. Variance between players' development rates was then considered by allowing the age terms to randomly vary. Subsequently a series of fixed explanatory variables were considered in turn, in the following order: professional playing status, playing position, and interactions between age, playing status, and playing position. Following each analysis, the assumption that the player-level random effects followed a bivariate normal distribution with zero means, was checked (Rasbash et al., 2017). Statistical significance was accepted at the 95% confidence level ($p < 0.05$). The size of the effects when comparing future playing status (professionals vs. non-professionals) and playing position (goalkeeper, defender, midfielder, forward, multi-positional) were examined using Cohen's d adapted for multilevel modeling (Feingold, 2019). Effect sizes were evaluated using <0.2, 0.2, 0.5, and 0.8 as the boundaries for trivial, small, moderate and large effects, respectively (Cohen, 1992). Mean ± SD were used to describe the average and variability of data, unless stated otherwise.

In terms of interpreting the outputs from multilevel models, the *Fixed Effects* part of the models show the expected characteristics (underlying trends) of professional and non-professional players at age 13.0 y for the different playing positions (see **Table 3**). At age 13.0 y, the average non-professional forward player is predicted to be 158.75 cm tall, weigh 48.80 kg, sprint 20-m straight at 6.098 m.s^{-1}, complete the slalom agility test at 4.647 m.s^{-1}, jump 36.645 cm on the vertical counter-movement jump with arm swing test, and complete 1,759 m during the multistage fitness test (see 4th row of data in **Table 3**). It is also possible to estimate the development of characteristics with age for players of future professional and non-professional playing standards and different playing positions, using the fixed coefficients from **Table 3**. For example, the prediction equation for vertical counter-movement jump with arm swing test performance for a 16.5-year-old professional forward is: Forward [β0 for forward) + (β1* Age centered at 13.0 y) + (β2 * Age centered at 13.0 y^2) + (β3 * Age centered at 13.0 y^3) + (β4 * Professional) + (β5* Age centered at 13.0 y*Professional), which is 36.645 cm + (2.624 cm * 3.5 y) +

TABLE 2 | Player physical performance test results by future playing status (non-professional vs. professional) and age group (U9 to U19).

Age group	Speed over 20 m (m.s^{-1})		Speed over the slalom agility test (m.s^{-1})		Vertical counter-movement jump with arm swing (cm)		Multistage fitness test distance completed (m)	
	Non-PROF [*n*]	PROF [*n*]	Non-PROF [*n*]	PROF [*n*]	Non-PROF [*n*]	PROF [*n*]	Non-PROF [*n*]	PROF [*n*]
U9	5.39 ± 0.24 [711]	5.46 ± 0.21 [144]	4.13 ± 0.25 [706]	4.21 ± 0.26 [144]	27.5 ± 4.0 [720]	28.0 ± 4.1 [144]	1,288 ± 275 [194]	880 ± 57 [2]
U10	5.52 ± 0.25 [801]	5.61 ± 0.25 [156]	4.28 ± 0.25 [801]	4.31 ± 0.24 [155]	29.1 ± 4.4 [811]	30.1 ± 4.4 [156]	1,431 ± 282 [221]	1,238 ± 286 [8]
U11	5.66 ± 0.26 [769]	5.72 ± 0.23 [196]	4.41 ± 0.27 [778]	4.45 ± 0.26 [195]	31.6 ± 4.5 [788]	31.7 ± 4.0 [196]	1,542 ± 276 [167]	1,287 ± 291 [6]
U12	5.80 ± 0.28 [841]	5.90 ± 0.28 [193]	4.50 ± 0.27 [837]	4.53 ± 0.30 [194]	32.8 ± 4.7 [849]	33.6 ± 4.4 [194]	1,562 ± 258 [189]	1,614 ± 330 [30]
U13	6.02 ± 0.31 [774]	6.06 ± 0.30 [213]	4.60 ± 0.28 [773]	4.63 ± 0.27 [212]	36.0 ± 5.3 [784]	36.5 ± 5.0 [219]	1,705 ± 289 [170]	1,729 ± 328 [28]
U14	6.29 ± 0.35 [744]	6.29 ± 0.33 [268]	4.75 ± 0.32 [741]	4.80 ± 0.30 [262]	39.4 ± 6.0 [737]	39.6 ± 5.0 [270]	1,912 ± 258 [164]	2,011 ± 281 [51]
U15	6.50 ± 0.34 [571]	6.55 ± 0.30 [256]	4.87 ± 0.27 [573]	4.98 ± 0.27 [254]	42.4 ± 5.4 [565]	43.0 ± 5.8 [251]	2,085 ± 250 [87]	2,149 ± 263 [41]
U16	6.64 ± 0.29 [382]	6.70 ± 0.28 [263]	4.94 ± 0.27 [386]	5.10 ± 0.29 [269]	44.2 ± 5.3 [385]	46.4 ± 5.8 [271]	2,163 ± 287 [63]	2,281 ± 246 [48]
U17	6.69 ± 0.30 [308]	6.75 ± 0.27 [266]	5.03 ± 0.28 [311]	5.14 ± 0.28 [264]	44.9 ± 4.7 [308]	47.0 ± 6.2 [264]	2,232 ± 282 [43]	2,265 ± 202 [48]
U18	6.73 ± 0.24 [213]	6.78 ± 0.25 [220]	5.01 ± 0.30 [216]	5.12 ± 0.28 [218]	45.5 ± 5.2 [213]	46.8 ± 5.5 [214]	2,364 ± 239 [18]	2,234 ± 210 [24]
U19	6.67 ± 0.30 [63]	6.75 ± 0.23 [50]	4.89 ± 0.28 [64]	5.05 ± 0.26 [50]	46.3 ± 7.1 [64]	46.9 ± 6.1 [50]	-	2,030 ± 184 [2]

Non-PROF, players who did not make a professional league appearance; PROF, players who made at least one professional league appearance; n, number of data points in the sample.

(0.012 cm * 12.3 y) + (−0.030 cm * 42.9 y) + (0.777 cm * 1)+ (0.191 cm * (3.5 y*1)] = 46.135 cm. The *Random Effects* section of **Table 3** allows the variation in development between players to be described (i.e., inter-individual differences). For example, for the development of multistage fitness test performance, the average distance for a 13.0 y for a professional midfielder is 1,876 m (1,829 m + 47 m, see **Table 3**, *Fixed Effects*), but with an intercept SD of 197 m (see **Table 3**, *Random Effects*) the coverage range within which 95% of professional midfielders intercepts are expected to lie at age 13.0 y can be estimated as 1,490–2,262 m [1,876 ± (1.96*197 m)]. Furthermore, multistage fitness test performance is predicted to increase by 132 m per year for the average player (see **Table 3**, *Fixed Effects*, Age^1), but with a slope (Age^1) SD of 40 m (see **Table 3**, *Random Effects*), the coverage range within which 95% of players' growth rates are expected to lie can be estimated as 54–210 m per year [132 ± (1.96*40 m)].

RESULTS

Descriptive Data

Tables 1, **2** describe the anthropometric and physical performance characteristics of the 2,875 elite youth football players examined in the study according to age group and future professional or non-professional playing status.

Stature, Body Mass, and Future Professional Playing Status

Table 3 shows the final multilevel models describing the longitudinal development of anthropometric characteristics (stature and body mass). No differences in stature and body mass were evident when the non-professional and professional players were compared (indicated by no parameter estimate in **Table 3** for the "Professional" variable, as, when added to the model, the ratio between the "Professional" variable parameter estimate and its associated standard error (z-score) did not achieve significance ($p > 0.05$), and the fit of the model was not improved by the inclusion of the variable, hence its omission). Also, no differences were evident in the longitudinal pattern of development of stature and body mass across age, when the non-professional and professional players were compared (indicated by no parameter estimates in **Table 3** for the interaction "Age^1*Professional" and "Age^2*Professional" variables). However, the analysis in **Table 3** does suggest that the longitudinal development of stature and body mass with age was not linear (as indicated by the significant "Age^2" and "Age^3" terms which add curvature to the model fit—see **Figure 4** for an illustration of this cubic pattern of development). There were inter-individual differences in stature and body mass at each age (random intercept), and inter-individual differences in the rate of change of stature and body mass with age (random slope for Age^1). The model suggests that 95% of 13.0-year-old players would have a stature within ±14.2 cm of the statures reported in the first five rows of **Table 3** (see the data analysis section for how this coverage range is calculated). For body mass, the equivalent boundary was calculated to be ±13.7 kg. In terms of the variation in growth rates, the predicted slope or annual change in stature for 95% of players from 13.0 to 14.0 y would be between 3.3 and 9.0 cm per year. For body mass, the equivalent boundaries would be between 3.2 and 8.5 kg per year.

Physical Performance Characteristics and Future Professional Playing Status

Table 3 also shows the final multilevel models describing the longitudinal development of physical performance characteristics (20-m sprint test, slalom agility test, vertical counter-movement jump with arm swing test, and multistage fitness test) in the sample of academy football players. Future professional players were faster in a 20-m sprint than future non-professional players throughout their development by 0.057 m.s^{-1} ($p < 0.001$, see "Professional" parameter estimate, **Table 3**; $d = 0.2$). This would equate to a 0.02–0.04 s faster 20-m sprint time in the professional players compared to the

TABLE 3 | Multilevel models for the development of physical characteristics in elite youth football players aged 8–19 y.

Parameter	Stature (cm)	Body mass (kg)	20-m speed (m·s^{-1})	Slalom agility speed (m·s^{-1})	CMJA (cm)	MSFT (m)
	Estimate (SE)	Estimate (SE)	Estimate (SE)	Estimate (SE)	Estimate (SE)	Estimate (SE)
FIXED EFFECTS						
Goalkeeper	162.17 (0.41)[a,b,c,d]	52.88 (0.43)[a,b,c,d]	5.860 (0.017)[a,b,c,d]	4.474 (0.017)[a,b,c,d]	34.948 (0.306)[a,b,c,d]	1,524 (28)[a,b,c,d]
Defender	158.80 (0.17)[b,e]	48.72 (0.18)[e]	6.039 (0.009)[c,e]	4.604 (0.009)[c,e]	35.873 (0.154)[c,e]	1,802 (15)[c,e]
Midfielder	158.54 (0.16)[a,e]	48.44 (0.17)[c,e]	6.034 (0.008)[c,e]	4.603 (0.008)[c,e]	35.668 (0.144)[c,e]	1,829 (14)[c,e]
Forward	158.75 (0.18)[e]	48.80 (0.19)[b,e]	6.098 (0.010)[a,b,d,e]	4.647 (0.010)[a,b,d,e]	36.645 (0.173)[a,b,d,e]	1,759 (17)[a,b,e]
Multipositional	158.61 (0.19)[e]	48.77 (0.21)[e]	6.030 (0.012)[c,e]	4.599 (0.012)[c,e]	35.855 (0.208)[c,e]	1,779 (27)[e]
Age^1	6.356 (0.048)	5.845 (0.052)	0.193 (0.003)	0.111 (0.002)	2.624 (0.050)	132 (3)
Age^2	−0.153 (0.008)	0.073 (0.009)	−0.001 (0.001)	−0.004 (0.001)	0.012 (0.009)	–
Age^3	−0.064 (0.002)	−0.069 (0.002)	−0.002 (0.001)	–	−0.030 (0.002)	–
Professional	–	–	0.057 (0.012)	0.034 (0.013)	0.777 (0.213)	47 (19)
Age^1 * Professional	–	–	–	0.011 (0.004)	0.191 (0.067)	–
Age^2 * Professional	–	–	–	0.003 (0.001)	–	–
RANDOM EFFECTS						
Intercept SD	7.27	6.99	0.21	0.20	4.09	197
Slope (Age^1) SD	1.45	1.36	0.03	0.03	0.66	40
Residual SD	1.04	1.54	0.16	0.17	2.58	165
Δ−2 loglikelihood (df)	31,453 (10)	27,655 (10)	15,055 (11)	10,058 (12)	13,413 (12)	3,789 (9)

*Parameters accepted at $p < 0.05$. Independent (intercept) estimates (at 13.0 y) for each playing position displayed. Between-position differences: [a]significant difference vs. Defender, [b]vs. Midfielder, [c]vs. Forward, [d]vs. Multipositional, [e]vs. Goalkeeper. Centered at 13.0 y, Age^1, Age^2, and Age^3 refer to the linear, quadratic, and cubic age terms, respectively. Professional: the effect of being professional at age 13.0 y. Age^1 * Professional: interaction between linear age and professional. Age^2 * Professional: interaction between quadratic age and professional. Intercept SD: inter-individual variation at age 13.0 y. Slope (Age^1) SD: inter-individual variation in linear growth rates. Residual SD: within-individual variation. Δ−2 loglikelihood (df) is the change in model fit, and associated degrees of freedom, from the empty model to the final model. CMJA, vertical counter-movement jump with arm swing; MSFT, multistage fitness test.*

non-professional players (with the variation relating to age). Age-related changes in 20-m sprint test performance were non-linear (indicated by the significant "Age^2" and "Age^3" terms in **Table 3**). The pattern of development was the same in the non-professional and professional players, and the non-linear but parallel pattern of development between the two player categories is evident in **Figures 5A,B**. There were inter-individual differences in 20-m sprint test performance at each age (random intercept), and inter-individual differences in the rate of change of 20-m sprint test performance with age (random slope for Age^1). The model suggests that 95% of 13.0-year-old non-professional players would have a 20-m sprint test performance within ±0.41 m.s^{-1} of the speeds reported in the first five rows of **Table 3** (add 0.057 m.s^{-1} to the values in the first five rows for the "Professional" group), which equates to a variation in 20-m sprint time of ±0.21–0.26 s. In terms of the variation in the rate of change of 20-m sprint test performance with age, the predicted slope or annual change in speed for 95% of 13.0- to 14.0-year-old players would be between 0.13 and 0.25 m.s^{-1} per year (which equates to a variation in the annual rate of change in 20-m sprint time of ±0.08–0.14 s per year).

The longitudinal pattern of development in slalom agility test performance was non-linear, and differed between the non-professional and professional players (indicated by the significant "Age^1," "Age^2," "Professional," "Age^1*Professional," and "Age^2*Professional" terms in **Table 3**, and illustrated in **Figures 5C,D**). At age 9.0 professional players were not faster on the slalom agility test ($p = 0.143$, $d < 0.2$), yet by age 12.0 professional players were significantly ($p = 0.048$), although trivially ($d < 0.2$), faster by 0.026 m.s^{-1} (equivalent to 0.03 s) than non-professional players, and by age 18.0 this difference had grown to 0.164 m.s^{-1} (equivalent to 0.14 s) ($p < 0.001$, $d = 0.5$). Professional players' annual rate of improvement was maintained at 0.11–0.13 m.s^{-1} per year throughout their development, but in the non-professional players the rate of improvement gradually declined as they got older (from 0.15 m.s^{-1} per year at 8.0 to 9.0 years of age to 0.08 m.s^{-1} per year at 17.0 to 18.0 years of age). There were inter-individual differences in slalom agility test performance at each age (random intercept), and inter-individual differences in the rate of change of slalom agility test performance with age (random slope for Age^1). The model suggests that 95% of 13.0-year-old non-professional players would have a slalom agility test performance within ±0.39 m.s^{-1} of the speeds reported in the first five rows of **Table 3** (add 0.034 m.s^{-1} to the values in the first five rows for the "Professional" group), which equates to a variation in slalom agility time of ±0.37–0.44 s. In terms of the variation in the rate of change of slalom agility test performance with age, the predicted slope, or annual change in speed for 95% of 13.0- to 14.0-year-old players would be between 0.05 and 0.18 m.s^{-1} per year (which equates to a variation in the annual rate of change in slalom agility time of ±0.05–0.18 s per year).

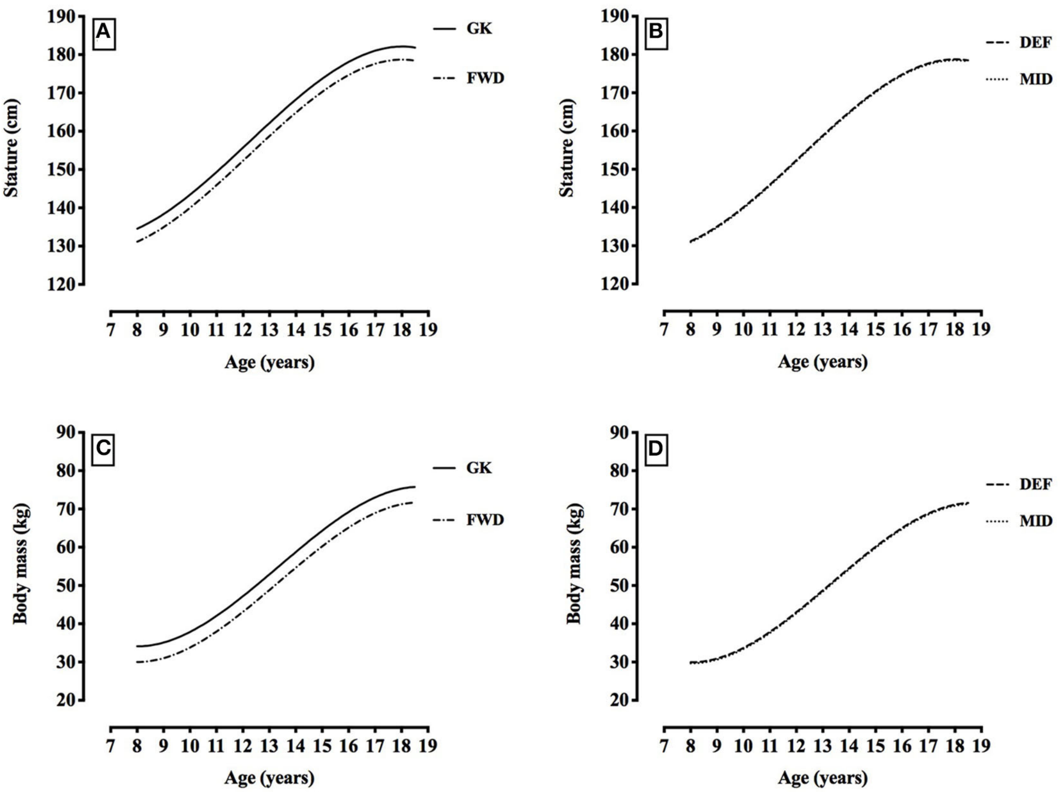

FIGURE 4 | Changes in stature and in body mass with age by playing position [stature: **(A)** goalkeepers (GK) and forwards (FWD), **(B)** defenders (DEF) and midfielders (MID); body mass: **(C)** goalkeepers (GK) and forwards (FWD); **(D)** defenders (DEF) and midfielders (MID)]. Data is based on the fixed parameter estimates from the models described in **Table 3**.

The longitudinal pattern of development in vertical counter-movement jump with arm swing test performance was non-linear, and differed between the non-professional and professional players (indicated by the significant "Age^1," "Age^2," "Age^3," "Professional," and "Age^1*Professional" terms in **Table 3**, and illustrated in **Figures 6A,B**). At age 9.0 there was no difference in vertical counter-movement jump with arm swing test performance between the non-professional and professional players ($p = 0.968$, $d < 0.2$), yet by age 12.0 the professional players jumped significantly ($p = 0.007$), although trivially ($d < 0.2$) higher by 0.6 cm, and by age 18.0 this difference had grown to 1.7 cm ($p < 0.001$, $d = 0.3$). Professional players' annual rate of improvement was always higher than the non-professional players, by 0.2 cm per year. There were inter-individual differences in vertical counter-movement jump with arm swing test performance at each age (random intercept), and inter-individual differences in the rate of change in vertical counter-movement jump with arm swing test performance with age (random slope for Age^1). The model suggests that 95% of 13.0-year-old non-professional players would have a vertical counter-movement jump with arm swing jump height within ±8.0 cm of the heights reported in the first five rows of **Table 3** (add 0.777 cm to the values in the first five rows for the "Professional" group). In terms of the variation in the rate of change of vertical counter-movement jump with arm swing test jump height with age, the predicted slope or annual change in jump height for 95% of 13.0–14.0-year-old players would be between 13.0- to 14.0-year-old cm per year.

Future professional players ran 47 m further on the multistage fitness test than future non-professional players throughout their development ($p = 0.014$, see "Professional" parameter estimate, **Table 3**; $d = 0.2$). The longitudinal pattern of development in multistage fitness test performance with age was the same in the non-professional and professional players, and the linear (indicated by the significant "Age^1" term in **Table 3**) but parallel pattern of development between the two player categories is evident in **Figures 6C,D**. There were inter-individual differences in multistage fitness test performance at each age (random intercept), and inter-individual differences in the rate of change of multistage fitness test performance with age (random slope for Age^1). The model suggests that 95% of 13.0-year-old players would complete a multistage fitness test distance within ±386 m of the distances reported in the first five rows of **Table 3** (add 47 m to the values in the first five rows for the "Professional" group). In terms of the variation in the rate of change of multistage fitness test performance with age, the predicted slope or annual change in distance for 95% of 13.0- to 14.0-year-old players would be between 54 and 210 m per year.

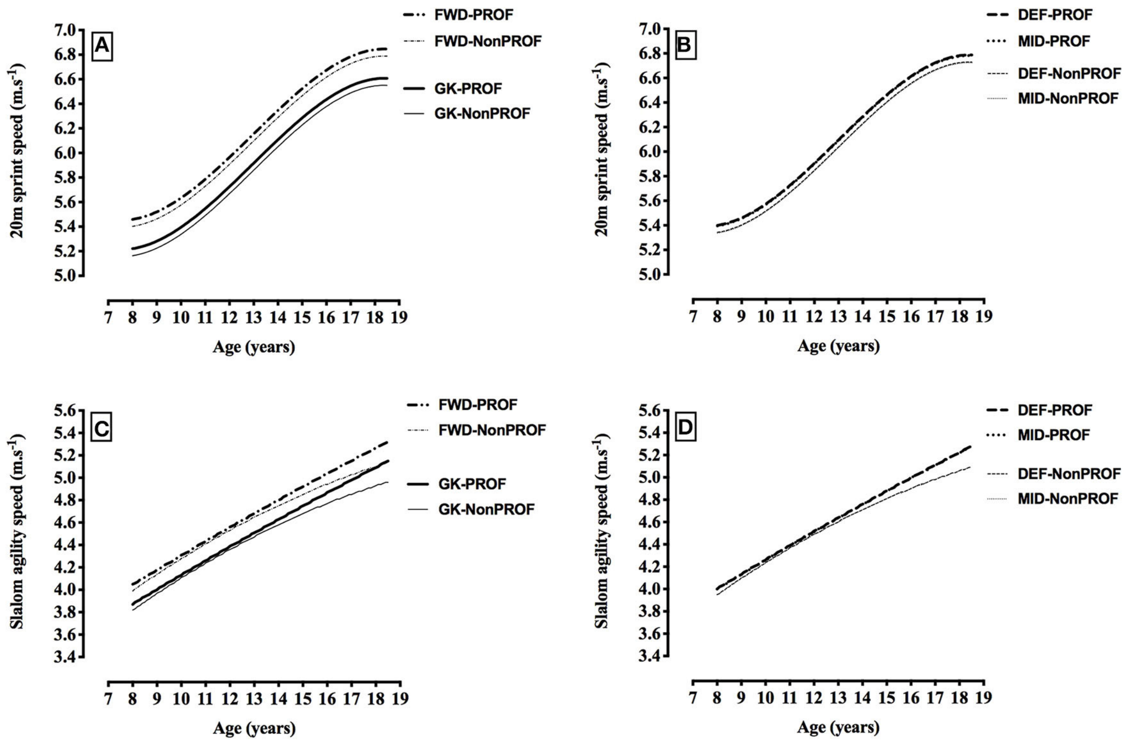

FIGURE 5 | Changes in 20-m sprint speed (m.s^{-1}) and slalom agility speed (m.s^{-1}) with age, by playing position and future playing standard [20-m sprint speed: **(A)** goalkeepers (GK) and forwards (FWD), **(B)** defenders (DEF) and midfielders (MID; slalom agility speed: **(C)** goalkeepers (GK) and forwards (FWD); **(D)** defenders (DEF) and midfielders (MID); PROF, players who made at least one professional league appearance; Non-PROF, players who DID NOT make any professional league appearances)]. Data is based on the fixed parameter estimates from the models described in **Table 3**. (Please see alternative representations of this data in the **Supplemental Material**).

Positional Differences

Throughout development, goalkeepers were 3.4–3.6 cm taller (all $p < 0.001$, $d = 0.3$–0.5) and 4.1–4.4 kg heavier (all $p < 0.001$, $d = 0.4$–0.6) than all other positions, defenders were 0.3 cm taller than midfielders ($p = 0.028$, $d < 0.2$), and forwards were 0.4 kg heavier than midfielders ($p = 0.025$, $d < 0.2$) (see **Table 3**, **Figure 4**). **Figure 4** displays the fixed effects from **Table 3** to illustrate the predicted age-related changes in stature and body mass for different playing positions. For 20-m sprint speed, goalkeepers were 0.17–0.24 m.s^{-1} slower than all other positions (all $p < 0.001$, $d = 0.5$–0.9), and forwards were 0.06–0.24 m.s^{-1} faster than all other positions (all $p < 0.001$, $d = 0.2$–0.9) (see **Table 3**, **Figure 5**). For slalom agility speed, goalkeepers were 0.13–0.17 m.s^{-1} slower than all other positions (all $p < 0.001$, $d = 0.4$–0.7), and forwards were 0.04–0.17 m.s^{-1} faster than all other positions (all $p < 0.001$, $d = 0.1$–0.7), (see **Table 3**, **Figure 5**). For vertical counter-movement jump with arm swing test performance, goalkeepers did not jump as high as all other positions by 0.72–1.70 cm ($p < 0.001$—$p = 0.026$, $d = 0.1$–0.4), and forwards jumped 0.77–1.70 cm higher than all other positions (all $p < 0.001$, $d = 0.1$–0.4) (see **Table 3**, **Figure 6**). For multistage fitness test distance, goalkeepers did not run as far as all other positions by 235–305 m (all $p < 0.001$, $d = 0.7$–1.2), and forwards did not run as far as defenders by 23 m ($p = 0.048$, $d < 0.2$) and midfielders by 50 m ($p = 0.001$, $d = 0.2$) (see **Table 3**, **Figure 6**).

DISCUSSION

This study examined if elite youth male football players aged 8–19 y from the English talent development system who ultimately achieved professional status differed in stature, body mass, and physical performance (20-m sprint speed, slalom agility speed, vertical counter-movement jump with arm swing jump height, multistage fitness test distance) compared with their non-professional peers. The study also examined the longitudinal pattern of development of stature, body mass, and physical performance, and if this was different between future professionals and non-professionals, while considering the effects of playing position. The key findings were that from 12.0 the future professionals performed better in slalom agility and vertical counter-movement jump with arm swing tests than future non-professionals, and improved at a faster rate, so that by age 18.0 the differences in slalom agility and vertical counter-movement jump with arm swing test performance were 0.14 s and 1.7 cm, respectively. In addition, future professional players were faster (by 0.02–0.04 s on the 20-m sprint) and ran further in the multistage fitness test (by 47 m) than future non-professional

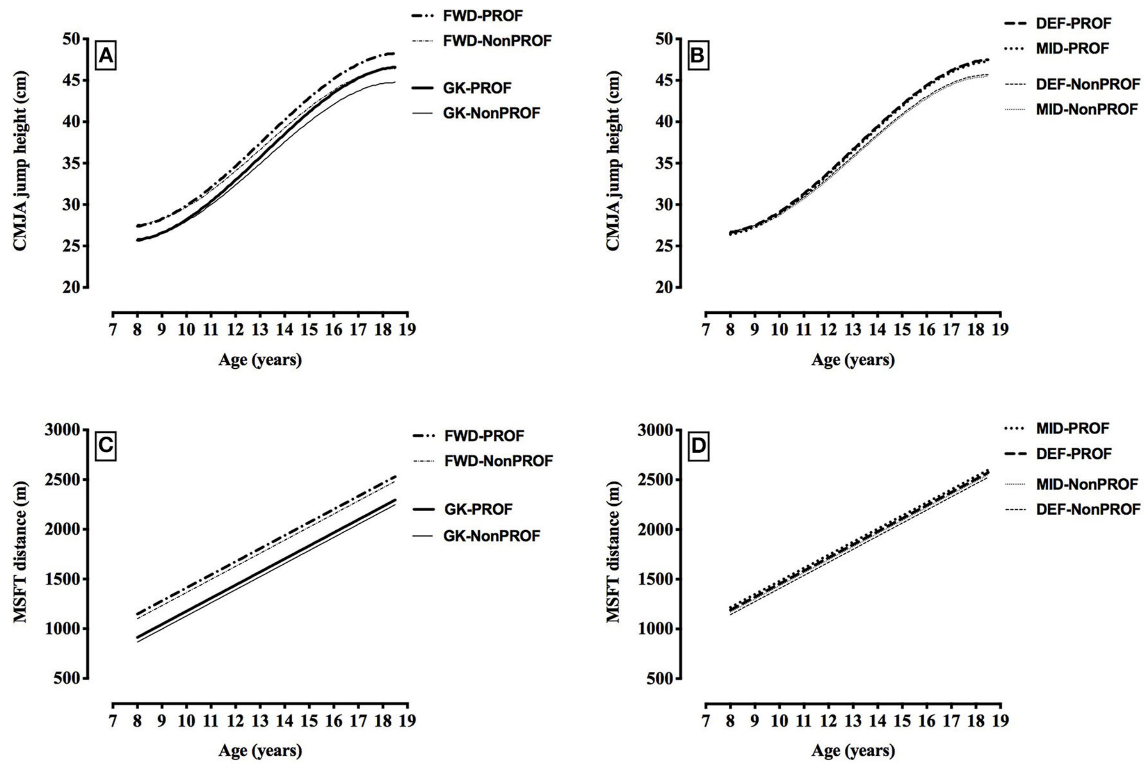

FIGURE 6 | Changes in vertical counter-movement jump with arm swing (CMJA) height (cm) and multistage fitness test (MSFT) distance (m) with age, by playing position and playing standard (vertical counter-movement jump with arm swing: **(A)** goalkeepers (GK) and forwards (FWD), **(B)** defenders (DEF) and midfielders(MID); multistage shuttle run test distance: **(C)** goalkeepers (GK) and forwards (FWD); **(D)** defenders (DEF) and midfielders(MID); PROF, players who made at least one professional league appearance; Non-PROF, players who DID NOT make any professional league appearances). Data is based on the fixed parameter estimates from the models described in **Table 3**. (Please see alternative representations of this data in the **Supplemental Material**).

players throughout their development, but there were no differences in stature or body mass during development between future professionals and future non-professionals. Furthermore, whereas multistage fitness test performance improved linearly with age, the development of all other physical characteristics was non-linear. The study also quantified the inter-individual differences in physical characteristics between all players, and also found that there were differences in physical characteristics when playing positions were compared.

The finding of physical performance differences between future professional and non-professional players during their development over the full duration of a talent identification and development programme (∼10 y) confirms and extends the findings of the other two longitudinal-prospective studies in the field. Leyhr et al. (2018) noted that among the 1,134 players they investigated, the 12.8% who became elite senior players were quicker by 0.07 s than their non-elite peers in a 19.5 m slalom agility test, in comparison with the 0.03–0.14 s faster 20.8 m slalom agility time (the variation being related to age) in the present study. For endurance performance Roescher et al. (2010) found that, although there was no difference between future professional and future non-professional players in the distance run in an interval shuttle run test between the ages of 14–16 y, at age 17–18 y professionals ran ∼220 m further than non-professionals. Similarly, the present study showed that future professionals ran 47 m more in the multistage fitness test than non-professional players. Therefore, consistent with previous research studies, the present study confirms that future professional football players perform better on slalom agility and endurance tests, compared with future non-professional players.

The present study also elaborates on these earlier findings by showing that future professionals sprinted faster and jumped higher than future non-professionals during their development. Future professionals were found to be 0.02–0.04 s quicker than non-professionals in the 20-m sprint test, and this is the first longitudinal-prospective study to show that future professionals jump higher than future non-professionals (up to 1.8 cm on the counter-movement jump with arm swing jump test, depending on age). It should be acknowledged that Leyhr et al. (2018) did not find any differences between future elite and non-elite players in 20-m sprint test performance, but they only considered U12-U15 age groups, and that cross-sectional-prospective studies have distinguished between playing standards based on jumping performance (for example, le Gall et al., 2010). Therefore, there seems good evidence from the current study to suggest that physical performance is better in future professional players during their development compared with future non-professionals, when examined over the full duration of a talent identification and development programme (∼10 y).

While physical performance may be generally better in the future professional players as they grow and age, it is potentially really important from a talent identification and development perspective to describe and understand the longitudinal pattern of development of physical performance characteristics such as 20-m sprint speed, slalom agility speed, counter-movement jump with arm swing jump height and multistage fitness test distance. The present study found a difference in the longitudinal pattern of development of slalom agility and counter-movement jump with arm swing test performance when the future professional and non-professional players were compared. The professional players' annual rate of improvement on the counter-movement jump with arm swing test was always higher than the non-professional players by 0.2 cm per year and while professionals maintained their annual rate of improvement on the slalom agility test at 0.11–0.13 $m.s^{-1}$ per year, the future non-professionals' rate of improvement gradually declined as they got older compared to future professionals. Thus, from 12.0 y and older the differences between future professional and non-professional players widened (see **Figures 5C,D**, **6A,B**), so that by age 18.0 the difference on the slalom agility test was 0.14 s and the difference on the CMJA test was 1.7 cm, representing meaningful effects of small and moderate, respectively. In contrast, although Leyhr et al. (2018) also found that future elite players performed better on a slalom agility test than future non-elite players and that the pattern of development was non-linear, the pattern of development between their groups was not different (i.e., was parallel). Possible reasons for the apparent discrepancies in findings between this study and the present one may be due to the difference in the length of development period examined, variations in testing protocols or cultural differences in training across countries, and in different academies. In only one other longitudinal-prospective study has a difference in pattern of development been observed between future professional and non-professional players and this was for an intermittent endurance test, and this study was potentially limited by a small sample size (Roescher et al., 2010). Improvement on the 20-m sprint test in the present study was non-linear, and future professionals were consistently 0.057 $m.s^{-1}$ faster than non-professionals, but the groups displayed parallel patterns of development as they aged. Leyhr et al. (2018) also found that development of 20-m sprint test performance was non-linear, however, unlike the current study they found no differences between future elite and non-elite players during development. The present study found that improvements in multistage fitness test performance were linear, and that future professionals consistently ran 47 m further than non-professional players, with the groups displaying parallel patterns of development throughout age. Therefore, based on findings from the current study, the longitudinal pattern of development of slalom agility and counter-movement jump with arm swing test performance is different in future professional players compared with future non-professionals, when examined over the full duration of a talent identification and development programme (∼10 y). For 20-m sprint speed and multistage fitness test distance the longitudinal patterns of development for the future professional and non-professionals groups were parallel throughout age. Also, while multistage fitness test performance improved linearly with age, the development of all other physical characteristics was non-linear.

It is unclear why for the counter-movement jump with arm swing and slalom agility tests the future professional players showed accelerated improvements in performance compared to non-professionals, yet for multistage fitness and 20-m sprint tests although future professionals were better than non-professionals throughout development the difference between the groups remained consistent (and parallel) and an accelerated development in sprint and endurance performance in the future professionals was not observed. Factors such as later physical maturation of future professional players, fewer injuries in these players or a better attitude to training, and performance improvement could play a role. Another possible explanation is that the slalom agility and vertical counter-movement jump with arm swing tests require better neuro-muscular or coordinative abilities, compared to slightly "simpler" tests such as the 20-m sprint and the multistage shuttle test (Sheppard and Young, 2006; Deprez et al., 2015b), and/or that the slalom agility and jumping tasks are more reflective of the complex movement patterns required during match-play. The implications for talent identification and development are that while all future professional players need to be fast, agile, good vertical jumpers, and endurance fit from an early age, perhaps slalom agility, and vertical jumping offer enhanced opportunities for accelerated development and so are particularly important because as they age future professionals may increasingly be required, and be able, to produce complex movement patterns that closely reflect motor patterns in football. Such accelerated improvements may allow them to gain advantages during training and match-play as they age, which in turn may help enhance the likelihood of their retention and progression and ultimate development into successful adult players.

Previous studies have longitudinally examined the development of anthropometric characteristics such as stature and body mass in elite youth football players (Mirkov et al., 2010; Fransen et al., 2017), and others have prospectively tracked elite youth football players into adulthood to examine the relationship between anthropometric characteristics and senior playing standard (le Gall et al., 2010; Carling et al., 2012; Deprez et al., 2015; Emmonds et al., 2016). However, the present investigation is the first longitudinal and prospective study to simultaneously examine the development of stature and body mass and its relationship with senior playing standard. No differences were found in the present study in the stature and body mass of the future professional and non-professional players, or in the longitudinal pattern of development of these characteristics between the groups, suggesting these are not key distinguishing factors in the development of future professional players within English academies. This is consistent with previous work which followed 443 English academy football players aged U12-U18 into adulthood and showed no differences in stature and body mass between players who turned, vs. those who did not turn, professional, from any of the age groups examined (Emmonds et al., 2016). Interestingly, in a study more relevant to junior rather than senior accomplishments, with a much shorter prognostic period (1 y), players ($n = 353$), from across several age groups (U9-U21), retained by an English academy at the end of the season were generally taller and heavier than those released (Patel et al., 2020). Thus, it is possible that in England, in the short-term, stature, and body mass might perhaps influence who is released or retained in an academy, and perhaps encourage the development of a playing population which is selected on this basis. However, the findings from the present study suggest that, over the longer-term, these anthropometric characteristics do not influence who achieves professional playing status at a senior level. Also, the random effects outputs from the modeling undertaken in this study suggest there is considerable inter-individual variation in stature and body mass among all the players studied, and this adds support to the conclusion that stature and body mass are not key influences on attainment of professional playing status.

Many papers exclude goalkeepers, partly because they are seen to be a very different positional group from all other outfield players and also because often in any sample there are relatively few goalkeepers (White et al., 2018). Given the sample size in the current study, it was possible to examine differences between positional groups including goalkeepers. Throughout their development the goalkeepers were taller and heavier than all other positional groups and their performance was poorer in all four of the field-based tests (at age 13.0 the models predict the goalkeepers were 3.4–3.6 cm taller, 4.1–4.4 kg heavier, 0.17–0.24 $m.s^{-1}$ slower in the 20-m sprint test, 0.13–0.17 $m.s^{-1}$ slower in the slalom agility test, jumped 0.9–1.6 cm less in the vertical counter-movement jump with arm swing test, and ran 235–305 m less in the multistage fitness test). Therefore, these findings confirm that, compared to other positional categories, goalkeepers are anthropometrically larger and have inferior performance, although it should be recognized that the tests used in the current study are more orientated toward outfield player performance (White et al., 2018). Interestingly, forwards were faster than all other positions in the 20-m sprint and slalom agility tests (at age 13.0 by 0.06–0.24 $m.s^{-1}$ and 0.04–0.17 $m.s^{-1}$, respectively) and they also jumped higher than all other positions (at age 13.0 by 0.8–1.7 cm). While some other differences did exist between the outfield playing positions, generally outfield players were much more similar to each other than they were to goalkeepers, which is in-line with previous cross-sectional analyses in elite youth football players (Deprez et al., 2015a). However, regardless of any differences that might be evident between positional groups, within players in a particular position the professional players outperformed their non-professional peers.

The observation that those players who achieved professional status had better performance (and by implication better physical capabilities) than their non-professional peers in speed, slalom agility, vertical jumping and endurance tasks, and also had different longitudinal patterns of development for slalom agility and vertical counter-movement jump with arm swing test performance, emphasizes the importance of performance testing and underlines its utility in the talent identification and development process. Despite the clearly better performance in the future professional players viewed retrospectively, a typical scenario faced by practitioners from a talent identification and development perspective is the necessity to make judgements about a player's capabilities in the period when the measurements are being made. It is an interesting question how useful the tests examined in the current study are for that purpose, especially given the time, effort and resources expended, and the (perhaps) inherent assumption that talent identification and development is the primary reason for such data collections, and the directives contained in documents such as the EPPP. These types of debate have been had previously (Mendez-Villanueva and Buchheit, 2013). Because the current study allows the variation in physical performance across individuals to be quantified, it shows that the differences in physical performance between the non-professional and professional groups is smaller than the inter-individual variation across all the players (the difference in performance across the four field-based tests between the non-professional and professional playing groups represents 6–7% of the inter-individual variation in 20-m sprint and multistage fitness test performance in all players, and up to 11 and 21% (at age 18.0) for the vertical counter-movement jump with arm swing test and slalom agility test, respectively). Consequently, at the time of measurement it could be argued that it is unlikely that performance on field-based tests will allow an individual future professional player to be distinguished and therefore perhaps the time, effort and resources involved in such performance field testing has some limits, certainly from a talent identification and development perspective. This observation also highlights perhaps the dangers of using one-off measurements of physical performance as a basis for early (de)selection of players (Vaeyens et al., 2008). But the present study clearly demonstrates that the professional players were better physical performers when the non-professional and professional groups were compared. Indeed, the magnitude of some the differences between the groups (based on effect size) was moderate ($d = 0.5$ at 18.0 y for slalom agility) and certainly at older ages large enough to be measurable. Also, it could be argued that even small magnitude differences in performance ($d = 0.2$ at 13.0 and 18.0 y for 20-m sprint speed) could be crucial at the elite level.

Furthermore, time spent conducting field-based tests ensures performance development is monitored, and maintained and perhaps even improved. It allows the identification of strengths and weaknesses in individuals and the effectiveness of training programmes to be accurately evaluated (Svensson and Drust, 2005). Also, such testing has value in evaluating a player recovering from injury. Thus, an ongoing programme of physical field "testing" helps provide players with the most appropriate learning environment to realize their potential. That is why, even if one thinks the physical tests examined in this study may have some limits in a practical context when trying to distinguish between future professional and non-professional players at the time of measurement, it is likely that time spent longitudinally monitoring and testing physical performance is worthwhile within elite talent development programmes in football. The current analysis allows practitioners to assess their players' longitudinal development of physical characteristics across exact chronological age in relation to academy players of varying positions who eventually turned professional, while also being able to consider the normal range of performance at each age and the normal range of rate of development, for each physical characteristic. Thus, the present findings could be used to support a long-term field-based testing programme for the identification of potential strengths and weaknesses in individuals across time, and for evaluating the effectiveness of individualized training plans.

The present study supports the notion that the development of physical characteristics (such as speed, agility, vertical jumping, and endurance), is dynamic, variable, and non-linear (Simonton, 1999; Abbott et al., 2005), and that talent identification and development should be viewed as a long-term process (Sarmento et al., 2018). Consequently, the study's findings encourage understanding the general patterns of development of stature, body mass, speed, agility, vertical jumping, and endurance in growing football players, as well-understanding the "normal" deviations from these general patterns, allowing a more individualized approach to supporting players' physical development, and taking a more long-term approach toward developing speed, agility, vertical jumping, and endurance in players.

Although this study is the first to follow the physical development of a large sample of young male football players from the English talent development system through to professional status, there are some potential limitations with the analysis that is presented here. During adolescence in particular, the variation in the speed of progression toward the adult state means that chronological age may not be a particularly good indicator of maturational status. In males, most of the changes associated with the adolescent growth spurt (such as increases in muscle mass and strength) are likely to have positive effects on performance (Philippaerts et al., 2006). Hence, variation in maturational status between the players investigated in the study that is not accounted for by chronological age could have influenced the results presented here. Given that the players were drawn from 16 different academies it is likely that the training and match environments to which they were exposed will have varied (in terms of type, intensity, duration), and obviously this variation could have influenced the findings of the present study. Furthermore, as seniors, this sample of players made appearances across 65 professional leagues across the world. While this may offer a more inclusive and comprehensive view of professional success compared to previous studies which have tended to judge future success based on appearances in just one country [e.g., Leyhr et al. (2018) considered appearances in German leagues only], it is likely there was considerable variation in the characteristics and standard of play in the 65 leagues considered, and this could have influenced the current results. While beyond the scope of the current study, future research may examine the development of academy footballers in relation to success in particular leagues and countries. Finally, this paper concerns itself only with anthropometric and physical performance characteristics. These are important, but clearly there are a number of other factors which contribute to the development of, and the successful progression of the academy football player to professional status (such as technical ability and game sense, psychological skills, family background), and the influence of these was not considered in this study (Huijgen et al., 2014).

CONCLUSION

In summary, of the 2,875 players examined in the current study, which covered the full 10 year duration of a football talent development programme in England, 23% went on to play at least one professional game, and while these players were not taller or heavier than their non-professional peers, from 12 y the future professionals produced better slalom agility and vertical counter-movement jump with arm swing test performance than future non-professionals, and the longitudinal pattern of development of these characteristics improved at a faster rate in the future professional players. Future professional players were also faster over 20-m and ran further in the multistage fitness test than future non-professional players throughout development. Whereas, multistage fitness test performance improved linearly with age, the development of all other physical characteristics was non-linear. There were inter-individual differences in the development of all characteristics, and there were differences between playing positions in the development of all characteristics. Thus, in summary, future professional players are more agile, better vertical jumpers, faster and more endurance fit than future non-professional players as they age, and the pattern of development is different in professional players and non-professional players for slalom agility and vertical jumping performance.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because, although the names of participants were removed before data were analyzed, the data itself contains information that could be identifiable given the availability of publicly available information (e.g., squad members, staff members, dates), the year of the season, and the identification of the clubs involved (by deducing from the author affiliations). Furthermore, participants agreed to have their data used in the current study, but not to have their data shared with external parties, which presents an ethical challenge. Requests to access the datasets should be directed to Chris Saward, chris.saward@ntu.ac.uk.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Ethical Advisory Committee for Research Involving Human Participants, Loughborough University and the Human Invasive Ethical Review Committee, College of Science and Technology, Nottingham Trent University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MN, CSu, JM, MH, HG, and CSa contributed to the conception and design of the study. CSa, MH, JM, and HG performed the data collection. CSa and JM performed the data analysis. CSa, JM, and MN wrote the first draft of the paper. All authors contributed to manuscript revision and read and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2020.578203/full#supplementary-material

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Interim Performance Progression (IPP) During Consecutive Season Best Performances of Talented Swimmers

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Objective: The main goal of the present study was to investigate the interim performance progression (IPP) of talented swimmers. Part of this group ultimately made it to the top (referred to as elite swimmers) whereas others did not make it to the top (referred to as high-competitive swimmers). Rather than investigating performance progression based solely on season best performances, we included the first swim performance of the season in the metrics of IPP. Knowledge about the IPP of talented swimmers from and toward their season best performances relative to the first swim performance of the season will enhance our understanding of changes in season best performances during the talent trajectory and provide valuable insights for talent development and selection processes in competitive swimming.

Methods: Fifteen thousand nine hundred and forty four swim performances (first swim performances of the season and season best performances) between 1993 and 2019 of 3,199 talented swimmers (of whom 556 reached elite level and 2,643 reached high-competitive level) were collected from Swimrankings and related to the prevailing world record of the corresponding sex. The pattern of IPP was represented by two phases: phase A and phase B. Phase A reflected the performance progression between the previous season best performance and the first swim performance of the current season (PP_A) and phase B reflected the performance progression between the first swim performance of the current season and the season best performance of the current season (PP_B). Depending on the normality check, we used independent sample *t*-tests or Mann Whitney tests to establish significant differences in PP_A and PP_B between elite and high competitive swimmers per age category per sex ($p < 0.05$).

Results: Without denying individual differences, male elite swimmers improved more during phase B from age 15 till 24 compared to high-competitive swimmers (20.5% vs. 13.1%, respectively, $p < 0.05$). Female elite swimmers improved more during phase B from age 13 till 23 compared to high-competitive swimmers (21.1% vs. 14.6%, respectively, $p < 0.05$). Except for age 14 in males, there were no significant differences between performance groups in PP_A.

Conclusion: Talented swimmers who ultimately made it to the top (elite swimmers) are characterized with different patterns of IPP compared to talented swimmers who did not make it to the top (high-competitive swimmers). After puberty, elite and high-competitive swimmers performed in general ∼1% slower at the start of their season compared to their previous season best performance (PP_A). However, elite swimmers improved more in the period between their first swim performance of the season and their season best performance (PP_B) from age 13 (females) and age 15 (males) onwards.

Keywords: swimming, acquisition of expertise, talent development, performance progression analysis, elite athletes

INTRODUCTION

For coaches and stakeholders in competitive swimming, season best performances and national rankings are the main information source for talent identification and selection processes (KNZB, 2018). Based on this information and their perception about how that information relates to future performance, they have to make decisions about whether or not a swimmer is selected for a talent development program (Schorer et al., 2017). However, several researchers are questioning this one-sided approach in which performance at early stages of development (e.g., age 12 onwards in competitive swimming; KNZB, 2018) is used as an indicator of future performance (Abbott et al., 2005; Vaeyens et al., 2009; Elferink-Gemser et al., 2011). They advocate that there are multiple pathways to reach expertise and that there is a risk to erroneously overlook athletes as being talented by focusing on current performance only (Vaeyens et al., 2008; Gulbin et al., 2013; Till et al., 2016).

In order to provide scientific-based knowledge about the value of early age performance in competitive swimming, Post et al. (2020) tracked down the junior-to-senior performance development of top-elite swimmers at the 100 m freestyle event. This research was based on the analysis of season best performances and provided support for both perspectives. The findings showed that (1) compared to each other, top-elite swimmers follow unique individual developmental pathways toward expertise and (2) compared to other performance groups, top-elite swimmers in general progressively outperform their elite, sub-elite and high-competitive swimmers of similar age from 12 years onwards.

In addition to examining group averages as in the research of Post et al. (2020), upper and lower limits of swimmers who have made it to the top can provide relevant insights as well. Stoter et al. (2019) used the upper limits of elite speed skating performance (slowest performance per age and per sex for those who later reached the elite level in this sport) to define performance benchmarks for future speed skaters. The results showed that the majority of talented male and female speed skaters who performed within the performance benchmarks at a younger age, did not make it to the top. These findings combined with previous results of Post et al. (2020) inspire to continue the investigation of youth performance. What characterizes the performance development of those who are considered as talented swimmers (e.g., perform within performance benchmarks) and do reach the top compared to their talented counter peers who do not reach the top?

Probably, the answer to this question may not be hidden in solely tracking season best performances. Although monitoring and modeling season best performances highly contributed to a deeper understanding of performance development to the swimming top (Stewart and Hopkins, 2000; Costa et al., 2011; Allen et al., 2014; König et al., 2014; Post et al., 2020; Yustrus et al., 2020), it would be interesting to include additional swim performances in mapping performance progression of talented swimmers. As such, scientific-based data about (1) the progression between a swimmer's previous season best performance and his first swim performances of the season and (2) the progression between a swimmer's first swim performance of the season and his current season best performance could provide meaningful information about the interim performance progression (IPP) during two consecutive season best performances.

Knowledge about IPP during consecutive season best performances of talented swimmers would enhance our understanding of changes in season best performances during the talent trajectory. In particular, this is the case when IPP is investigated from a retrospective perspective in which talented swimmers who made it to the top (elite swimmers) are compared to their talented counter peers who in the end did not make it to the top (high-competitive swimmers). In here, a longitudinal approach is necessary as the road to the top is long and often combined with large inter-individual differences between swimmers due to processes of growth and maturation (Kannekens et al., 2011; Malina et al., 2015; Elferink-Gemser et al., 2018). This would provide valuable and additional insights about the general and individual performance patterns of swimmers on their way to the top, which can be used to optimize talent development programs. As such, federations, coaches and swimmers would benefit from a more detailed guideline toward elite swimming performances and be able to set and monitor realistic and data-driven goals about the development of swim performances during a swimming season. Moreover, IPP may be an additional variable to select and monitor swimmers who have the potential to make it to the top.

However, to the best of our knowledge, a longitudinal, retrospective analysis of IPP of talented swimmers with the potential to make it to the elite level has not been conducted yet. Therefore, the main goal of this study was to longitudinally and retrospectively investigate the IPP during consecutive season best performances of talented swimmers. Part of this group ultimately made it to the top (referred to as elite swimmers) whereas others did not make it to the top (referred to as high-competitive swimmers). Given the fact that at some point during their career, elite swimmers outperformed their peers, we hypothesize that elite swimmers have higher IPP compared to swimmers who did not reach elite level (high-competitive swimmers).

MATERIALS AND METHODS

Ethical Approval

All procedures used in the study were approved by the Local Ethical Committee of the University Medical Center Groningen, University of Groningen, The Netherlands (201900334) in the spirit of the Helsinki Declaration with a waiver of the requirement for informed consent of the participants given the fact that the study involved the analysis of publicly available data.

Data Collection

The swimmers we selected for this study were international male and female swimmers with performance data on the 100 m freestyle long course event. We chose this event because it is considered as the key distance in competitive swimming. It has been on the Olympic program since 1904 (men) and 1912 (women) and is characterized with the largest number of world-wide participants. Moreover, competition starts from an early age on and the word-wide competition level is high for both male and female swimmers (FINA, 2019; Swimrankings, 2019).

Performance data (in terms of swim times) was obtained from Swimrankings (2019), a recognized public data source which records international swimming race results. Performance data were collected from 88 countries across different parts of the world including Africa, America, Asia, Australia and Europe. We collected all available 100 m freestyle long course results from Swimrankings' database, which initially resulted in 2,864,4481 observations between 1993 and 2019.

Data Processing

For the purpose of the present study, we transformed the structure of the dataset. Starting with individual competition observations (each observation e.g., swim performance stored into a unique row), we restructured the dataset in individual season observations (two observations e.g., swim performances stored in one row). The two observations we stored in one row were the first swim performance of the swimming season and the best swim performance of the swimming season. All other performance data within the season were discarded from further analysis.

Performance data from the 1st of January 2008 till the 1st of January 2010 were excluded from analysis (we exclude full-body polyurethane swimsuits; Toussaint et al., 2002; Tiozzo et al., 2009; Tomikawa and Nomura, 2009). Swim performances over 180 s were excluded from analysis to ensure a representative dataset. Based on swim dates, performance data were classified in swimming seasons. Each swimming season officially starts on the 1st of September of a calendar year and ends on the 31st of August of the next calendar year (FINA, 2019). Swimmers were classified in age categories based on their age on the 31st of December of the swimming season (KNZB, 2018). Therefore, all ages mentioned in the present study refer to the age category in which a swimmer participated during the swimming season and not the calendar age of the swimmer.

Defining Swim Performance and Performance Groups

The present study includes swim performances of multiple generations, necessitating the correction of evolution in a given sport (Stoter et al., 2019; Post et al., 2020). The method we used to correct for the evolution in competitive swimming was introduced by Stoter et al. (2019) in the sport of speed skating and later successfully used by Post et al. (2020) in the sport of competitive swimming. Swim performances were related to the prevailing world record (WR) or the fastest time in textile swimsuit of the corresponding sex. The prevailing WR is the official WR at the date the swimmer performed the swim time. WRs from 2008 or 2009 were replaced by the prevailing fastest time in textile swimsuit. The corrected swim time will be referred to as relative Swim Time (rST) and is presented as a percentage of the prevailing world record or fastest time in textile swimsuit. In this study, rST defines swim performance (see Equation 1).

$$\text{relative swim time (rST)} = \left(\frac{\text{swim time}}{\text{world record}}\right) * 100\% \quad (1)$$

Two performance levels were defined: elite and high-competitive. Each performance level was characterized by sex-specific limits to account for differences in competition level between males and females (elite males: best rST $\leq$ 103.9%; elite females: best rST $\leq$ 105.8%; high-competitive males: 103.9% $<$ best rST $\leq$ 114.0%; high-competitve females: 105.8% $<$ best rST $\leq$ 115.1%). The limits were calculated as the mean of 5 season best rST's for the 50th swimmer from either the 100 m freestyle performance FINA World Ranking Lists of 2015-2019 (FINA, 2019) or the 100 m freestyle performance National Ranking Lists of the Netherlands 2015–2019 (Swimrankings, 2019). The limits of the elite performance level were equal to the average of the season best rST's of the 50th male and female swimmer of the FINA World Ranking List 2015-2019. The limits of the high-competitive level were defined so that they represented the 50th male and female swimmer of the National Ranking List of the Netherlands.

We determined each swimmer's best performance group by allocating the best rST ever to one of the two performance levels, meaning that a swimmer either once or multiple times has reached this performance level at any age. For example, if a male swimmer has a best rST of 109.0%, his best performance level corresponds with the limits of the high-competitive performance group. Swimmers with a best rST ever outside the limits of the high competitive level (best rST >114.0% for males and best rST > 115.1% for females) were excluded from further analysis.

Inclusion Criteria

We included talented swimmers of which some swimmers ultimately made it to the top (elite swimmers) and others did not (high-competitive swimmers). The inclusion criteria were: (1) swimmers who had at least one swim performance in the age category of 22 years or older (males) or 20 years or older (females). Based on research of Allen et al. (2014) we suggest that this is in general the expected minimum age for swimmers to achieve their career best performances. To ensure a dataset representing the developmental pathway toward peak performance, we solely included (2) swim performances up to and including the swimmer's career best swim performance. Furthermore, we selected only those swimmers who (3) where between the 12 and 24 years old; (4) had performance data of at least two consecutive swimming seasons (5) had two observations within a swimming season and (6) had season best rST's within the performance benchmarks.

The performance benchmarks were taken as indicator for future performances toward elite level swimming. Therefore, swimmers performing within these performance benchmarks were in the present study considered as talented swimmers. The performance benchmarks were based on previous research of Post et al. (2020) and reflect the maximal season best rST for elite swimmers per age and per sex (see **Supplementary Table 1**). Performance benchmarks were set to be monotone, meaning that with every successive maximal season best rST lower than the previous, the benchmark will decrease toward the value of this season best rST, but with every successive maximal season best rST higher than the previous, the benchmark will remain at the same value.

Table 1 represents the male/female distribution and the number of observations (i.e., total rSTs) for each performance group included for analysis, with an average of 3.6 ± 2.0 observations per swimmer.

Defining Interim Performance Progression (IPP)

The concept of interim performance progression (IPP) is explained as the pattern of performance progression during two consecutive seasons relative to a common reference point. Therefore, the pattern of IPP is described by two phases: phase A and phase B.

Phase A is presented as the period between the previous season best rsT and the first swim performance of the current season (first rST). Phase B is presented as the period between the first rST and the current season best rST. So, the first rST is the common reference point in phase A and phase B (see **Figure 1**). The first rST can be worse, the same or better than the previous season rST. In **Figure 1**, it is shown as worse. The current season best rST can be the same or better than the first rST. In **Figure 1**, it is shown as better. Ultimately, the current season best rST can be the worse, the same or better than the previous season best rST. In **Figure 1**, it is shown as better.

The performance progression during phase A (PP_A) is defined as the percentage of the first rST relative to the previous season best rST (see Equation 2). This measure is constructed to reflect the start level of a swimmer relative to his best swim performance of the previous season. An outcome below the 100% means that the swimmer was faster than his previous season best rST (improved) and an outcome above the 100% means that the swimmer was slower than his previous season best rST (deteriorated). An outcome of 100% means that the swimmer is at the exact same level as his previous season best rST (stabilized).

$$PP_A = \left(\frac{\text{first rST}}{\text{previous season best rST}}\right) * 100\% \qquad (2)$$

The performance progression during phase B (PP_B) is defined as the percentage change a swimmer has moved toward the prevailing world record (see Equation 3). In other words, PP_B is relative to the gap a swimmer needs to close in order to break the prevailing world record or fastest time in textile swimsuit. PP_B reflects the difference between the best rST of the current season (current season best rST) and the first rST divided by the difference between the first rST and the prevailing world record or fastest time in textile swimsuit (see Equation 3).

A positive outcome indicated that a swimmer has moved toward the prevailing world record or fastest time in textile swimsuit and improved relative to his first rST. An outcome of 0% indicated that the swimmer's gap to the prevailing world record or fastest time in textile swimsuit stayed the same and that the swimmer did not improve relative to his first rST.

$$PP_B = -\left(\frac{\text{current season best rST} - \text{first rST}}{\text{first rST} - 100}\right) * 100\% \qquad (3)$$

As an example, we illustrate the pattern of IPP of a fictive swimmer with a season best rST of 106.5 in the previous season (2016/2017), a first rST of 107.6% in the current season (2017/2018) and a season best rST of 106.0% in the current season (2017/2018). His PP_A will be [107.6 (first rST)/106.5 (previous season best rST)*100%. In short his PP_A is (107.6/106.5)* 100% = 101.0%. An outcome above the 100% means that the swimmer's SL is slower than his best rST of the previous season. His PP_B will be—[106.0 (current season best rST)−107.6 (first rST)]/107.6

TABLE 1 | Total number of swimmers ($N = 3{,}199$) and observations ($N = 8{,}005$) for each performance group specified by sex for the analysis on interim performance progression (IPP).

	Males		Females	
Performance level	**Individuals**	**Observations**	**Individuals**	**Observations**
Elite	196	638	360	1,062
High-competitive	1,279	3,085	1,364	3,220

elite males: best rST ≤ 103.9%; elite females: best rST ≤ 105.8%; high-competitive males: 103.9% < best rST ≤ 114.0%; high-competitve females: 105.8% < best rST ≤ 115.1%.

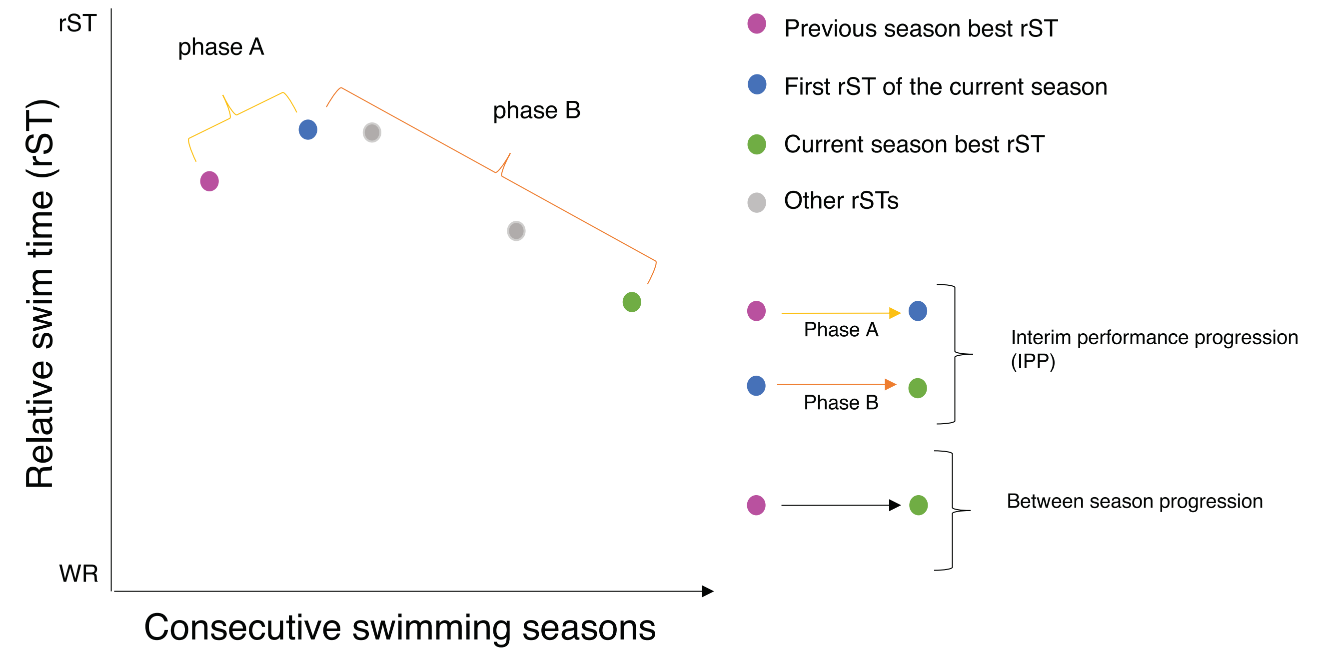

FIGURE 1 | The concept of interim performance progression (IPP).

(first rST)−100%. In short his PP_B is—(−1.6)/7.6 *100 = 21%. A positive outcome indicates the swimmer moved toward the prevailing world record or fastest time in textile swimsuit and that he improved his swim performance between the start of the current season and the moment he swum his best rST of the current season. The pattern of IPP of this fictive swimmer is characterized by a small decrease in phase A (1% above his previous attained performance level), followed by an increase during phase B.

Statistical Analysis

All data were analyzed for male and female swimmers separately using IBM SPSS Statistics 24 and R (R Core Team, 2019) (R version 3.6.0). Mean scores and standard deviations were calculated for swim performance (previous season best rST, first rST and current season best rST), performance progression in phase A (PP_A) and performance progression in phase B (PP_B) for the two performance groups per age category (see **Supplementary Tables 2**, **3**). The normality of the distributions was assumed for $n > 30$, according to the central limit theorem (Field, 1993). For $n < 30$, distributions were visually inspected by histograms and Q-Q plots. Per age category, an independent-samples *t*-test (normality assumed) or Mann-Whitney test (normality violated) was conducted to compare PP_A en PP_B between elite and high-competitive swimmers. To interpret the scores, effect sizes (r of *d*, depending on normality) were calculated. An effect size of ∼0.20 (*d*) or 0.10 (r) was considered small, 0.50 (*d*) or 0.30 (r) moderate and 0.80 (*d*) or 0.50 (r) large (Cohen, 1969). Statistical tests were executed for the age categories in which there were more than six observations in the elite performance group. For all tests, $p < 0.05$ was set as significance.

RESULTS

Figures 2, **3** illustrate the performance progression in phase A (PP_A) and phase B (PP_B), respectively, of talented male and female swimmers on the 100 m freestyle from age 14 to 24 (males) and 12 to 22 (females). Within each age category, all swimmers performed within the corresponding performance benchmarks, however part of them reached the top (elite swimmers) and part of them did not reach the top (high-competitive swimmers). The average period of PP_A was 252 ± 87 days and the average period of PP_B was 102 ± 76 days.

Except for age 14 in males, Mann-Whitney tests and independent sample *t*-tests showed no significant differences between elite and high-competitive swimmers in PP_A.

For males, we found significant differences in PP_B between elite and high-competitive swimmers from age 15 till 24 ($p < 0.05$). From age 15 onwards, male elite swimmers improved on average more in their swim performance than male high-competitive swimmers in the period between their first swim performance of the current season and their current season best performance.

For females, we found significant differences in PP_B between elite and high-competitive swimmers from age 13 till 22 ($p < 0.05$). From age 13 onwards, female elite swimmers improved on average more in their swim performance than female high-competitive swimmers in the period between their first swim performance of the current season and their current season

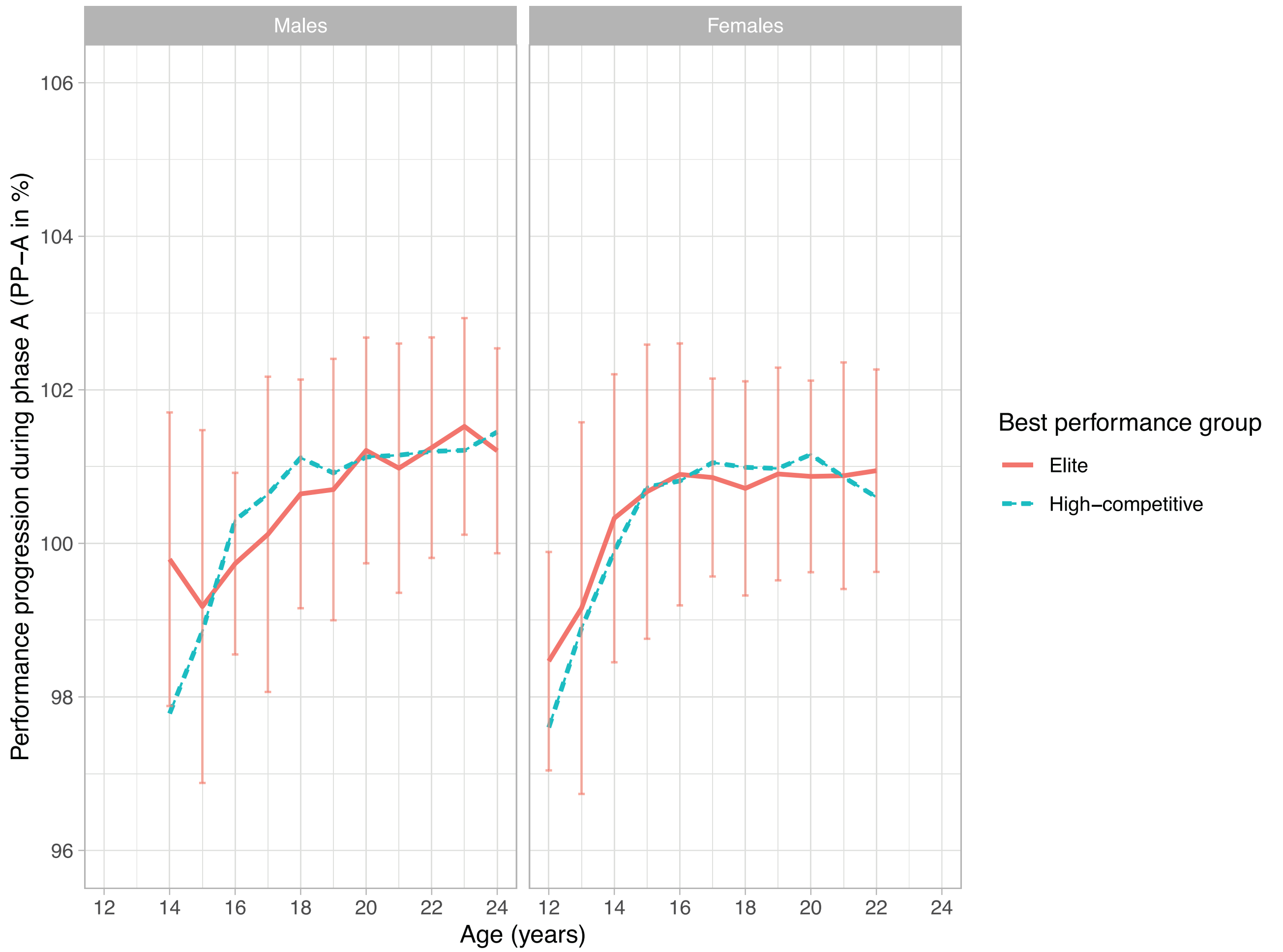

FIGURE 2 | Performance progression in phase A (mean PP_A) of male and female elite and high-competitive swimmers. Scores above the 100% indicate that the first rST is slower compared to the previous season best rST. For the purpose of this study, SDs are only shown for elite swimmers.

best performance. Corresponding test statistics are reported in **Supplementary Tables 4**, **5** (males and females, respectively).

DISCUSSION

The present study investigated the in interim performance progression (IPP) during consecutive season best performances of talented swimmers. Part of this group ultimately made it to the top (referred to as elite swimmers) whereas others did not make it to the top (referred to as high-competitive swimmers). The main findings of this study showed that without denying individual differences (1) elite swimmers improved more in swim performance than high-competitive swimmers during phase B (the period between the first rST and the current season best rST) and that (2) there were no differences between elite and high-competitive swimmers in performance progression between the previous season best performance and the first swim performance of the current season (PP_A) (except for age 14 in males).

Considering these outcomes, it is important to notice that the results of the present study are inextricably linked to how we defined the metrics of IPP: PP_A and PP_B. As it is well-known that at some point during a swimmers' career, the rate of performance progression begins to reduce (known as the principle of diminishing returns to training; Hoffman, 2014), we found it highly important to include metrics of IPP that enabled the interpretation of performance progression of swimmers relative to their previous performance level (PP_A) and relative to the elite performance level (PP_B). By relating performance progression to the gap a swimmer needs to close in order to break the prevailing world record or fastest time in textile swimsuit, PP_B accounted for the principle of diminishing returns and related performance progression to the (prevailing) fastest male or female swimmer of the world. Together, this makes that PP_B can be compared between swimmers of different performance levels and generations and simultaneously can function as measure to point out how much a swimmer moved forward to the prevailing world record or fastest time in textile swimsuit. In here, the

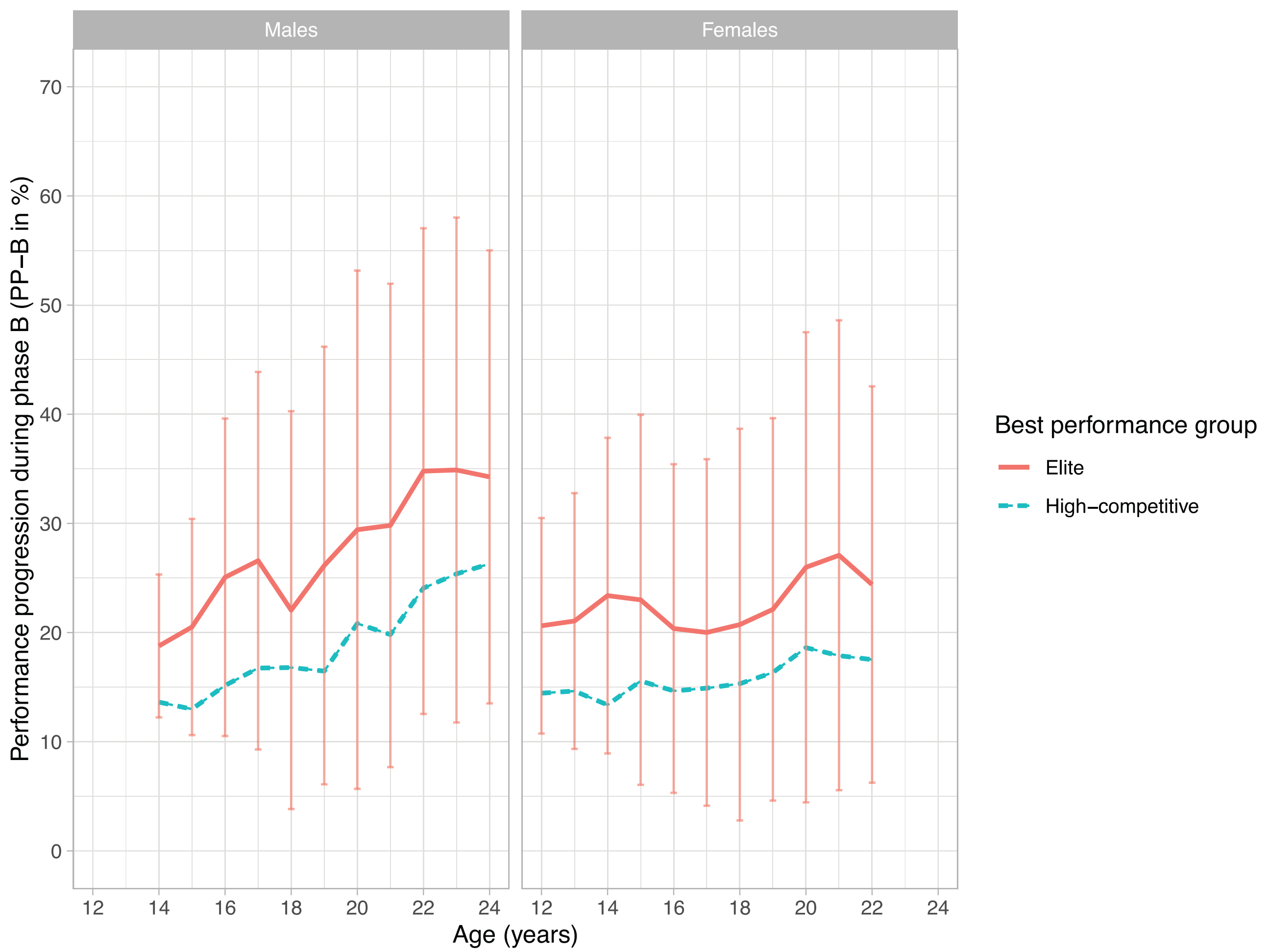

FIGURE 3 | Performance progression in phase B (mean PP_B) of male (right) and female (left) elite and high-competitive swimmers on the 100 m freestyle from age 12 to 24. Higher scores indicate higher progression. For the purpose of this study, SDs are only shown for elite swimmers.

present study aimed to make a more "fair" comparison between and within swimmers in a multigenerational and longitudinal dataset. To the best of our knowledge, the perspective on IPP and the related metrics of IPP have not been described in swimming literature yet.

Since IPP is explained as the pattern of performance progression during two consecutive seasons relative to a common reference point (first rST), the present study contributed to additional insights about the course of performance progression of talented swimmers. Descriptive statistics show that during puberty, talented male and female swimmers progress in the period between the previous season rST and the first rST (PP_A) and in the period between the first rST and the current season best rST (PP_B). In other words: they progressed in both phase A and phase B. However, post-puberty, progression during two consecutive season best performances generally took place in phase B rather than phase A. The latter suggests that coaches and swimmers should not get too discouraged if the first swim performance of the current season is ∼1% slower compared to the previous season best performance.

As elite swimmers and high-competitive swimmers did not significantly differ in the performance progression in phase A (except for age 14 in males), we suggest that differences in PP_B between elite and high-competitive swimmers should not be accounted to previously emerged differences in PP_A, but to different developmental patterns in phase B. Obviously, an intriguing question is: what causes these differences in developmental patterns and the higher PP_B of elite swimmers? In here, it is interesting to consider the inter-individual differences in adolescent growth processes and the quantity and quality of training hours as explaining factors (Ericsson et al., 1993; Malina et al., 2015). Moreover, differences in underlying performance characteristics between elite and high-competitive swimmers might relate to a larger performance potential (Elferink-Gemser et al., 2011). If so, PP_B might be a promising variable for talent development and selection processes as it may reflect this larger performance potential. However, the present study did not include any of these factors and consequently, more research is warranted. Therefore, a recommendation for future research would be to further unravel successful performance development to the top by tracking maturation, learning and training related to the personal performance characteristics of the individual swimmers (e.g., between 12 and 18 years) and their environment over time (Jonker et al., 2010; Elferink-Gemser and Visscher, 2013; Till et al., 2013). Moreover, as the present study showed large SDs within age categories and different effect sizes between age categories, it would be interesting to include multilevel modeling to examine within-subject variations and age-related effects in future studies investigating talented swimmers.

CONCLUSION

The present study showed significant differences in IPP between talented swimmers who have made it to the top (referred to as elite swimmers) and talented swimmers who did not make it to the top (referred to as high-competitive swimmers). Without denying individual differences, talented swimmers who have made it to the top, improved more in the period between the first swim performance of the season and their current season best performance (PP_B) than talented swimmers who did not make it to the top.

Practical Implications

The findings of the present study can be used to compare interim performance progression (IPP) of talented swimmers nowadays with the age-related IPP of swimmers who have reached elite level. In this way, IPP might in addition to swim performance function as an additional tool for federations and coaches to further select and monitor future talented swimmers. However, at all times, federations and coaches should be aware that performance progression is not a linear process and that there are different pathways to elite level performance. Therefore, we want to emphasize to use IPP as one of many parameters which can provide insight about performance progression of talented swimmers.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: www.swimrankings.net.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Local Ethical Committee of the University Medical Center Groningen, University of Groningen, The Netherlands. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

AP wrote the manuscript and conducted all statistical analysis. AP and RK conducted the data collection, processing, and analysis. RK, IS, CV, and ME-G reviewed the concept and final manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2020.579008/full#supplementary-material

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Youth Football Players' Psychological Well-Being: The Key Role of Relationships

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Well-being in youth sport is a growing topic in literature. Practicing sports at a youth level is recognized as an important opportunity for growth and development but also an experience that conversely can prove to be tiring and cause discomfort. Sometimes expectations and pressures make it a risky experience. This is emphasized even more when looking at very popular and spectacular sports, such as football in some European Countries; practicing football often solicits the hope of becoming champions one day and thus being able living thanks to the beloved sport. How do young Italian football practitioners feel? What role do relationships with significant others belonging to the world of sport and extra-sport play on the well-being of young athletes? On which specific aspects of psychological well-being (PWB) are these relationships based? Are there any differences between elite and amateurs levels? These are the questions upon which this paper focuses, considering a sample of young Italian football practitioners. Analysis reveals a strong and positive influence of some dimensions of the relationships with significant others on PWB, specifically team effort, coach closeness, and parental learning climate. Moreover, elite players perceive significantly better relationships than sub-elite and amateurs and have significantly higher levels of PWB. Those results provide a first evidence for the importance of good relationships within and outside sport for an effective development of youth football players since they positively influence players' PWB, which is higher in elite players. It emerges the necessity to further investigate different aspects of PWB and to deepen the knowledge about the meaning of relationship in developmental athletes according to a psychosocial approach.

Keywords: psychological well-being, youth athletes, football, relationships, psychosocial approach

INTRODUCTION

Practicing a sport, especially at a young age, can involve meetings and formative experiences or vice versa turn out to be a tiring experience and can sometimes also a cause of deep discomfort if not managed well (Sanchez-Martin, 2003; Holt et al., 2008; Balague et al., 2013)—relationships of trust versus feelings of loneliness, aggregation versus exclusion, a sense of improvement versus de-motivation and a sense of self-doubt. Furthermore, the more the level of competition increases, the more sports commitments increase and the conciliation with studies becomes more complicated. Usually the expectations of the young person and of the context increase.

The increasing demands from the sport setting during the developmental years of athletes challenge them with always increasing pressures, like more and more hours of training and competitions (Baker, 2003; Fraser-Thomas et al., 2008), along with the necessity to leave the family home at a very young age and to lead an "adult life" during a period of life which is particularly delicate for both their growth (physical, social, and psychological) and their athletic development (Balish and Côté, 2014). All these transitions (Wylleman and Lavallee, 2004, D'Angelo et al., 2017) can be hard to face without adequate relational support; such pressures could negatively impact on the development of athletes, in particular on their well-being.

For this reason, deepening the theme maintaining a focus on the well-being of young athletes seems relevant in coherence with a holistic perspective, and specifically with the psychosocial approach, which emphasizes how the well-being or malaise of each person is influenced by his life context and in particular by the quality of relationships with people significant to him/her.

How do young Italian football practitioners feel? What role do relationships with significant others belonging to the world of sport and extra-sport play on the well-being of young athletes? On which specific aspects of psychological well-being (PWB) are these relationships based? Are there any differences between elite and amateurs levels?

Using a psychosocial approach (Manzi and Gozzoli, 2009; Larsen et al., 2012; Gledhill et al., 2017), the present work examines the impact of the relationships youth football athletes have with significant others (within and outside sport) on their PWB, considering well-being as a basic condition moreover for good performance in sport (Rees, 2007; Larson et al., 2019). According to our perspective (Tseng and Seidman, 2007; Manzi and Gozzoli, 2009; Gozzoli et al., 2014; D'Angelo et al., 2018; Gozzoli et al., 2018), relationship is considered both a mutual bond among people—that can be a constraint and a resource for them—and also a set of specific meanings, values, and expectations assigned to it. Thus, considering sport practice under a psychosocial point of view means keeping in mind that young athletes are continuously involved in relationships that are create constrain among people that they give a meaning to.

Before presenting the empirical study, the state of the art of literature on the subject will be briefly presented.

Well-being is a complex multidimensional concept that has been studied mainly from two perspectives, namely, hedonic and eudaimonic. These can be considered two different parts of the same general concept of well-being, but their origins are different (Sirigatti et al., 2009; Huta and Ryan, 2010). Hedonic perspective defines well-being from a subjective point of view [subjective well-being (SWB); Diener, 2009], considering the cognitive and affective evaluation that people give about their lives as fundamental for their well-being (Diener et al., 2002). Eudaimonic perspective, instead, introduces the concept of PWB (Ryff and Keyes, 1995), which refers more to the possibility to reach human potential and to have the resources necessary to reach an optimal level of functioning in the long term (Ryff, 1989). Carole Ryff is the main reference author of eudaimonic PWB: she affirms that well-being is based more on the psychological abilities that people need to grow up and develop, that help them in facing effectively with life challenges and crisis (Ryff and Keyes, 1995). The author created the *multidimensional model of PWB*, which includes six dimensions (Ryff, 1989, 2013; Ryff and Keyes, 1995): *self-acceptance*, a positive attitude toward the oneself and one's past life and experiences; *positive relations with others*, that is the ability to have an open and satisfying relationship with others; *autonomy*, or a sense of independence and self-determination in own's life; *environmental mastery*, the competence to manage the daily activities; *purpose in life*, or the belief of a unique meaning to one's life; *personal growth*, a positive attitude toward new experiences and the openness of mind.

Current research on well-being in sport has been carried out mainly by Carolina Lundqvist. Lundqvist suggested a model of well-being in èlite sport which is based on the union of subjective and PWB on both general and sport aspects of development (Lundqvist, 2011). The model lies on the awareness that athletes have two main areas of development—a "non-sporting/personal" area and a "sporting" one—and thus they could experience a different kind of well-being in each.

Lundqvist has deepened its studies especially in the field of elite sport (Lundqvist and Sandin, 2014) and it is to them that we have referred for the operationalization of the construct of well-being in our empirical study. The choice to apply the study to a population of young athletes led us to choose to investigate in particular PWB, the most interesting dimension from the point of view of its development in adolescence. In fact, previous studies have shown that PWB is associated with a more positive individual development, both as athletes and as person, a long-term involvement in sport, intrinsic motivation, and better coping strategies (Adie et al., 2012; Ivarsson et al., 2015; Cheval et al., 2017), which are fundamental conditions for developing high-level performance.

Ryff's multidimensional model referred to the sports context as from the work of Lundqvist and Sandin (2014) defines the six dimensions of PWB as follows. Self-acceptance in sport is the self-awareness of personal strengths and weaknesses with a realistic evaluation of current performance level and future achievements, and the acceptance of the difference between the person and the athlete's results. Positive relations with others both within and outside sport are considered a fundamental pillar of their serenity, and negative events in one of them often impact on the other one. Autonomy in sport means knowing how to regulate everyday behaviors and decisions without the help of others or their direct request, as well as the awareness of the responsibilities of being an athlete. Environmental control is seen as the ability to identify and use environmental resources to face everyday challenges (e.g., combine school and training) or unexpected ones (e.g., injuries). Meaning in (athletic) life implies the effort to be devoted to a specific and higher life goal through sport. Finally, personal growth involves the possibility to develop holistically, trying to connect all life's areas and feeling that each area brings positive effects to the rest.

Studies on PWB in developing athletes are increasing only recently. For instance, Rongen et al. (2020) in a recently published work studied the psychological impact of living in academies of young footballers. These contexts, in fact, require a growing commitment to training and competitions (Elbe et al., 2005), constant monitoring of performance, highly structured full-time schedules, and numerous sacrifices compared to non-sporting life (school attendance, time with friends) (Christensen and Sorensen, 2009). All these elements are potentially stressful for a young adolescent (DiFiori et al., 2014; Bergeron et al., 2015; Sabato et al., 2016) and can also compromise athletic performance and PWB.

Van Rens et al. (2019) investigated the issue of well-being of young athletes in relation to their dual career paths, assuming the development of an academic identity as a protective factor with respect to the development of the well-being of young Australian athletes.

Studies such as those just mentioned therefore confirm a growing interest in the psychological literature on youth sport regarding PWB as a fundamental condition for the promotion of development and athletic performance.

The importance of relationships in the developmental path of young athletes is currently an increasingly important issue (Larson et al., 2019). In recent years, the role of social environment and relationships in the development of young athletes has become one of the most investigated topics in the field of sport psychology (Sheridan et al., 2014). Better relationships are linked to an easier recovery from injuries, positive sport participation, increased self-confidence, and better performance outcomes, and as a consequence, lower levels of burn-out (Rees, 2007; Sheridan et al., 2014; Larson et al., 2019). Ivarsson et al. (2015) suggested that players who perceive their environment to be supportive and have a focus on long-term development are less likely to suffer from stress and experience greater well-being.

Positive relationships with significant others (e.g., coaches, teammates, parents, or siblings) have been identified as one of the most important resources for young athletes' development since Bloom (1985) and Côté's (1999) research. For example, increases in perceived autonomy support from the coach over two competitive seasons have been related to increases in youth elite football players' well-being and decreases in their ill being (Adie et al., 2012). In a longitudinal study among youth elite swimmers, a task-oriented parent-initiated motivational climate was positively related to decreases in trait anxiety over the competitive season (O'Rourke et al., 2011). In addition, the coach- and peer-created motivational climate has been related to youth athletes' moral attitudes and well-being, with positive associations shown with a task oriented climate and negative associations shown with a performance-oriented climate (Alvarez et al., 2012; Ntoumanis et al., 2012).

In summary, literature highlights that the well-being of athletes is a dimension studied especially among elite athletes (Lundqvist, 2011) and studies that consider the well-being of youth athletes are recently increasing (Kipp and Weiss, 2013; Lundqvist and Raglin, 2015; Van Rens et al., 2019; Rongen et al., 2020; Thomas et al., 2020), research on the importance of a good relationship with the coach, teammates, and parents is huge but tends to consider the impact of relationships mainly on the performance and considering them individually (Jowett et al., 2012; Ntoumanis et al., 2012; Jowett and Shanmugam, 2016; Gledhill et al., 2017). Most of these mentioned researches on PWB of athletes are qualitative studies, mostly with retrospective designs; moreover, these studies have investigated each relationship individually, but no studies have yet studied the contemporary impact of all these relationships on well-being. Completely absent are studies on well-being in youth sport in the Italian context.

The proposed study aims to make a contribution to the understanding of the well-being of young players within the Italian context with the particular focus not so much on the influence of a specific relationship (with the coach, with parents), but on the intertwining, the set of different relationships. In our study, we tested the influence of relationships with significant others on the PWB of youth football players, comparing players of different competitive level (i.e., professional, semi-professional, and amateur), to identify possible differences.

MATERIALS AND METHODS

Participants

The sample is made up of 415 male young soccer players from two professional (League A and B, $N = 127$), two semi-professional (League C, $N = 162$) and four amateur ($N = 128$) Italian youth soccer academies, aged between 14 and 20 years ($M_{age} = 16.2$, $SD = 1.51$), mainly situated in the north of Italy (see **Table 1** for mean age and range of each category). The clubs involved in the research were selected by convenience, using personal contacts of the first three authors of this work.

The majority of them were born in Italy (91%), while a minority were foreign (8.4%) or had dual nationality (2.4%). Most players lived with their parents (87.6%), a minority in a specific residential structure provided by the club (6.7%) or with one parent (4.3%).

Measures

Socio-Demographic Information

Participants were asked to give details about their age, month of birth, nationality (also for their parents), siblings, parental educational level, and some details related to sport, like sports practiced in the family, other sports practiced in the past, sports practiced by siblings, and current injuries.

Psychological Well-Being

Psychological well-being was measured using Ryff's PWB Scale (Ryff, 1989; Ryff and Keyes, 1995; Italian version by Sirigatti et al., 2009). Ryff's PWB Scale is composed of 18 items, rated on a

TABLE 1 | Mean age and range of each category.

	Additional data on sample subgroups				
	N	M_{age}	***DS***	**Min.**	**Max.**
Professional	122	16.61	1.36	14	20
Semi-professional	151	16.20	1.54	14	19
Amateur	124	15.89	1.53	14	19

four-point Likert scale, ranging from (1) "completely disagree" to (4) "completely agree." It measures six dimensions, namely: self-acceptance (e.g., "In general, I feel confident and positive about myself"), ω = 0.529; positive relations with others (e.g., "I often feel lonely because I have few close friends with whom to share my concerns"), ω = 0.588; autonomy (e.g., "It's difficult for me to voice my opinions on controversial matters"), ω = 0.459; environmental mastery (e.g., "I am good at juggling my time so that I can fit everything in that needs to get done"), ω = 0.430; purpose in life (e.g., "I am an active person in carrying out the plans I set for myself"), ω = 0.476; personal growth (e.g., "I think it is important to have new experiences that challenge how you think about yourself and the world"), ω = 0.409.

Relationship With the Coach

The Coach–Athlete Relationship Questionnaire (Jowett and Ntoumanis, 2004) is used to measure the link between athlete and the coach. The Coach–Athlete Relationship Questionnaire consists of 11 items that measure three dimensions: commitment (e.g., "I am committed to my coach"), ω = 0.800; closeness (e.g., "I like my coach"), ω = 0.836; and complementarity (e.g., "When I am coached by my coach, I am responsive to his/her efforts"), ω = 0.782. Answers were scored on a five-point Likert scale, ranging from (1) "not at all" to (5) "very much."

Relationship With Teammates

The 21 version of the Peer Motivational Climate in Youth Sport Questionnaire (Ntoumanis and Vazou, 2005) was used. The Peer Motivational Climate in Youth Sport Questionnaire measures five dimensions, namely: focus on improvement (e.g., "On this team, most athletes... help each other to improve"), ω = 0.760; relatedness support (e.g., "On this team, most athletes... care about everyone's opinion"), ω = 0.749; effort (e.g., "On this team, most athletes... encourage their teammates to try their hardest"), ω = 0.755; intrateam competition (e.g., "On this team, most athletes...look pleased when they do better than their teammates"), ω = 0.664; intrateam conflict (e.g., "On this team, most athletes...make negative comments that put their teammates down"), ω = 0.748. Items were scored on a five-point Likert scale, ranging from (1) "not at all" to (5) "very much."

Relationship With Parents

We used the Parent-Initiated Motivational Climate Questionnaire (White et al., 1992). It is made of 28 items divided for father (14) and mother (14), which measure three dimensions: learning/enjoyment climate (e.g., "I feel that my mother/father... encourages me to enjoy learning new skills"), ωF = 0.544, ωM = 0.646; worry conductive climate (e.g., "I feel that my mother/father... makes me worried about performing skills that I am not good at"), ωF = 0.584, ωM = 0.619; success without effort climate (e.g., "I feel that my mother/father... believe that it is important for me to win without trying hard"), ωF = 0.661, ωM = 0.737. For all 28 items, players answer twice to the introductory segment "I feel that my mother/father...," and items were scored on a five-point Likert scale, ranging from (1) "not at all" to (5) "very much."

Procedure

After gaining the approval from the ethical commission of the university, professional, semi-professional, and amateur soccer clubs were contacted in different ways, but all thanks to the personal knowledge of the Italian authors of the present work. After the club's formal acceptance, a presentation of the research (e.g., a brochure with the main aims of the research, technical information about the duration of the data collection, and the contacts of the researchers) was sent by email. Managers used it to present the research to parents and coaches and give contacts for the researchers in case of questions from the participants. After gaining informed consent from participants or their parents, a session of group data collection was organized for each team before or after one of the weekly trainings. Before each data collection session, the researcher explained to the players the main aims of the research and the main tasks required (e.g., "To investigate the experience players were living in their development as soccer players and to understand the involvement and role of significant others"). The total duration of each data collection session was between 30 and 45 min.

Data Analysis

Preliminary Analysis

Using SPSS 20.0 (IBM Corp, 2011), we tested items' scores for normality and calculated the means and standard deviations for each variable (see **Table 2**). After that, we ran a confirmatory factor analysis using Mplus 7.11 (Muthén and Muthén, 1998–2017) for each scale.

Structural Equation Model on the Impact of Relationships on Psychological Well-Being

Structural equation models (SEMs) are used in the analysis of behavioral data, as they make it possible to study the interrelationships between different latent factors and observed variables. They are particularly suitable for testing complex models in which the interactions provide for the inclusion of

TABLE 2 | Mean and standard deviations for each variable considered in the whole sample.

	M	*SD*
PWB_composite	9.57	0.94
PWB_autonomy	9.32	1.52
PWB_meaning	9.47	1.70
PWB_self-acceptance	9.50	1.31
PWB_positive relation	9.92	1.55
PARENT_worry	3.42	0.64
PARENT_learn	3.82	0.53
COACH_composite	3.74	0.74
COACH_closeness	4.03	0.78
COACH_complementarity	3.75	0.76
COACH_committment	3.46	0.86
TEAM_learning	3.49	0.74
TEAM_effort	3.79	0.67
TEAM_intracompet	3.30	0.69
TEAM_intraconflict	2.83	0.86

multiple variables and the presence of latent variables that cannot be measured directly. We adopted SEM because instead of studying singularly the impact of each relationship on PWB as in previous studies, we wanted to connect all the relationships with significant others and study their overall impact on the PWB of athletes. The SEM we tested using Mplus 7.11 (Muthén and Muthén, 1998–2017) is drawn in **Figure 1**: we form two latent variables (namely "Characteristics of the relationships" and "PWB," reported in the circles) and their direct effects, which are composed of different observed variables (or the measurement model in the squares). The analysis of missing data patterns shows that the model considers only 302 subjects.

Analysis of Variance

To identify potential differences among the three competitive level groups (elite, subelite, and amateur) on the dimensions investigated (PWB, coach–athlete relationship, peer motivational climate in youth sport, parent-initiated motivational climate), we performed an ANOVA using SPSS 20.0.

RESULTS

Preliminary Analysis

The PWB scale shows a non-normal distribution for some items: this could be imputed to the four-point Likert scale, which could lead to a positive–negative polarization of responses, found also in other works (Sirigatti et al., 2009); therefore, we treated factors as categorical when running the subsequent analysis. The CFA for the PWB Scale shows that only four factors over six emerged as reliable in our sample that are self-acceptance, positive relationships with others, autonomy, and purpose in life. Fit indices for this model were acceptable [$\chi^2(48) = 100.635$; $p < 0.001$; RMSEA = 0.051, $p < 0.001$; CFI = 0.924; WRMR = 0.912]. Factor loading of the remaining factors are between 0.30 and 0.77 and significant ($p < 0.001$).

The CFA for the Coach-Athlete Relationship Questionnaire shows a good internal consistency [$\chi^2(41) = 136.473$; $p < 0.001$; RMSEA = 0.075, $p < 0.001$; CFI = 0.940; SRMR = 0.043]. Factor correlation is between 0.93 and 0.97, and this could indicate collinearity problems between factors: the literature reveals a high correlation among those dimensions, and many studies try to validate a single factor structure without obtaining satisfactory results (Yang and Jowett, 2012, 2013). For the Peer Motivational Climate in Youth Sport-Questionnaire, the CFA shows that only four factors over five resulted in being reliable in our sample; therefore, in the analysis, we only considered focus on improvement, effort, intrateam competitiveness, intrateam conflict. Fit indices for this model were acceptable [$\chi^2(122) = 220.649$; $p < 0.001$; RMSEA = 0.044, $p < 0.001$; CFI = 0.941; SRMR = 0.069]. Factor loadings were between 0.35 and 0.75 and significative ($p < 0.0001$). Finally, for the Parent-Initiated Motivational Climate Questionnaire, the CFA reveals only two motivational climates emerged as reliable in our sample; therefore, we only considered a double factorial solution, composed of the learning/enjoyment climate and worry conductive climate (by father and by mother). Fit indices for this model were acceptable [$\chi^2(154) = 282.513$; $p < 0.001$; RMSEA = 0.045, $p < 0.001$; CFI = 0.934; SRMR = 0.062]. All results of the CFA are reported in **Supplementary Tables 1–16**.

Analyses of the mean and *SD* for each dimension considered in our analysis show that positive relationships with others

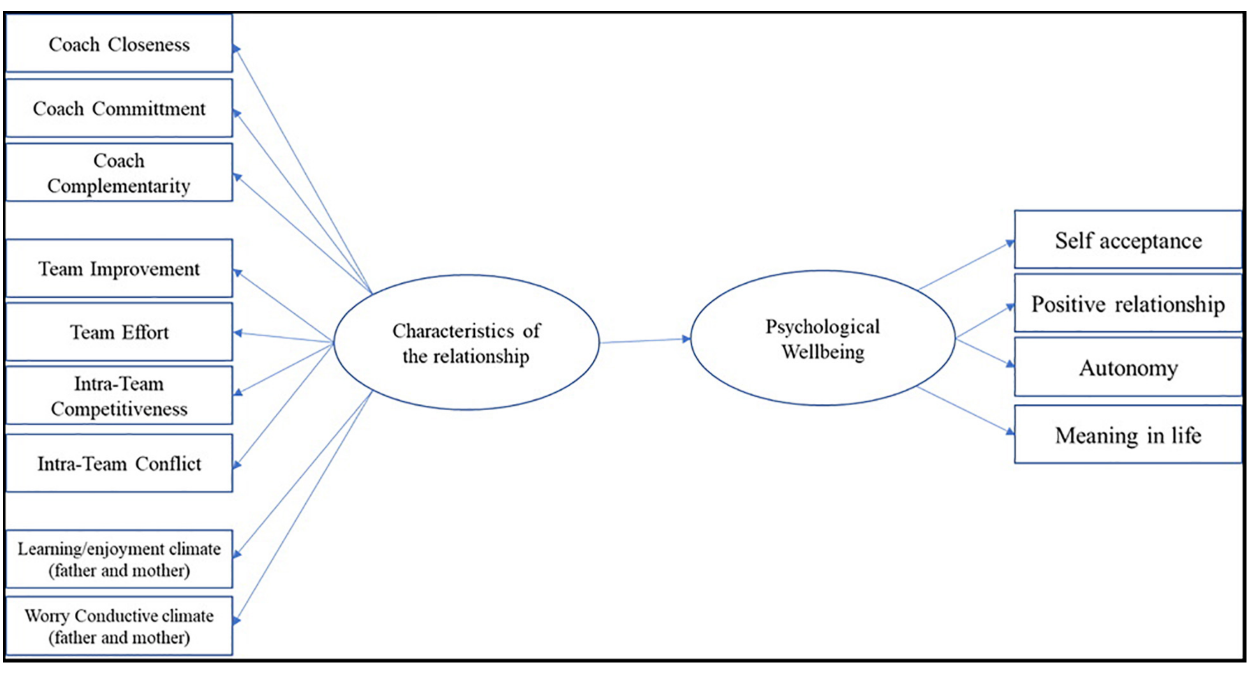

FIGURE 1 | Hypothesized SEM on the impact of relationships on the psychological wellbeing of players.

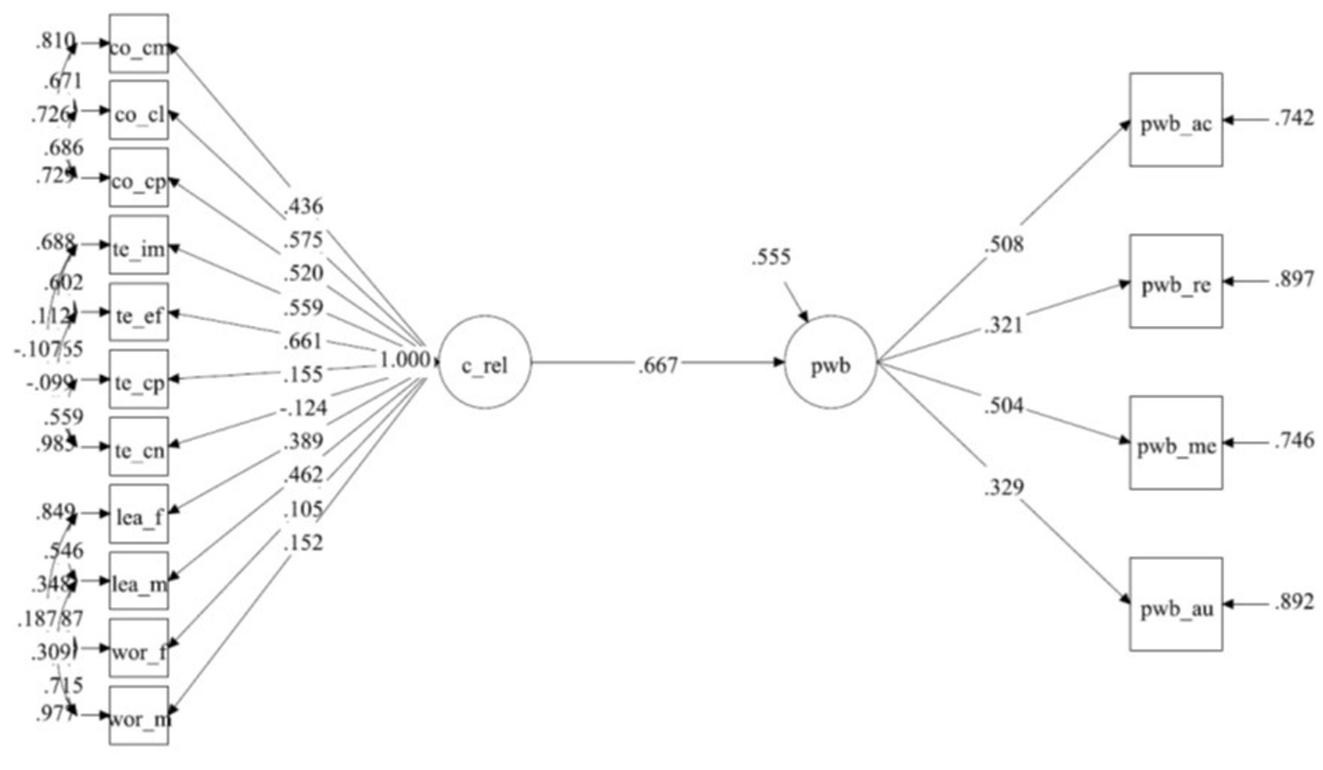

FIGURE 2 | Resulted SEM on the impact of relationships on the psychological wellbeing of players.

has the highest score among the PWB dimensions (M = 9.92; SD = *1.55*), parental learning climate has the highest score among the two dimensions considered (M = 3.82; SD = 0.53), closeness with the coach has the highest score among the three dimensions of the scale (M = 4.03; SD = 78) and finally team effort has the highest score among all the other dimensions considered (M = 3.79; SD = 67). It is curious to note that all the variables with the highest mean score resulted also in impacting the SEM most, except for positive relationships with others. This could indicate that, overall, young players in the sample perceive having good relationships with others and that this doesn't vary across competitive-level groups (see the ANOVA section).

Structural Equation Model

Characteristics of Relationships and Psychological Well-Being

The model fit information (reported in **Table 3**) together with the standardized model result of factor loading and factor correlations show an overall good fit for the model [$\chi^2(74) = 142.917$; $p < 0.001$; RMSEA = 0.047, $p < 0.001$; CFI = 0.963; SRMR = 0.049] (see **Supplementary Table 17**). The impact of the latent factor characteristics of relationships on the PWB is strong (0.667) and significative (see **Figure 2** for the results of the analysis and **Supplementary Table 17**).

Factor loading results (see **Table 4**) show that self-acceptance (0.508) and meaning in life (0.504) are the most significative dimensions in the PWB factor, while team effort (0.661), coach closeness (0.575), and team improvement (0.559) are the most important dimensions in the characteristics of relationships factor. The parental approach that mostly impact on the PWB factor was learning climate, promoted especially by mothers (0.462). Coach complementarity (0.520) and commitment (0.436) were only secondary dimensions in this model, while team conflict and worry conductive climate results were non-significant for father, while worry conductive climate has a minimal factor loading for mother (0.152, $p < 0.05$), as well as team competitiveness (0.155, $p < 0.05$).

All in all, results confirm our hypothesis about the importance of relationships for the well-being of young athletes. In particular, there are some very specific features within the relationships with significant others that positively impact on athlete's PWB, specifically on self-acceptance and meaning in life dimensions.

Analysis of Variance Among Three Competitive Groups of Players

A comparison between the three competitive groups (elite, subelite, and amateur) was performed by an ANOVA (see

TABLE 3 | Model fit information for the SEM.

χ^2 (*df*)	*RMSEA*	*CFI*	*p*	*SRMR*
142.917 (74)	0.047	0.963	0.0001	0.049

TABLE 4 | Estimated factor loading in the SEM.

Dimensions of the latent factors	Estimated factor loading
Self-acceptance	0.508***
Positive relationship	0.321***
Meaning in life	0.504***
Autonomy	0.329***
Coach commitment	0.436***
Coach closeness	0.575***
Coach complementarity	0.520***
Team improvement	0.559***
Team effort	0.661***
Intrateam competitiveness	0.155*
Intrateam conflict	−0.124
Learning/enjoyment climate (father)	0.389***
Learning/enjoyment climate (mother)	0.462***
Worry conductive climate (father)	0.105
Worry conductive climate (mother)	0.152*

*$p < 0.05$.
***$p < 0.001$.

Supplementary Tables 18–25). Next to each constituent dimension, we also calculated and compared groups on a composite score for the following dimensions: PWB, formed by a mean of the four significant constituent dimensions scores (α = 0.50); parent-initiated motivational climate, namely, respectively parental worry (α = 0.77) and parental learning motivational climate (α = 0.83) formed by the mean of the mother and father scores; at each dimension, the coach–athlete relationship (α = 0.90) formed by the mean of the three constituent dimensions.

ANOVA results were significant for the following dimensions: meaning in life, $F(2,401) = 11.143$, $p < 0.001$, autonomy, $F(2,394) = 9.943$, $p < 0.001$, and composite PWB, $F(2,378) = 10.601$, $p < 0.001$; parental worry motivational climate $F(2,367) = 6.463$, $p < 0.002$ and parental learning motivational climate $F(2,367) = 6.174$, $p < 0.002$, coach–athlete closeness $F(2,408) = 6.041$, $p < 0.003$, and finally ANOVA on peer motivational climate show a difference only in intrateam conflict, $F(2,399) = 7.601$, $p < 0.001$.

Post hoc test (HSD Tukey) reveals that composite PWB in elite ($M = 9.85$, $SD = 0.85$) is significantly higher than amateur ($M = 9.31$, $SD = 0.94$); autonomy in elite ($M = 9.72$, $SD = 1.49$) is significantly higher than amateur ($M = 8.87$, $SD = 1.51$); meaning in life in elite ($M = 9.95$, $SD = 1.36$) is significantly higher than amateur ($M = 8.95$, $SD = 1.65$). For the dimension intrateam conflict, results show that amateurs ($M = 3.05$, $SD = 0.85$) were significantly higher than elite ($M = 2.63$, $SD = 0.70$). For the coach–athlete relationship, we obtained a statistically significant difference only in the dimension of closeness, where amateurs ($M = 3.84$, $SD = 0.95$) were only lower than subelite ($M = 4.14$, $SD = 0.64$). Finally, regarding parent-initiated motivational climate, amateurs ($M = 3.25$, $SD = 0.70$) were significantly lower than elite ($M = 3.55$, $SD = 0.58$) on the worry motivational climate and also on the learning motivational climate, where amateur ($M = 3.68$, $SD = 0.60$) were lower than elite ($M = 3.91$, $SD = 0.48$) (see **Supplementary Tables 18–25** for complete results of the ANOVA).

DISCUSSION

In this study, we wanted to examine how the relationships with significant others influenced the PWB of young soccer players. We analyzed for the first time the combined influence of three main significant others, namely, the coach, team, and parents. The literature shows that each of them is important for players' well-being, but a comprehensive study of their combined influence has not been done until now.

Results of our analysis confirmed our hypothesis about the combined influence of relationships with significant others on the PWB of young athletes, in particular on their self-acceptance and their sense of having a purpose in life. Lundqvist (2011) described self-acceptance in athletes as their self-awareness of strengths and weaknesses, a realistic evaluation of current performance level and future achievements, and the acceptance of the difference between the person and the athlete's results, while purpose in life was described as a sensation that implies the effort to be devoted to a specific and higher life goal through sport. Our analysis showed that perceiving effort and a focus on improvement within the team, having a close relationship with the coach and the promotion of a learning attitude by parents strongly influence players' PWB, specifically to enhance their self-acceptance and sense of purpose in life. Moreover, our analysis also revealed that this influence was particularly strong in those players who were enrolled in professional and semi-professional clubs: this can be a possible sign of a very high degree of sensitivity toward the importance of relationships in those contexts.

Let us now explore the meaning that these specific characteristics of relationships can have in relation to the promotion of PWB in a young player. First, young players emphasize the importance of teammates' motivational climate in their developmental path, more than the current research seems to have investigated (Holt et al., 2008; Fry and Gano-Overway, 2010; Bruner et al., 2014; García-Calvo et al., 2014; Sheridan et al., 2014). Our analysis showed that young players consider effort and focus on improvement within their team as the most effective relational elements for their PWB, being even more important than their coach or parents. A task-oriented motivational climate leads athletes to appreciate improvements, increase efforts, and consider errors as a part of the learning process and growth, leading everyone to be more satisfied with their sporting outcomes and remain engaged in sport for longer (Jõesaar et al., 2012; García-Calvo et al., 2014). This result seems to be particularly important in a team sport like football, as the improvement of one player could lead to the improvement of the overall team, thus supporting also the development of leadership and social skills (i.e., the ability to develop effective relationships with others). In other studies, Bruner et al. (2014) have shown how a higher level of task and social cohesion lead to more positive youth development, specifically in personal and social skills, initiative, goal setting, cognitive skills, and lower levels of negative experiences. Moreover, the ability to stay focalized on improvement and showing effort are also important when facing difficulties or important changes in life, like career transitions from junior to senior, specifically as a resource within sport context and as part of coping skills in relying on social support (Drew et al., 2019). Such findings support the importance of deepening the role of the peer motivational climate in the development of young athletes, especially in team sports (Ntoumanis et al., 2007, 2012).

Second, results highlighted the role of the coach–athlete relationship in promoting PWB. In particular, the relevance of the emotional closeness among other dimensions shows that feeling close to the coach can positively influence not only the performance (Jowett et al., 2012) but also the PWB of youths (Jowett and Poczwardowski, 2007; Davis et al., 2013; Jowett and Shanmugam, 2016). In general, the literature affirmed that athletes who perceive higher closeness, cooperation, and commitment with the coach also perceive their coaches to be more task-oriented (Olympiou et al., 2008). This could be more effective for their athletic career since such orientation allows sport engagement and continuation for a time, better and more effective goal setting, and higher levels of satisfaction from sport participation. Nevertheless, the quality of coach–athlete relationship has been found to be more effective within a long-term timeframe: thus, the longer the relationship, the better the results are (Jowett and Nezlek, 2012). In the clubs where data were collected—and in general in Italian football clubs—coaches usually change the team they train every year; thus both players and coaches need the ability to create a positive relationship within a very short time frame. If such an ability could be easier for adults, this would not be the same for adolescents who need to be supported in such aspects of development, especially in early adolescence (Wylleman et al., 2013).

Third, the parental motivational climate that promotes learning is considered as the most supportive for PWB. Specifically, elite players perceive their parents as more supportive for that climate than other groups do. In general, both parents emphasize a learning climate, as suggested by the results of previous studies. Those studies consider the motivational climate promoted by parents as a precursor of self-determined motivation toward sport, engagement, and higher levels of satisfaction with sport (White, 1998; White et al., 1998; Salselas and Marquez, 2009; Kolayiş et al., 2017). Moreover, parent-initiated motivational climate was found to be a significant predictor of late-season self-esteem, trait anxiety, and autonomous regulation, even higher than the coach-initiated motivational climate (O'Rourke et al., 2014). Interestingly, we found a difference in the weight of father and mother promotion of motivational climate, and this appears to be a curious emerging issue regarding the different parental approaches to sport (Wuerth et al., 2004; Kolayiş et al., 2017).

The results of our analysis allowed us to do another more general reflection. Adolescence is the period of life when new models are looked for to exit from the parental idealization phase and find new adults to trust and aspire to as role models. Coaches are the main landmark for youth in their sporting career: they are responsible for selecting players, organizing training to develop the best, deciding players for matches, and many other aspects that can help players to progress in their career, even more than parents. Our results show that coaches, next to teammates, assume a key role within the developmental path of young athletes as the relationship with them has been considered necessary for their PWB and sense of growth. Therefore, both coaches and parents need to be aware of such issues since they can be supported in developing a set of new relational skills to deal with athletes in this delicate phase-of-life transition.

Results of the comparison of the three competitive-level groups confirm that elite players have higher levels of PWB. It seem to confirm the recent study by Rongen et al. (2020), and we think it can be explained as follows: although the life of elite young footballers is busy and demanding, the value and achievement for them is high, they are in the place where they would like to be (generally top club academies), doing what they love more.

Specifically in our study elite athletes perceive higher levels of meaning in life, have higher levels of closeness with their coach, and also perceive that their parents promote a learning climate in sport more. Such results underline that not only relationships impact the PWB of players but also that elite ones have higher levels of PWB and better kinds of relationships with significant others. We consider this as evidence of our initial hypothesis—having better relationships within and outside sport can be considered as some of the psychosocial factors that support players to develop more effectively, as they promote the PWB, which in turn supports them in staying involved in sport and facing transitions and difficulties better.

Some Final Reflections

According to a psychosocial approach, sport is a complex relational space (Sanchez-Martin, 2003; Holt et al., 2008) where relationships play a fundamental role in athletes' development and throughout their entire athletic career. PWB, as formulated by Ryff and studied in sport by Lundqvist (Lundqvist, 2011; Lundqvist and Sandin, 2014) seems to be a useful basic condition for positive and effective development of young athletes.

The study is of course a first exploration of some constructs according to the need to consider the importance of PWB in the development of youth in sport, specifically for youth athletes involved on path of talent development (in our study, the elite group of football players). In the future, it could also be interesting to deepen the qualitative study of the meanings of well-being for this specific category of athletes.

Therefore, the study also shows some limits. The sample involved in the data collection is made of players from clubs situated mainly in the north of Italy: this could influence the representativeness of the sample with respect to the Italian population. Moreover, the literature has suggested some differences in males and females' perceptions of the motivational climate induced by parents (Vesković et al., 2013; Gledhill and Harwood, 2014). It could be interesting to expand the sample and also involve female soccer players in order to compare the results with those of males. A third limitation is linked to the fact that we explored a developmental topic without using a longitudinal method. It would be of great interest to introduce a longitudinal methodology to investigate the process of talent development and eventual changes in relationships' characteristics. Moreover, it would be of great interest to further explore the role of individual psychological characteristics, as for example motivational orientation on PWB.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Commissione Etica per la Ricerca in Psicologia (CERPS) of the Catholic University of the Sacred Heart, Milan. Written informed consent to participate in this study was provided by the participants, and where necessary, the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

ER, CD'A, and CG conceived the study and the hypothesis. ER collected the data and run the analysis. CD'A and ER wrote the first draft of the manuscript, while CG and ML supervised the work. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.567776/full#supplementary-material

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Competition-Based Success Factors During the Talent Pathway of Elite Male Swimmers

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Marginal differences in race results between top swimmers have evoked the interest in competition-based success factors of long-term athlete development. To identify novel factors for the multi-dimensional model of talent development, the aim of the study was to investigate annual variation in competition performance (ACV), number of races per year, and age. Therefore, 45,398 race results of all male participants ($n = 353$) competing in individual events, i.e., butterfly, backstroke, breaststroke, freestyle, and individual medley, at the 2018 European Long-Course Swimming Championships (2018EC) were analyzed retrospectively for all 10 years prior to the championships with Pearson's correlation coefficient and multiple linear regression analysis. Higher ranked swimmers at the 2018EC showed significant medium correlations with a greater number of races per year and small but significant correlations with higher ACV in 10 and nine consecutive years, respectively, prior to the championships. Additionally, better swimmers were older than their lower ranked peers ($r = -0.21$, $p < 0.001$). Regression model explained a significant proportion of 2018EC ranking for 50 m (47%), 100 m (45%), 200 m (31%), and 400 m races (29%) but not for 800 and 1,500 m races with number of races having the largest effect followed by age and ACV. In conclusion, higher performance variation with results off the personal best in some races did not impair success at the season's main event and young competitors at international championships may benefit from success chances that increase with age. The higher number of races swum per year throughout the career of higher ranked swimmers may have provided learning opportunities and specific adaptations. Future studies should quantify these success factors in a multi-dimensional talent development model.

Keywords: age, key performance indicators, long-term athlete development, number of races, performance variation

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INTRODUCTION

The men's recent Olympic 50 m freestyle final was won by only a 100th of a second (IOC, 2016a). Such marginal differences in race results of top swimmers have evoked interest in success factors at all competition levels, from elite to junior swimmers (Stewart and Hopkins, 2000; Pyne et al., 2004; Post et al., 2020). For scientific and longitudinal race analyses, Olympic pool swimming provides highly standardized conditions, due to FINA (Fédération International de Natation) rules (FINA, 2020b). These only allow for a tolerance of +0.01 m for pool length and specify that the current must be below 1.25 m per 60 s (FINA, 2020b). Furthermore, electronical time keeping is compulsory (FINA, 2020b). Therefore, comparison of results across various venues and championships over several years is feasible and variations in performance can be determined.

At a junior level for instance, faster swimmers showed a lower performance variation (1.1%) between two important competitions than their slower counterparts (1.5%) (Stewart and Hopkins, 2000). At elite-level, variation in competition performance decreased in the 5 years leading up to the Olympics (Costa et al., 2010; Clephas and Wilhelm, 2019). Furthermore, performance variation increased from short-distance (0.5%) to long-distance (1.0%) events (Pyne et al., 2004), while differences between swimming strokes remained unclear (Pyne et al., 2004; Trewin et al., 2004). However, at major competitions, i.e., World Championships and Olympic games, higher performance variation that improve current seasonal best times was an important contributor to success of finalists (Mujika et al., 2019). With these conflicting data, practical application of performance variation in competitive swimming is limited. Lack of significant findings or presentation of trend-like effects warrant further investigations, in particular on performance variation during the development process of young talented swimmers.

Top-level Olympic swimmers competing in long-distance freestyle events reached peak performance at a younger age (22.9 ± 2.2 yrs) than the competitors in freestyle sprint events (25.9 ± 1.9 yrs). However, there was no difference in the window of peak performance, i.e., 2.9 ± 1.5 and 3.1 ± 1.8 yrs, respectively, between freestyle long-distance and sprint swimmers (Allen et al., 2014). While achievement of top performances might result from multiple factors, i.e., genetics, economies, and available support (Tucker and Collins, 2012; Breitbach et al., 2014), there is a heated debate about the effect of age and the associated accumulation of practice (Ericsson et al., 1993; Tucker and Collins, 2012; Ericsson and Harwell, 2019). Therefore, the effect of age on final ranking at international competitions is of further interest. In addition, a recent study examining swimmers showed that the number of years competing at a high international level is an important success factor for upcoming competitions (Yustres et al., 2017). From a physiological and psychological perspective, multiple competitions might help develop race routines and resilience (Carrasco et al., 2007; Meggs et al., 2016; Burns et al., 2019). However, little is known about the optimal number of races over the course of the season, or how it affects performance variation and long-term athlete development.

Therefore, the aim of this study was to identify novel competition-based success factors and investigate annual variation in competition performance (ACV), number of races per year, and age for all 10 years prior to the 2018EC. It was hypothesized that better swimmers at the 2018EC would (1) show more consistent performance and lower ACV, (2) participate in more races per year, and (3) be older than athletes at the bottom of the 2018EC ranking.

MATERIALS AND METHODS

Participants

Race results of all male participants (n = 353, age 22.5 ± 3.2 yrs) competing in individual events at the 2018EC in Glasgow were analyzed retrospectively for all 10 years preceding the championships. In total, 45,398 races were analyzed. Pearson's correlation coefficient and multiple regression analysis were used to analyze the relationship between ranking achieved at the 2018EC as the dependent variable and potential success factors i.e., ACV, number of races per year, and age. The study was approved by the leading institution's review board (Reg.-Nr. 088LSP250919) and is in the spirit of the Code of Ethics of the World Medical Association (Helsinki Declaration).

Data Collection

For the present study, data were provided by the publicly accessible domain "swimrankings.net," which displays race results from the official database of LEN (Ligue Européenne de Natation), the governing European swimming federation. The database lists results from registered races which are in accordance with official FINA (Fédération Internationale de Natation) rules (FINA, 2020b), including electronical time keeping and limits to in-pool current. As the European championships are the highest international competition of the LEN, the 2018EC ranking was chosen as the dependent variable. Written informed consent was provided by the domain's owner for anonymized usage and publication of the data.

Data Analysis

Competition results of long-course competitions were analyzed for ACV and number of races per year. Swimmers' annual ACVs were determined as the coefficient of variance (standard deviation divided by the mean) for each swimming stroke and race distance they performed in every year back to 2009. A minimum of two races per event per year were required to calculate the coefficient of variance and to include data in the regression model. Number of races were determined for each year, stroke, and distance. Age in the year of the 2018EC was added as third independent variable to the model.

Previous studies showed an improvement of 3–4% in performance in the five seasons leading up to the Olympics (Costa et al., 2010). For the present study, data were analyzed with no information on tapering, pacing strategies, injuries, or illnesses. No information was available on importance of the races within the competition schedule. In less important races, athletes lying far behind might have given up the race and finished beyond a functional variation in competition performance. Therefore, outliers were defined as coefficients of variance showing an ACV >4% within 1 year. This led to the exclusion of 113 out of 5'555 calculated coefficients.

Statistical Analysis

Athletes' ACV and number of races per year (2018–2009) were correlated with their 2018EC ranking using Pearson's correlation coefficient for an initial descriptive analysis. Correlation coefficients of 0.1–0.3, 0.3–0.5, and 0.5–0.7 were classified as small, medium, and large (Hopkins, 2002). Since butterfly, backstroke, and breaststroke events involve race distances up to 200 m only, swimming strokes were compared using pooled data of the 50, 100, and 200 m events. Freestyle events were used for the comparison between race distances (50, 100, 200, 400, 800, and 1,500 m). Using multiple linear regression analysis, predictive values were determined with ACV, number of races per year, and age for the final 2018EC ranking. Mean values of the last 2 years before the 2018EC were applied in the regression model. An alpha level of < 0.05 confirmed a statistically significant effect. Based on standard procedure for multiple regression analysis on large sample sizes, normality was investigated on the standardized residuals and predicted values (Field, 2013). In scatterplots, data were evenly distributed in a random pattern around zero. Histograms showed a Gaussian distribution of the regression standardized residuals and normal probability plots showed a diagonal straight line confirming normally distributed data (Field, 2013). Data were collected and prepared with Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA). Analysis were carried out using SPSS statistical software package for Windows Version 25.0 (IBM Corporation, Armonk, NY, USA).

RESULTS

Descriptive Statistics

Correlations between ranking at the 2018EC and ACV and number of races per year are presented in **Tables 1**, **2** as well as **Figures 1**, **2**. Pooled data of all swimming strokes and race distances showed that higher ranked swimmers at the 2018EC had a larger ACV for nine consecutive years prior to the championships, compared to their lower ranked counterparts. More variation was also evident for the years that immediately preceded the championships for butterfly and freestyle as well as the 50 m and 100 m events.

The pooled data of all swimming strokes and race distances showed that higher 2018EC ranking was related to more races per year during 10 consecutive years prior to the championships (refer to **Table 2**). The more detailed analyses showed that this was the case for all swimming strokes, but less clear for individual medley. Furthermore, a higher 2018EC ranking was associated with more races per year in the 50, 100, 200, and 400 m events. Finally, age was related to success, with older swimmers ranking higher at the 2018EC ($r = -0.21$, $p < 0.001$). Regarding swimming strokes, age was related to ranking for butterfly (22.4 ± 3.5 yrs, $r = -0.29$, $p < 0.001$), backstroke (21.6 ± 2.8 yrs,

TABLE 1 | Annual variation in competition performance (mean ± standard deviation) correlated with ranking at the 2018 European Swimming Championships.

	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009
All strokes and distances	1.6 ± 0.7%	1.6 ± 0.7%	1.6 ± 0.7%	1.6 ± 0.7%	1.6 ± 0.8%	1.7 ± 0.8%	1.6 ± 0.8%	1.6 ± 0.8%	1.7 ± 0.8%	1.7 ± 0.9%
	*–0.18****	*–0.19****	*–0.17****	*–0.13****	*–0.22****	*–0.26****	*–0.11**	*–0.13**	*–0.13**	*–0.06*
Butterfly	1.6 ± 0.6%	1.6 ± 0.7%	1.6 ± 0.7%	1.6 ± 0.7%	1.6 ± 0.8%	1.6 ± 0.8%	1.7 ± 1.0%	1.8 ± 0.7%	1.7 ± 0.8%	2.0 ± 1.0%
	*–0.22***	*–0.17**	*–0.25***	*–0.13*	*–0.12*	*–0.37****	*–0.18*	*–0.18*	*–0.21*	*0.06*
Backstroke	1.8 ± 0.7%	1.8 ± 0.7%	1.8 ± 0.7%	1.7 ± 0.8%	1.8 ± 0.9%	1.9 ± 0.8%	1.7 ± 0.9%	1.5 ± 0.7%	1.6 ± 0.9%	1.7 ± 0.9%
	–0.12	*–0.27***	*–0.26***	*–0.12*	*–0.28***	*–0.21**	*–0.24**	*–0.23*	*–0.17*	*–0.26*
Breaststroke	1.6 ± 0.7%	1.6 ± 0.8%	1.6 ± 0.7%	1.6 ± 0.7%	1.5 ± 0.8%	1.6 ± 0.8%	1.6 ± 0.9%	1.6 ± 0.9%	1.9 ± 1.0%	1.6 ± 1.0%
	–0.04	*–0.22**	*0.01*	*–0.13*	*–0.15*	*–0.24**	*–0.19*	*–0.04*	*–0.14*	*0.02*
Freestyle	1.4 ± 0.6%	1.4 ± 0.7%	1.4 ± 0.7%	1.5 ± 0.6%	1.4 ± 0.6%	1.4 ± 0.7%	1.5 ± 0.8%	1.6 ± 0.7%	1.6 ± 0.7%	1.4 ± 0.8%
	*–0.25****	*–0.17**	*–0.10*	*–0.11*	*–0.13*	*–0.10*	*0.05*	*–0.33***	*–0.10*	*–0.11*
Individual medley	1.8 ± 0.5%	2.1 ± 0.7%	2.0 ± 0.8%	2.0 ± 0.5%	2.0 ± 0.8%	2.3 ± 1.0%	2.1 ± 0.8%	1.5 ± 0.9%	1.8 ± 0.6%	1.7 ± 0.7%
	–0.05	*0.02*	*0.27*	*0.30*	*0.04*	*–0.39*	*–0.17*	*–0.34*	*–0.14*	*0.05*
50 m	1.5 ± 0.6%	1.4 ± 0.7%	1.6 ± 0.8%	1.6 ± 0.7%	1.3 ± 0.6%	1.2 ± 0.6%	1.4 ± 0.8%	1.5 ± 0.8%	1.5 ± 0.8%	1.1 ± 0.8%
	*–0.43****	*–0.35**	*–0.03*	*–0.12*	*–0.23*	*–0.05*	*0.17*	*–0.32*	*–0.28*	*–0.44*
100 m	1.4 ± 0.6%	1.4 ± 0.7%	1.2 ± 0.5%	1.4 ± 0.6%	1.4 ± 0.7%	1.5 ± 0.6%	1.4 ± 0.7%	1.5 ± 0.7%	1.5 ± 0.7%	1.5 ± 0.7%
	*–0.33**	*–0.09*	*–0.21**	*–0.16***	*–0.06**	*–0.19***	*0.08*	*–0.25*	*–0.01*	*–0.08*
200 m	1.5 ± 0.5%	1.5 ± 0.7%	1.4 ± 0.6%	1.5 ± 0.5%	1.5 ± 0.5%	1.6 ± 0.9%	1.7 ± 0.9%	1.7 ± 0.6%	1.9 ± 0.8%	1.7 ± 1.0%
	0.16	*–0.16*	*0.12*	*0.08*	*–0.11*	*–0.12*	*–0.04*	*–0.58***	*–0.05*	*–0.22*
400 m	1.7 ± 0.8%	1.7 ± 0.6%	1.7 ± 0.6%	1.6 ± 0.6%	2.2 ± 0.7%	2.4 ± 0.8%	1.9 ± 0.7%	1.9 ± 0.8%	1.8 ± 0.7%	1.6 ± 0.9%
	0.00	*–0.01*	*–0.22*	*–0.33*	*–0.23*	*–0.41**	*0.01*	*0.46*	*0.23*	*0.12*
800 m	1.5 ± 0.6%	1.5 ± 0.7%	1.5 ± 0.6%	1.7 ± 0.7%	1.9 ± 0.7%	1.8 ± 1.0%	1.5 ± 0.6%	1.2 ± 0.7%	1.9 ± 1.0%	1.3 ± 0.9%
	–0.19	*–0.01*	*0.19*	*0.28*	*–0.37*	*–0.05*	*0.40*	*0.50*	*–0.31*	*–0.17*
1,500 m	1.4 ± 0.8%	1.1 ± 0.6%	1.3 ± 0.4%	1.4 ± 0.8%	1.7 ± 0.8%	1.4 ± 0.7%	1.2 ± 0.4%	1.3 ± 0.7%	1.8 ± 0.8%	1.5 ± 0.7%
	–0.06	*0.10*	*0.08*	*0.22*	*–0.06*	*–0.21*	*–0.02*	*–0.42*	*–0.10*	*–0.51*

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.
Pearson's correlation coefficient (r) with corresponding statistical significance is indicated in italic letters below the descriptive data for all 10 years prior to the championships.

TABLE 2 | Number of races per year (mean ± standard deviation) correlated with ranking at the 2018 European Swimming Championships.

	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009
All strokes and distances	9.8 ± 4.9	9.3 ± 4.7	9.0 ± 4.3	9.4 ± 4.9	8.6 ± 4.9	7.7 ± 4.6	6.7 ± 4.1	6.6 ± 4.3	6.4 ± 4.2	5.8 ± 3.8
	*−0.33****	*−0.31****	*−0.25****	*−0.28****	*−0.29****	*−0.29****	*−0.23****	*−0.26****	*−0.27****	*−0.19***
Butterfly	10.6 ± 5.3	10.0 ± 5.1	8.4 ± 4.2	9.0 ± 5.3	7.7 ± 4.7	7.2 ± 4.3	5.9 ± 3.4	6.9 ± 4.6	6.1 ± 4.0	6.2 ± 3.8
	*−0.35****	*−0.33****	*−0.24***	*−0.33****	*−0.41****	*−0.24**	*−0.30***	*−0.45****	*−0.32**	*−0.02*
Backstroke	9.6 ± 4.4	10.0 ± 4.3	9.9 ± 4.8	9.9 ± 5.2	10.1 ± 5.2	8.3 ± 4.8	6.7 ± 3.8	6.6 ± 4.8	7.2 ± 5.2	6.3 ± 4.2
	*−0.48****	*−0.25***	*−0.28***	*−0.33****	*−0.39****	*−0.32****	*−0.27**	*−0.36***	*−0.43***	*−0.37**
Breaststroke	10.7 ± 5.3	9.7 ± 5.1	9.8 ± 4.2	9.9 ± 5.0	8.5 ± 4.9	7.9 ± 4.3	6.8 ± 3.9	6.2 ± 3.8	6.6 ± 3.9	6.8 ± 4.6
	*−0.60****	*−0.46****	*−0.34****	*−0.31****	*−0.25***	*−0.37****	*−0.28***	*−0.22**	*−0.32***	*−0.30**
Freestyle	10.3 ± 5.0	9.1 ± 4.8	9.2 ± 4.2	9.7 ± 4.8	8.8 ± 5.0	7.2 ± 4.3	6.6 ± 3.9	6.9 ± 4.2	6.2 ± 4.2	4.9 ± 2.9
	*−0.49****	*−0.48****	*−0.37****	*−0.42****	*−0.27****	*−0.26***	*−0.14*	*−0.27**	*−0.28**	*−0.25*
Individual medley	9.6 ± 4.2	9.7 ± 4.4	10.5 ± 4.0	10.5 ± 4.9	9.2 ± 4.4	8.1 ± 4.0	7.1 ± 4.3	7.3 ± 4.4	7.6 ± 4.4	5.4 ± 3.5
	−0.25	*−0.33*	*−0.38*	*−0.42**	*−0.70****	*−0.58***	*−0.52**	*−0.73****	*−0.41*	*−0.24*
50 m	10.2 ± 5.6	9.5 ± 5.1	9.1 ± 4.4	9.6 ± 4.7	8.6 ± 5.3	6.8 ± 4.5	7.1 ± 3.9	7.4 ± 5.0	5.8 ± 4.9	5.2 ± 3.8
	*−0.49****	*−0.39***	*−0.37***	*−0.40***	*−0.42***	*−0.43***	*−0.42***	*−0.57***	*−0.47**	*−0.28*
100 m	10.0 ± 4.7	9.1 ± 4.7	9.2 ± 4.5	9.8 ± 5.2	9.6 ± 5.2	7.6 ± 4.2	7.0 ± 3.9	7.0 ± 4.3	6.9 ± 4.3	5.2 ± 2.7
	*−0.55****	*−0.50****	*−0.46****	*−0.48****	*−0.29**	*−0.26**	*−0.04*	*−0.23*	*−0.28*	*−0.25*
200 m	10.8 ± 4.7	8.7 ± 4.5	9.4 ± 3.6	9.9 ± 4.3	8.0 ± 4.4	7.0 ± 4.3	5.4 ± 3.5	6.3 ± 3.2	5.3 ± 2.9	3.6 ± 1.6
	*−0.43***	*−0.60****	*−0.22*	*−0.39***	*−0.17*	*−0.14*	*−0.09*	*−0.08*	*−0.00*	*−0.34*
400 m	8.1 ± 4.0	8.5 ± 4.1	8.3 ± 3.5	8.8 ± 3.7	10.7 ± 5.7	12.1 ± 7.7	10.8 ± 7.6	9.4 ± 5.5	7.9 ± 4.8	5.8 ± 4.4
	*−0.41**	*−0.48***	*−0.59***	*−0.47***	*−0.73****	*−0.65****	*−0.42*	*0.44*	*−0.05*	*−0.08*
800 m	6.0 ± 2.1	5.9 ± 2.6	5.8 ± 2.2	7.1 ± 3.4	6.6 ± 1.8	6.4 ± 3.9	6.7 ± 3.1	5.4 ± 3.2	5.0 ± 3.0	4.0 ± 2.4
	−0.03	*−0.14*	*−0.24*	*−0.04*	*−0.23*	*−0.50 **	*−0.18*	*−0.15*	*0.21*	*−0.64*
1,500 m	5.4 ± 2.1	5.6 ± 2.3	6.1 ± 1.8	7.0 ± 3.2	5.1 ± 1.7	5.8 ± 2.3	5.7 ± 2.6	4.4 ± 2.2	4.5 ± 1.8	4.3 ± 1.5
	−0.06	*−0.06*	*−0.25*	*0.19*	*−0.09*	*−0.67***	*−0.30*	*−0.11*	*−0.39*	*−0.28*

$^{*}p < 0.05$.
$^{**}p < 0.01$.
$^{***}p < 0.001$.
Pearson's correlation coefficient (r) with corresponding statistical significance are indicated in italic letters below the descriptive data for all 10 years prior to the championships.

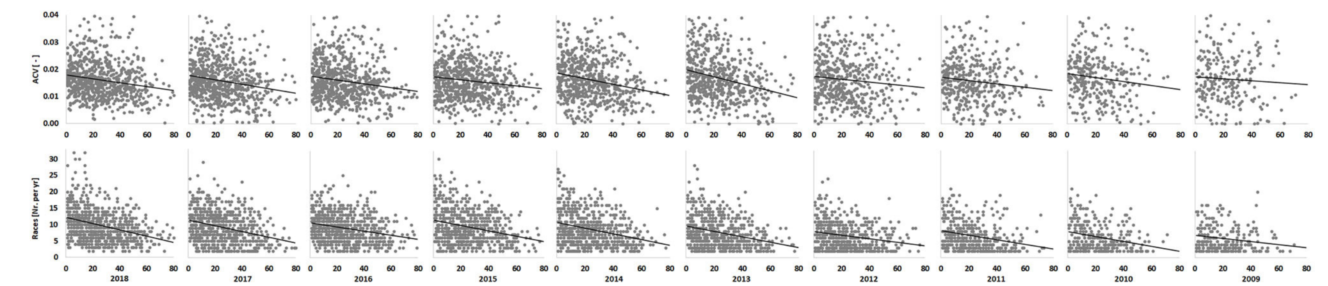

FIGURE 1 | Correlation matrixes of all swimming strokes and race distances for annual variation in competition performance (ACV) and number of races per year (Races). Data points represent individual values for each participant and year in regard to ranking at the 2018 European Swimming Championships.

$r = -0.27$, $p = 0.002$), breaststroke (23.3 ± 3.1 yrs, $r = -0.17$, $p = 0.045$), and freestyle (22.2 ± 3.0 yrs, $r = -0.20$, $p = 0.005$) but not individual medley (24.0 ± 3.7 yrs, $r = -0.25$, $p = 0.215$).

Regression Analysis

Using multiple linear regression, predictive values determined the 2018EC ranking based on ACV, number of races per year, and age. For pooled data of all strokes and distances, regression analysis explained 20% ($p < 0.001$) of total variance in the 2018EC ranking (**Table 3**). All predictors contributed significantly to the outcome variable ($p < 0.001$). Number of races had the largest effect ($\beta = -0.34$), followed by age ($\beta = -0.19$), and ACV ($\beta = -0.16$).

The regression model explained a significant proportion ($p < 0.001$) of total variance in the 2018EC ranking for butterfly (28%), backstroke (30%), breaststroke (39%), and freestyle (37%). Individual medley remained unexplained. For all strokes, number of races per year had the largest effect on ranking ($\beta = -0.37$

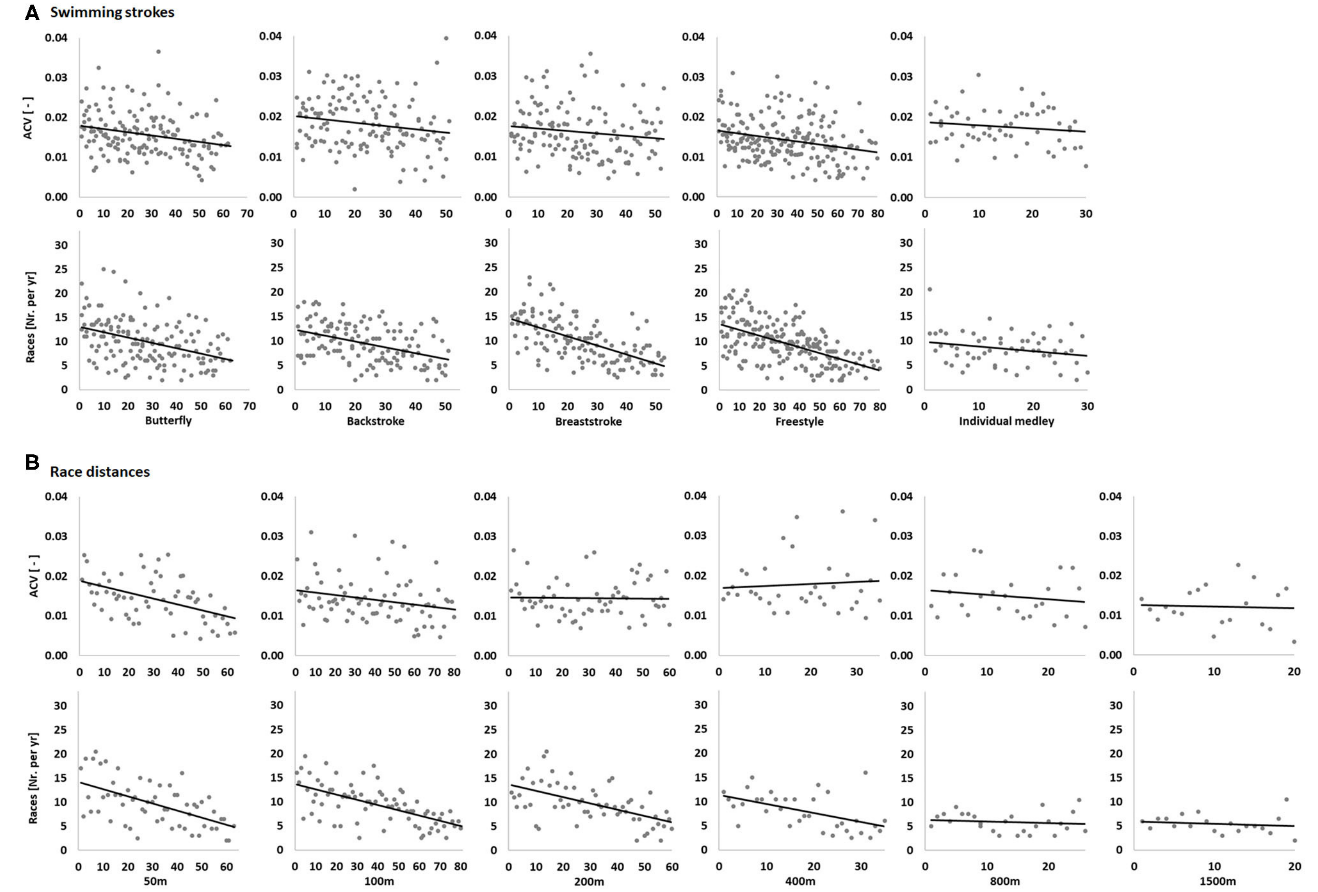

FIGURE 2 | Correlation matrixes of each swimming stroke **(A)** and race distance **(B)** for annual variation in competition performance (ACV) and number of races per year (Races). Data points represent individual values for each participant in regard to ranking at the 2018 European Swimming Championships.

to −0.59). In addition, ACV and age contributed significantly to variation of the 2018EC ranking for butterfly, backstroke, and freestyle (refer to **Table 3**).

In regard to race distance, the regression model explained a highly significant proportion ($p < 0.001$) of variance in the 2018EC ranking for 50 m (47%), 100 m (45%), and 200 m races (31%). A significant proportion ($p = 0.013$) was also explained for 400 m (29%) but not 800 and 1,500 m races. Number of races showed the largest effect on the dependent variable for the 50, 100, 200, and 400 m races ($\beta = -0.42$ to -0.59). A significant age effect was evident for 50 m ($\beta = -0.29$) and 100 m races ($\beta = -0.20$). The ACV showed a significant effect on 50 m races only ($\beta = -0.25$).

DISCUSSION

The main findings of this study were that number of races per year had the largest effect on ranking at the 2018EC, followed by age and ACV. The regression model explained a significant proportion of the 2018EC rankings for butterfly (28%), backstroke (30%), breaststroke (39%), and freestyle (37%) but not individual medley. Regarding race distance, rankings for 50 m (47%), 100 m (45%), 200 m (31%), and 400 m races (29%) were explained, but not for 800 and 1,500 m races. Although, correlations were small to medium, higher ranked swimmers at the 2018EC showed a significantly greater number of races per year and larger ACV for all ten and nine consecutive years, respectively, prior to the 2018EC.

The recent development in swimming, with the introduction of new multi-stage events, such as the International Swimming League (ISL, 2019), in addition to the established World Cup races and season's main events, i.e., Europeans, World Championships, and Olympic games, increased number of races in the competition schedule (FINA, 2020a). Especially successful swimmers may be invited to and qualify for additional events. Indeed, the results of the present study showed a larger number of races per year for higher ranked swimmers at the 2018EC. With such a high number of races, a complete 2–4 week taper period is not feasible for every competition, as loss of training time would accumulate over the course of the season (Hellard et al., 2019). However, when training and competition load are matched and incorporated into a well-periodized season (Hellard et al., 2019), racing can be a very specific and intense way of training (Carrasco et al., 2007; Nugent et al., 2017) and aid physiological,

TABLE 3 | Multiple linear regression analysis for annual variation in competition performance (ACV), number of races per year (Races), and age.

	Regression model					Regression coefficients		
	Entries	R square	*F*-value	*P*-value		Beta	*T*-value	*P*-value
All strokes and distances	752	0.20	$F_{(3,748)} = 62$	$P < 0.001$	ACV	−0.16	$T = -5$	$P < 0.001$
					Races	−0.34	$T = -10$	$P < 0.001$
					Age	−0.19	$T = -6$	$P < 0.001$
Butterfly	152	0.28	$F_{(3,148)} = 19$	$P < 0.001$	ACV	−0.19	$T = -3$	$P = 0.008$
					Races	−0.37	$T = -5$	$P < 0.001$
					Age	−0.30	$T = -4$	$P < 0.001$
Backstroke	132	0.30	$F_{(3,128)} = 19$	$P < 0.001$	ACV	−0.15	$T = -2$	$P = 0.049$
					Races	−0.45	$T = -6$	$P < 0.001$
					Age	−0.31	$T = -4$	$P < 0.001$
Breaststroke	133	0.39	$F_{(3,129)} = 27$	$P < 0.001$	ACV	−0.06	$T = -1$	$P = 0.416$
					Races	−0.59	$T = -8$	$P < 0.001$
					Age	−0.09	$T = -1$	$P = 0.204$
Freestyle	197	0.37	$F_{(3,193)} = 37$	$P < 0.001$	ACV	−0.13	$T = -2$	$P = 0.024$
					Races	−0.53	$T = -9$	$P < 0.001$
					Age	−0.15	$T = -3$	$P = 0.008$
Individual medley	27	0.17	$F_{(3,23)} = 2$	$P = 0.228$	ACV	0.08	$T = 0$	$P = 0.687$
					Races	−0.34	$T = -2$	$P = 0.099$
					Age	−0.18	$T = -1$	$P = 0.389$
50 m	60	0.47	$F_{(3,56)} = 16$	$P < 0.001$	ACV	−0.25	$T = -2$	$P = 0.027$
					Races	−0.42	$T = -4$	$P < 0.001$
					Age	−0.29	$T = -3$	$P = 0.005$
100 m	77	0.45	$F_{(3,73)} = 20$	$P < 0.001$	ACV	−0.17	$T = -2$	$P = 0.056$
					Races	−0.59	$T = -7$	$P < 0.001$
					Age	−0.20	$T = -2$	$P = 0.024$
200 m	60	0.31	$F_{(3,56)} = 9$	$P < 0.001$	ACV	0.02	$T = 0$	$P = 0.894$
					Races	−0.56	$T = -5$	$P < 0.001$
					Age	−0.02	$T = 0$	$P = 0.837$
400 m	35	0.29	$F_{(3,31)} = 4$	$P = 0.013$	ACV	0.01	$T = 0$	$P = 0.987$
					Races	−0.54	$T = -3$	$P = 0.001$
					Age	−0.17	$T = -1$	$P = 0.281$
800 m	26	0.28	$F_{(3,22)} = 3$	$P = 0.063$	ACV	−0.17	$T = -1$	$P = 0.405$
					Races	−0.07	$T = 0$	$P = 0.749$
					Age	−0.50	$T = -3$	$P = 0.012$
1,500 m	20	0.19	$F_{(3,16)} = 1$	$P = 0.315$	ACV	−0.07	$T = 0$	$P = 0.803$
					Races	−0.13	$T = -1$	$P = 0.617$
					Age	−0.42	$T = -2$	$P = 0.084$

technical, and psychological skill acquisition (Gould and Rolo, 2004; Carrasco et al., 2007; Meggs et al., 2016; Nugent et al., 2017; Ribeiro et al., 2017). Therefore, races of minor importance should not be neglected but used for training purpose although these unprepared and untapered races may lead to race results off the swimmer's personal best and may increase performance variation. However, higher ACV was related to better 2018EC ranking and unsuccessful races did not seem to hamper peak performance at the season's main event.

In addition to physiological, psychological factors may affect number of races per year. Highly talented and successful athletes are associated with a high intrinsic motivation (Issurin, 2017), task orientation, and a growth mindset (Cervello and Santos-Rosa, 2001; Dweck, 2009; Dweck and Yeager, 2019). The success these swimmers experience in competition may further motivate them for race participation (Weinberg, 1979) and help to explain the relation between higher ranking and greater number of races per year. Thus, lower ranked and less successful swimmers may also benefit from more opportunities to practice their race specific skills and prove themselves to others in competition (Mccormick et al., 2015). With the right assessment, less important races can be accepted as a challenge and help to develop the right mindset, build competition routine, and self-confidence, rather than fear and anxiety (Gould and Rolo, 2004). In particular, during adolescents, a larger number of races could provide learning opportunities to develop important psychological skills, such as dealing with defeat, coping with expectations, and developing resilience (Sarkar et al., 2015; Meggs et al., 2016; Burns et al., 2019). As higher ranked swimmers at the 2018EC swam more races for all 10 years prior to the championships, we conclude that a high number of races, when differing between so-called learning competitions and major events, may support the development of young swimmers.

In the present study, higher ranked athletes at the 2018EC were older compared to their lower ranked peers. Ericsson and co-workers proposed the concept of deliberate practice, where a certain amount of training, i.e., ∼10,000 h within 10 yrs, is required to achieve elite performance (Ericsson et al., 1993; Ericsson and Harwell, 2019). While there is a heated debate on total variance explained within the multifactorial talent model (Macnamara et al., 2014; Ericsson and Harwell, 2019), quality and amount of practice accumulated with age seems to impact long-term athlete development in swimming, in addition to genetics, economies, and available support (Tucker and Collins, 2012; Breitbach et al., 2014). More detailed analyses of the present data showed that age was correlated to ranking in butterfly, backstroke, breaststroke, and freestyle but not to individual medley ranking. This may be explained by young age at peak performance for individual medley (Allen et al., 2014; Dormehl et al., 2016), the early specialization in swimming (Moesch et al., 2011; Feeley et al., 2016), or performance density that may also be different between swimming strokes of the pool events (Baldassarre et al., 2017). However, differences in performance density between swimming strokes warrant further investigation, in particular its effect on swimmers' age.

Previous studies showed that performance of elite swimmers peaked at a mean age of 24.2 ± 2.1 yrs with a 2.6 ± 1.5 yrs window of peak performance (Allen et al., 2014). While age of peak performance decreased with increased race distance (Wolfrum et al., 2013; Allen et al., 2014), the present study also showed a smaller effect of age on ranking with increased distance in 50–200 m freestyle races. This finding is in contrast to other endurance sports, in which age of peak performance increases with longer distances (Allen and Hopkins, 2015). From a physiological perspective, the aerobic capacity and movement economy is built up over years (Zaryski and Smith, 2005), increasing far beyond the age of 22.9 ± 2.2 yrs that is established as age of peak performance in male long-distance pool swimmers (Allen et al., 2014). However, swimming, in particular long-distance pool events, is generally perceived to be mentally tough, with psychological factors dominating drop-out numbers (Monteiro et al., 2017). Therefore, motivational rather than physiological aspects may affect age of peak performance. Previous studies showed, that participation at (Junior-) World Championships are important success factor for upcoming competitions (Yustres et al., 2017, 2019) and that success is a great motivator to keep up the hard work needed for training and competition at a high level (Weinberg, 1979). However, early success at junior level is no guarantee for success at elite age (Barreiros et al., 2014) and long-term athlete development systems, which vary depending on the nation, may affect age at peak performance (Ford et al., 2011; Lloyd et al., 2016). As the present study showed that higher ranked swimmers at the 2018EC were older, from an individual swimmer's perspective, peaking at a later age may be beneficial for elite age success. Swimmers who do not progress to (semi-)finals at European championships are encouraged to gain experience and maintain motivation for high-level training and competition (Yustres et al., 2017, 2019). As such, swimmers below age at peak performance may increase their success chances for later championship participations.

Methodological Considerations

Higher ranked swimmers at the 2018EC may participate in more races, due to racing in the heats, semi-finals, and finals (Pyne et al., 2004; Trewin et al., 2004). Additionally, at a senior elite level, more successful swimmers may be more frequently invited to meets and qualify for more competitions, i.e., International Swimming League, World Cup, etc. (ISL, 2019; FINA, 2020a). However, qualification trials for the European championships are fully competitive with no wild cards granted (LEN, 2020a). Therefore, lower ranked swimmers participate in heats, semi-finals, and finals at qualification, national, and other international competitions throughout the season and may experience a similar number of options for race participation. From a practical perspective, international swimmers may compete successfully in more than one swimming stroke, which would contribute to an increased number of races (IOC, 2016b; LEN, 2020b). However, skill transfer between swimming strokes and the effect on number of races per year, long-term athlete development, and competition success warrant further investigations.

The present study is limited to European swimmers. Despite statistical significance, only small to medium correlations for number of races and ACV were found. However, the present study represents the initial approach to identify novel success factors. Future studies should quantify the effect of number of races and ACV in the multi-dimensional model of talent development and progression, which involves psychological, economical, genetic, and social factors (Tucker and Collins, 2012; Breitbach et al., 2014; Gullich and Emrich, 2014; Macnamara et al., 2014; Lloyd et al., 2015a,b; Malina et al., 2015; Ericsson and Harwell, 2019). For the practical application, competition data are feasible to derive and provide objective data for talent development and identification. For the present investigation, data were derived with no information on pacing strategies applied in the races. Better swimmers commonly pace through the heats and semi-finals in order to save energy for the finals, which may have increased ACV for the higher ranked swimmers (Pyne et al., 2004; Trewin et al., 2004). Future studies should take race analyses and applied pacing strategies into account when investigating performance variation.

CONCLUSION

While talent development undoubtedly involves multiple factors, i.e., genetics, economies, available support, quality and amount of practice accumulated with age (Tucker and Collins, 2012; Ericsson and Harwell, 2019), the present study investigated ACV, number of races per year, and age as potential success factors for international swimming competitions. Higher ranked swimmers were older than their lower ranked peers. Therefore, young swimmers below age of peak performance who do not progress to (semi-)finals at European championships are encouraged to continue competing at a high-level and benefit from success chances that increase with age. As higher ranked competitors swam more races per year, with a greater ACV across the 10 years investigated, future studies should quantify the effect of these factors on the multi-dimensional model of long-term athlete development and progression (Tucker and Collins, 2012; Breitbach et al., 2014; Gullich and Emrich, 2014; Macnamara et al., 2014; Lloyd et al., 2015a,b; Malina et al., 2015; Ericsson and Harwell, 2019). From a practical perspective, race results far off the personal best during the course of the season did not impair success at the season's main event, where athletes were fully tapered and prepared. The larger number of races per year that are swum throughout the career of successful swimmers could provide mental learning opportunities and race specific technical and physiological adaptations. In particular, young swimmers could use races of less importance for these learning opportunities which may increase success later on in their career. Coaches should assess unsatisfactory race results with care and help athletes to build competition routine and self-confidence, rather than fear and anxiety (Gould and Rolo, 2004). While participation in competition requires time and energy for traveling (Calleja-Gonzalez et al., 2020), number of races (entries) at a given number of competition could be increased in order not to compromise time for practice. Future research needs to compare number of competitions and number of races (entries) per year regarding success at the season's main event.

DATA AVAILABILITY STATEMENT

All data are available on the publicly accessible database https://www.swimrankings.net/ and can be retrieved by any user.

AUTHOR CONTRIBUTIONS

D-PB and MR: conception of the experimental design. D-PB, IL, EM, PS, DB, and MR: data collection. D-PB, IL, SH, EM, PS, DB, and MR: data analysis and reading and approving final version of the manuscript. D-PB, SH, and MR: data interpretation. D-PB: preparing the manuscript. IL, SH, EM, PS, DB, and MR: critically revising the manuscript. All authors contributed to the article and approved the submitted version.

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REVIEW
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Future Directions and Considerations for Talent Identification in Australian Football

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As the focus on the elite Australian Football League competition becomes greater so too does the demand for success. Clubs are heavily scrutinized for their draft selections and as such are taking more interest in the younger levels of competition in an attempt to identify and monitor talent. Based on contemporary talent identification knowledge, this review examines the current talent identification process in Australian football, with a focus on areas to potentially improve or inform future developments. Currently, a significant gap exists between static and isolated assessment procedures used to identify talent in Australian football and the dynamic nature of match play. Future assessments should consider factors such as maturation, fatigue and ecological dynamics. The addition of a valid and reliable technical skill assessment (e.g., a small-sided game) to the current Australian Football League draft combine was recommended.

Keywords: Australian football, talent identification, ecological dynamic, skill assessment, small-sided games (SSG), kicking, AFL, talent selection

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INTRODUCTION

Talent is a multi-dimensional concept and requires the effective and efficient organization of an individual's technical, tactical, physiological, and psychological competencies to be applied concurrently to meet the requirements of both the environment and the sporting situation (Vaeyens et al., 2009; Johnston et al., 2018). Talent identification programmes endeavor to discover this "talent" in individuals with the greatest potential to respond to a training intervention and reach the highest level in their sport (Hoare and Warr, 2000; Abbott and Collins, 2004). The ability to identify talented players in team sports is not only a financially rewarding business but a key component of future winning teams and long term success (Gee et al., 2010; Larkin and Reeves, 2018).

Talent pathways provide identified players with additional resources (e.g., expert coaching) and training to support the development of players to progress into high performance sport (Williams and Reilly, 2000). In Australian football, the talent pathway involves players progressing from regional development squads, to state squad selection, through to state and national academies with the eventual goal of being drafted into the Australian Football League (AFL). Talent pathways in Australian football have grown considerably with clubs now establishing their own youth academies. These academies aim to attract, retain and develop male and female players from 11 to 13 years (Tribolet et al., 2019) in an attempt to increase the talent pool, identify talent and select players onto their senior club list. Another way for players to showcase their talent is at the Australian Football League draft combine where physical, technical, and psychological capabilities are tested. These measures are then combined with talent recruiter subjective opinions to help identify playing status (i.e., elite or sub-elite) (Woods et al., 2015a) and select players (Robertson et al., 2015).

The specific traits assessed within talent identification programmes are varied. Key components of performance, such as the technical, tactical, physiological, and psychological, have all been used and examined within the literature (Johnston et al., 2018). These investigations; however, have delivered inconsistent results due to factors such as varying study designs, high variability (Johnston et al., 2018), unidimensional assessment designs (Bonney et al., 2019) or performance being constrained due to the task, environment and/or the individual (Newell, 1986). Based on contemporary talent identification knowledge, this review will examine the current talent identification process in Australian football from a physical (maturation; fatigue), technical, and tactical (i.e., decision making) perspective, while considering the associated theories (i.e., ecological dynamics; representative design) to potentially improve or inform future developments. It should be noted; however, there are many critical determinants of talent development including psychological, sociological, demographical, and socio-cultural influences (Woolcock and Burke, 2013; Toohey et al., 2018).

TALENT IDENTIFICATION IN AUSTRALIAN FOOTBALL

Australian football is an example of a team sport based upon many interconnected performance components (i.e., technical, tactical, physical, psychological). Each year, talent identified players are screened for their competency in each of these components. This screening occurs at a draft combine where players complete a testing battery of standardized technical (e.g., handball test), physical (e.g., 20-m sprint test), psychological (e.g., personality test), and medical tests (e.g., eye test) conducted over a 4-day period (Bonney et al., 2019). Results from these assessments are then used in combination with club recruiter opinion to justify talent selection decisions (Toohey et al., 2018).

Physical capabilities are commonly used in talent identification programmes (Johnston et al., 2018). When assessing drafted Australian football players, researchers discovered players who can perform above level-14 on the multistage fitness test and sprint 20-m in under 3 s were more likely to be drafted (Robertson et al., 2015). Furthermore, physical capabilities, such as aerobic capacity, speed and power have been used to distinguish between team selection and non-selection, career progression, and playing performance (Young and Pryor, 2007; Veale et al., 2010). Although physical testing does provide an insight into the physical abilities of potential draftees it does not identify how proficient a player is with the ball.

Match play performance requires a player to combine their technical, tactical, physical, and psychological components to effectively participate in the game. However, unidimensional assessment models are weak predictors of team selection and match performance. Gogos et al. (2020) investigated 1,488 drafted players between 1999 and 2016. They found physical and anthropometric testing results could only explain 4% of matches played and 3% of in-game performance measures with individual combine tests only explaining <2% of the matches played. The authors summarized these results by suggesting the Australian Football League draft combine is a poor measure of talent selection. This result is similar to research conducted in the National Football League (Kuzmits and Adams, 2008) and may suggest when tasks are completed in isolation, and low in representation of match play demands, their suitability to talent selection is limited (Bonney et al., 2019).

Whilst physiological capabilities are important in the game of Australian football, ball possession, and technical skill proficiency have been shown to be greater influences on match outcomes (Robertson et al., 2016). In addition, skill proficiency has been shown to have a higher level of reliability when attempting to identify talent (Gabbett et al., 2007a). For example, in a study of junior volleyball players it was found particular skill test results of game proficiency (subjective coach evaluation of passing and serving) were the only variables to discriminate between selected and non-selected players in comparison to physiological or anthropometric results (Gabbett et al., 2007a). A similar result was found in rugby players. When investigating first grade rugby players Gabbett et al. (2007b) found selection was based more upon playing experience and skill proficiency of players than their physical capacities. The authors did; however, note a high level of physical fitness did contribute to effective playing ability in these selected players. In Australian football, the analysis of skill effectiveness has been successful in identifying first round draft picks in comparison to second and fourth round picks. First round draft picks had more kicks, effective disposals, contested possessions, and contested marks than athletes selected later in the draft selection (Woods et al., 2017). Furthermore, drafted players were able to deliver the ball more times within the attacking 50-meter (50 m) zone than non-drafted players (Woods et al., 2016a).

Sport specific skill proficiency has also been shown to be a sensitive predictor of successful teams (Kempton et al., 2017). When comparing winning to losing a game, it was discovered winning quarters consisted of more skill involvements (i.e., kicking and handballing) and higher skill efficiency whilst quarters lost involved more physical requirements (Sullivan et al., 2014a). This highlights the importance of skill involvements and skill proficiency, in comparison to physical activity profiles, to team success. Although the current technical assessments used in the Australian Football League draft combine can potentially predict talent it must be considered that the assessments used (i.e., the Australian Football League kicking efficiency test) are predominantly performed in an isolated setting, separating the skill from the demands of match performance. Consequently, these assessments may lack the identification of key components such as decision making, game tempo adjustment, and tactical awareness (Burgess and Naughton, 2010). Due to the scarcity of representative validity within these assessments it is plausible to suggest the results obtained may not accurately identify all talented players and may produce results different from match play. As such, talent identification models need to provide opportunities for athletes to develop these underlining skills and have these skills monitored throughout their involvement in the programme as well as adjusting training loads accordingly

(Abbott and Collins, 2004; Abbott et al., 2005; Burgess and Naughton, 2010).

When contemplating talent identification in Australian football, it is apparent more sport specific research is required to obtain clarity on the interconnecting components. Researchers have used multidimensional assessment designs (e.g., isolated assessments of technical, physical, and psychological capabilities) to identify talent (Woods et al., 2016c; Tribolet et al., 2018). Although these designs were more successful than single assessments, they do not consider how these components are interconnected or replicate the performance demands of the game. More recently, Bonney et al. (2020d) developed a small-sided game where all the performance components were combined into the one assessment. This assessment was 97% successful in identifying talented youth players and was suggested to be a more time efficient and ecologically valid way to identify talented players. Reviews of talent assessment; however, have highlighted the high level of variability in the elements separating higher and lesser skilled players (Johnston et al., 2018). Although, variability should be carefully considered as variability can be "good" (functional) and "bad" (dysfunctional) (Woods et al., 2020b). A possible suggestion to achieving greater continuity is to have studies based on sound theoretical principles and valid research designs (Bergkamp et al., 2018).

Current research suggests sports training and assessment environments should be guided by an ecological dynamics framework (Davids et al., 2013b; Bonney et al., 2019; Woods et al., 2020a,b). This framework may be used to guide the design of new assessments by practitioners developing assessments centered around the athlete-environment interaction (Woods et al., 2020a). These assessments should consider the interacting constraints, movement behaviors, contain adequate environmental variables and ensure the functional coupling between perception and action processes (Pinder et al., 2011). Additionally, they should consider the effect of physical and psychological maturity and relative age effect (Burgess and Naughton, 2010) whilst challenging players to make accurate and timely decisions whilst executing the skill under some level of fatigue (Dawson et al., 2004; Gonzailez-Va-llora et al., 2015).

The ability to proficiently kick the ball under match performance demands (e.g., evading opponents and kicking the ball to a teammate) is a critical factor in Australian football. A coach's perception of player performance is largely influenced by the number of disposals they have had and their effectiveness to pass the ball and maintain possession (Sullivan et al., 2014b). Considering the importance of kicking in Australian football, it is surprising there is currently very little research conducted on the application of using kicking performance as an assessment tool for talent identification (Cripps et al., 2015; Woods et al., 2015b). In an attempt to assess kicking skill performance of elite youth Australian football players, the Australian Football League included two skill tests to the Australian Football League draft combine; however, the ecological validity of both tests is a major concern (Bonney et al., 2019). The most representative skill test at the Australian Football League Combine is the set-shot goal kicking test. A set-shot is a closed skill performed during a stop in play as a result of a mark or free-kick penalty. To the author's knowledge no research has been conducted on this test to validate its use and without established validity it is unclear whether the test measures what it claims to Larkin et al. (2014). The second assessment, the kicking efficiency test, involves a player running toward a feeder who receives the ball and delivers it to one of six randomly assigned stationary targets (Cripps et al., 2015). Kicking performance is subjectively assessed on a scale from 0 to 5 (5 being the highest score) for each kick. Cripps et al. (2015) investigated the test on 121 semi elite under 16 (U16) male players and found the inter-rater reliability to be high; however, the test could only differentiate between dominant and non-dominant kicking leg accuracy across varying distances. The authors concluded more research was required to determine if the test can distinguish between higher and lesser skilled players and if kicking ability changes with age (Cripps et al., 2015). Woods et al. (2015b) also assessed the kicking efficiency test on 50 U18 male players (25 state representatives and 25 non state representatives) and found when kicking accuracy and ball speed were combined playing status was able to be predicted. A limitation of the current kicking test is the assessment is conducted in isolation and does not assess the range of in-game kicking constraints typically performed within the performance environment. As such, the dynamic interactions between organismic, environmental, and task constraints are not necessarily representative of the requirements of match play leading to possible invalid results (Newell, 1986; Abbott et al., 2005; Pinder et al., 2011; Vilar et al., 2012).

Researchers have attempted to provide greater clarity on skill assessments through the suggestion of a 5-Level Performance Assessment Model (Bonney et al., 2019). The model applies match play notational analysis to separate technical game skill on a continuum comprising of Level-1 (i.e., laboratory test), Level-2 (i.e., static field-based test), Level-3 (i.e., dynamic field-based test), Level-4 (i.e., small-sided game field-based test), and Level-5 (i.e., match play). The proposed model provides coaches with a better understanding of the potential performance demands and key outcomes associated with each level. In an attempt to fill the void between Level-2 and Level-5 researchers have developed the first two valid and reliable Australian football kicking skill assessments: a dynamic kicking assessment (an example of a Level-3 test) (Bonney et al., 2020c) and a small-sided game (an example of a Level-4 test) (Bonney et al., 2020d). These assessments used notational analysis to consider match play kicking demands and applied a more integrated approach of match play components. Interestingly, the authors found both the dynamic kicking assessment (68.3% successful) and the small-sided game (97%) were successful at identifying player skill levels. The results may suggest as assessments move further along the continuum, integrating more components of match play, they are also more successful at identifying talent. It was proposed these results may provide coaches with worthwhile information regarding player kicking performance during competition rather than specific details on how they will perform the skill. As such, Level-3 and Level-4 assessments (such as the ones discussed above) may provide greater insights into match play kicking proficiency thereby improving current talent identification programmes. Accordingly, these assessments are recommended to be included in future Australian football draft combines.

MATURATION

Maturation is an important factor to be considered when trying to identify talent. When identifying athletes below the age of 15, differences as small as 1-year in stages of puberty can have a significant effect upon an athlete (Cobley et al., 2009). Early maturers have more developed physical attributes such as height and weight which are related to a player's strength, power, and speed (Russell et al., 1998; Sheppard et al., 2012). As such, these players appear more competent than their peers and consequently more likely to attract the attention of talent recruiters (Cobley et al., 2009; Figueiredo et al., 2010). Coutts et al. (2014) investigated 806 players drafted to play elite Australian football. They found drafted players were more likely to be born in the first quartile and first half of the year, had advanced physical and psychological maturity and had exposure to higher level coaching.

The term relative age effect (RAE) is used to describe a selection bias dependent upon the time of year the athlete is born (Andronikos et al., 2016). The relative age effect appears to be most pronounced between the ages of 15 and 18 at representative level (Cobley et al., 2009). Haycraft et al. (2018) examined the influence of relative age effect across the Australian Football League talent pathway. They found a relative age effect was present at the state U16 level and is maintained at State and National level combines. Collectively these studies would imply early maturers are being selected based more upon physical statue rather than skill proficiency.

In soccer, stabilization in physical activities, such as repeated sprint ability, do not occur until 18-years of age (Spencer et al., 2011). As such, trying to identify players on physical abilities prior to this age was unpredictable. Interestingly, once all athletes have gone through maturation, it has been found the late maturers are more likely to reach the elite level (Pearson et al., 2006), achieve longer careers and potentially have greater financial contracts (Gibbs et al., 2012; Deaner et al., 2013). This phenomenon has been identified as the "underdog" hypothesis, whereby younger players overcome early disadvantages (e.g., non-selection in early stages of a player's career) to become elite players (Schorer et al., 2009; Gibbs et al., 2012). This is largely due to once they have caught up to the early maturers physical statue, their years of playing against bigger and stronger competition have enabled them to develop superior technical proficiencies, tactical awareness (Schorer et al., 2009; Gibbs et al., 2012) and psychological advantages (Cumming et al., 2018).

It is important selection does not discriminate against late-maturing players who may develop their abilities later. A suggestion to avoid this is for coaches to apply a more skilled based selection criterion (e.g., skill proficiency) and look toward long term athlete development rather than short term success (Cobley et al., 2009). Cripps et al. (2016) investigated the effect of maturation on technical skills on 94 under 16 Australian football players. They found no significant differences between early and late maturation groups when examining technical skills; however, coaches' subjective opinion of overall technical skill, marking, and ball winning abilities were advanced in the earlier maturing group. In a follow-up study, Cripps et al. (2019) investigated if development pathway coaches' were influenced by the maturational status of adolescent players when predicting long-term career attainment predictions. The authors found predictive accuracy to be greatest for the late maturing player (79%) in comparison to early maturing players (52%), highlighting the complexity associated with identifying players at early stages of development pathways. These results have been supported from investigations in other sports. Figueiredo et al. (2010) noted how soccer-specific skills performed by players 11–14-years old were less affected by maturation than physiological attributes. Whilst in handball (Matthys et al., 2012) and basketball (Silva et al., 2010) sport-specific skill appeared to be independent of pubertal status. Overall, these results suggest technical skill assessments may be less influenced by maturation and subsequently a more appropriate way to identify and select talent in youth Australian football.

FATIGUE AND PRESSURE SITUATIONS

Successful athletes not only display a high proficiency of technical skill and decision making ability but they can display these traits under both fatigue and pressure situations (Kitsantas and Zimmerman, 2002; Royal et al., 2006). Fatigue; however, is an element often neglected by skill tests. There are many opinions on how to explain fatigue such as a decline in muscle force (Komi and Tesch, 1979), an increase in metabolic accumulation (Hargreaves et al., 1998) or energy substrate depletion (Balsom et al., 1999). These opinions can be further examined according to the time period where the activity took place. For example, fatigue following an intense period of exercise appears to be related to disturbances in muscle ion homeostasis whilst the initial constraint in generating maximal force post half time may be due to a lower muscle temperature; with the fatigue experienced toward the end of the game due to low levels of glycogen (Mohr et al., 2005).

Due to the varying definitions of the word "fatigue" researchers have suggested each definition has its own place in the literature dependent upon the context in which the term is being used (Abbiss and Laursen, 2007). During the game of Australian football, fatigue can lead to many detriments in playing performance. Kicking performance may decline due to alterations in the neuromuscular systems and force generation capacity, which may alter the mechanics of the kicking performance (Kellis et al., 2006). More recently, it has been shown elite level players adjust their movement strategy when kicking "fresh" compared to when they are fatigued (Coventry et al., 2015). Furthermore, fatigue can impact the speed at which information is taken in, processed and a response is initiated thereby impeding a player's ability to effectively select the correct passing option and execute the skill proficiently. Finally, moderately to high fatigue can impair performances requiring strength, endurance, and rapid movements (Lidor et al.,

2009) such as those displayed in Australian football marking, tackling, running and kicking.

When comparing experienced and less experienced players in Australian football, the experienced players had more skill involvements during the second and fourth quarters (in peak 3-min block) and performed technically and physically better following peak periods of match play than their counterparts (Black et al., 2016). A possible reason for this may be the shorter break duration at quarter and three quarter time, with lesser skilled players having more residual fatigue in their bodies following these breaks (Abbiss and Laursen, 2007). This research highlights how important skill proficiency is when not only in a fresh state but also, if not more importantly, in a fatigued state.

The type of activities players participate in will have a large impact upon their performance. Activities such as tackling and collisions have been shown to significantly impact the number of repeated high intensity efforts performed (Gabbett, 2013). In a study of 24 elite Australian football players it was shown less experienced players were more likely to cover less high-speed distances during the period following the most intense passage of play in comparison to experienced players (Black et al., 2016). Furthermore, these less experienced players had fewer involvements during high-intensity periods of the match as well as during the periods subsequent to the most intense periods of play. Joseph et al. (2017) investigated the relationship between aerobic capacity and kicking performance in Australian football. They noted players who had a higher yo-yo intermittent recovery two score had higher kicking speeds and better accuracy scores than players with lower aerobic capacities. This research is important as it demonstrates as fatigue increases technical and tactical abilities may deteriorate and this regression is more prominent in less experienced players than experienced players.

Many sport skills are performed in a fatigued state. Research; however, has suggested match related fatigue has a greater effect on a players ability to get involved with the ball than it does on a player's skill proficiency (Rampinini et al., 2009). The intensity of the fatigue is an important factor to consider within this context. In a study of 20 college students it was found soccer passing performance was better following moderate muscle fatigue in comparison to rest or high levels of fatigue. This test; however, was completed in a static environment where players had to dribble the ball within a certain area and pass the ball to a stationary box with no involvement from "live" opponents (Lyons et al., 2006). The level of the athlete may also be an important consideration. In water polo it was shown elite athletes are more resilient to physiological stresses occurring during competition and as such are better able to maintain their technical accuracy. These elite water polo players made 18% better decisions with high fatigue than with low fatigue with shooting accuracy and velocity being unaffected (Royal et al., 2006). Shooting technique; however, did decrease by 43% between pre-test and high-fatigue suggesting elite athletes are able to self-regulate in order to optimize their performance (i.e., they decreased their proficiency on non-essential technique to ensure accuracy and speed was maintained) (Kitsantas and Zimmerman, 2002; Royal et al., 2006). As current Australian football talent identification skill tests do not cater for fatigue, it is suggested a new skill test is implemented, where the level of fatigue is appropriate for the age and ability level of the athlete. Players can then be assessed on their ability to obtain possession of the ball, make decisions and execute a skill under fatigue conditions. The information gained from such a test may provide critical details to coaches regarding a player's technical skill performance during competition, rather than specific details on how a player will execute the skill.

DECISION MAKING

When athletes move, they do so with purpose. They carefully consider the information available in their environment, establishing their options and likely outcomes, before progressing (Araujo et al., 2006). Elite team sport players are therefore expert decision makers with the ability to read the play and make timely and accurate decisions (Berry et al., 2008). Furthermore, these attributes can take up to 13 years/4,000 h of invasion-type activity and sport specific practice to obtain (Baker and Cote, 2003; Berry et al., 2008). In knowing this, sport practitioners have used decision making assessments to identify talent.

In an attempt to assess decision making ability in Australian football players, video-based decision making tasks have been examined (Lorains et al., 2013; Woods et al., 2016b). When investigating 85 male Australian football players, across three skill levels (elite, sub-elite, and novice), it was found elite players have superior decision making accuracy compared to sub-elite and novice players (Lorains et al., 2013). Furthermore, it was suggested elite players use superior processing efficiency to perform more accurately when the speed of the video is increased from 0.75 speed to 2.0 speed. Similar results were also found when investigating the decision making ability of U18 Australian football players. Results indicated a video-based decision making task could correctly classify 92% of talent-identified players and 72% of the non-identified players, with the talent-identified players making more accurate game-based decisions compared to non-talent-identified players (Woods et al., 2016b). More recently, 360 degree virtual reality footage has been used as an alternative off-field decision making assessment tool to match broadcast; however, more research is needed to clarify its application to Australian football players (Kittel et al., 2019, 2020).

When trying to decipher how a player makes a decision it is crucial to examine the environmental and task constraints present, as these two components have an integral effect on the decision making process. A model used by practitioners to examine decision making ability is the constraints-led approach. This approach is an ecological model, centered on the relationships that emerge from interactions of players and their performance environment (Renshaw et al., 2016). It requires the practitioner to identify and modify interacting constraints to facilitate the emergence of perception-action couplings (Renshaw et al., 2016). To replicate match play decision making, it is critical these same constraints are present otherwise movement patterns may alter and the decision making process will adjust in order to adapt to the different stimulus (Araujo et al., 2006). To enhance decision making ability players use specific stimuli from the environment to inform their movement decision. In cricket, less skilled players spent more time fixating on distal cues, such as the ball hand area, whilst skilled players fixated on more proximal predictive cues such as the bowling arm, trunk-hips and predicted ball-release area (McRobert et al., 2011). Interestingly, both groups improved when more contextual information was available. In addition, players may also use cues such as postural movements of opponents and task specific structures or patterns to make accurate decisions (Roca and Williams, 2016). This research suggests how practice needs to be representative of the actual task and the context constraints in order to elicit enhanced player decision making (McRobert et al., 2011).

Search strategy has been suggested to differentiate between skilled and lesser skilled players. Roca et al. (2011) found skilled soccer players were able to search the environment more effectively and efficiently than lesser skilled players. Although they search the entire situation they are more focused on informative locations assisting them in making more accurate decisions in a timelier manner (Roca et al., 2011). The ability to successfully achieve this in a quick and unconscious manner is trainable; however, it takes time to build (Roca et al., 2011). An interesting observation by Berry and Abernethy (2009) outlined how elite Australian football players felt much of the training environment is not effective enough at developing perceptual and decision-making skill to a level where it meets the demands of match play. This provides an important consideration when assessing talent. When determining a player's ability to play at the highest level, technical skill assessments need to ensure they are challenging a player's ability to perceive information from the environment, process this information, make a decision and execute a skill under the same demands as match play. It is therefore critical recruiters and coaches understand the identification of talented athletes will be limited in value unless information regarding the proficiency of skills of the game are considered with the ability to read the game and anticipate an opponent's intention (Reilly et al., 2000). This is supported by Cupples and O'Connor (2011) who investigated performance indicators in elite youth rugby from a coach's perspective. They discovered cognitive ability to be the greatest influence of playing position in elite youth rugby league players, followed closely by game skills and finally to a lesser extent physiological indicators. It was further discussed how the development of a skills test, simulating game specific conditions, will improve the coach's knowledge of player strengths and weaknesses, whilst providing performance criteria for the monitoring of improvements throughout the season or longer (Gabbett, 2002; Cupples and O'Connor, 2011). Accordingly, the current skill assessments utilized within the Australian Football League draft combine should be reviewed with more match specific skill assessments implemented (e.g., requiring players to make decisions and execute skills under representative conditions).

ECOLOGICAL DYNAMICS

Ecological dynamics is a framework researchers use to understand and explain sport performance (Seifert et al., 2017). This framework is based on human behavior and motor learning understandings to underpin the learning design in the performance context (Davids et al., 2012; Seifert et al., 2017). There are three main components of ecological dynamics. The first is viewing players and teams as a complex adaptive system, the second involves cognition and behavior being considered together and the third component relates to how behaviors are organized based upon the information available (Seifert et al., 2017). In comparison to other methodologies (e.g., perceptual-cognitive training), ecological dynamics requires all parts of the system (brain, body, and environment) to be dynamically integrated (Renshaw et al., 2018). Alternative methodologies assume perceptual and cognitive systems and brain processes can be trained in isolation from the informational constraints of competitive performance environments (Renshaw et al., 2018). Although training these systems and processes in isolation can be an efficient use of time and money, current research suggests there is little evidence to support their effectiveness (Harris et al., 2018). Accordingly, sport scientists have suggested the use of this framework to improve the analysis of data collected and to gain greater insights into competitive performance behaviors (Travassos et al., 2013; Browne et al., 2019).

Ecological dynamics is an important consideration in the assessment of performance as player skill acquisition and tactical behaviors are constrained by player task constraints (Silva et al., 2014). During competition players are constantly changing their behaviors based upon the constraints imposed by other players and the environment (Araujo et al., 2006). For example, when executing a kick in Australian football, players need to consider the movement and speed of their teammates, the movement and speed of the opposition, who they will kick the ball to, the type of kick to be executed, the amount of force to be applied to the ball and the amount of time they have to execute the kick. Woods et al. (2020a) provided a practical example of how to apply ecological dynamics to the performance preparation of Australian football players. This framework was called "Heads Up Footy" and considered the individual environment, self-regulating and adaptable foundations of ecological dynamics. Although advancements have been made in developing the relationship between a player and their training environment (Woods et al., 2020b), further considerations are required when selecting and designing performance assessments. The ecological dynamics framework is therefore an important factor to consider when developing performance assessments to ensure players are afforded enough information to achieve the goal of the task (Araujo et al., 2006).

When designing performance assessments, the opportunity players are afforded to perform actions should be based from a specific performance context (Araujo et al., 2006; Woods et al., 2019). Factors to be considered in the performance context should include the interactions between players and teams, notational analysis of game performance and time motion

(Travassos et al., 2013; Bonney et al., 2019). When attempting to assess player performance the assessment should ensure the same intentions, information and behaviors are available and performed (Davids et al., 2012). Additionally, these assessments should create a context where the decision making behavior is largely anticipatory based on the availability of information from the player's actions and their environment (Araujo et al., 2006). These performance contexts can then be used to assess a player's ability to recognize affordances for action and execute their skill (Davids et al., 2012).

Current Australian football methods of technical match play assessment are largely focused on recording frequency of actions and patterns of player's movements (Travassos et al., 2013). These approaches are too centered around discrete actions, considered in isolation from the game context and do not consider the interpersonal interactions between players and teams (Travassos et al., 2013). Match play constraint interactions are an important consideration as they can influence technical skill proficiency. For example, an Australian football players kicking proficiency average may be 54%; however, when the player kicks the ball in under 2 s and over 40 m the proficiency may decline to 47% (Browne et al., 2019). As such, when constraints are viewed from a more integrated manner greater insights into player behavior performance can be found (e.g., kicking performance of players). The use of the ecological dynamics framework, to understand these interacting constraints, may also assist in the identification of key events which can be replicated in training and performance assessments (Couceiro et al., 2016). Therefore, to achieve a greater understanding of how a player may perform under match like conditions a more representative performance assessment, where more constraints can be applied to the one task (e.g., time, distance, and pressure), may be more appropriate for talent identification in Australian football.

REPRESENTATIVE DESIGN

The main aim of a performance evaluation assessment is to demonstrate how the assessment relates to the competitive environment (Davids et al., 2013a). To increase the likelihood of the assessment session to be representative of the competitive environment, researchers have suggested the use of a "representative learning design" as a theoretical framework. This framework suggests testing and practice sessions should be reflective of match play conditions including the technical and tactical execution of skills (Corbett et al., 2018) and the environmental conditions, actions, and perceptual stimuli present during the competitive environment (Davids et al., 2005, 2013a; Araujo et al., 2006, 2007; Pinder et al., 2011; Vilar et al., 2012).

Team sport athletes are well-rehearsed with intended movement patterns. These movements; however, cannot be entirely planned and acted upon due to the unpredictable environmental elements and constraints (i.e., opposition movement) (Chow et al., 2011). Therefore, movements and decisions are largely anticipatory in nature based upon key information from their actions and the external environment (Araujo et al., 2006). When assessing the anticipatory visual cues for 25 tennis players (13 skilled and 12 novice) it was found skilled players were more accurate with live and video displays (but not with point-light displays) than novices (Shim et al., 2005). This research highlights the importance of visual perception (i.e., opposition movement) in the assessment task and how this can effect skill execution.

A player's ability to effectively move is dependent upon the environment, perceptual stimulus, goal of the task and/or constraints present (Pinder et al., 2009). If alternative movement patterns are implemented, dissimilar outcomes may occur leading to an ineffective assessment of the skill. Static assessments lack functionality and do not successfully represent the constraints of the performance environment (Pinder et al., 2009). In a study analyzing the practice and free-throw performance of male Division 1 basketballers, it was shown practice free-throw percentage (74.5%) was higher than game percentage (69.2%) (Kozar et al., 1995). Free-throw shooting is typically practiced in a block modality, whereas in a game a free-throw is typically taken twice in succession. However, when only the first two practice free-throws were accounted for the percentage decreased to 69.8% which is comparable to match play performance (Kozar et al., 1995). In another study of seven team coaches in the Federation of International Hockey 2011 Champions Trophy tournament (field hockey) it was identified six of the coaches used more match representative designs when constructing their field goal shooting practice (Slade, 2015). The coaches found by moving away from the closed skill drilling sessions, into a more match representative task design, players were able to improve their tactical understanding, decision making and likely player patterns when attempting field goal shooting (Slade, 2015).

The development and implementation of a skill assessment should be carefully considered. Renshaw et al. (2007) investigated the differences in cricket batting actions when facing a human bowler in comparison to a bowling machine. Four 21-year old premier league cricket participants demonstrated how changing from a human bowler to a bowling machine instigated a re-organization of the coordination and timing of the forward defensive shot (Renshaw et al., 2007). Similar results were also found in a follow up study were a change in movement pattern occurred when batters faced a real bowler compared to a bowling machine (Pinder et al., 2009). The findings showed when facing a bowling machine participants modified their peak height of backswing, drive initiation of the downward swing, front foot initiation, and front foot placement (Pinder et al., 2009). Careful consideration therefore needs to be applied to designing assessments for athletes to complete. Assessments should be dynamic and consider the perceptual information being presented to ensure the movement patterns performed are representative of those experienced during match play (Pinder et al., 2011). It could be argued these more random situations more closely resemble the dynamic nature of sport allowing the athlete to practice under match like conditions thereby facilitating a more effective transfer of skill into match play (with the same concept being applicable to skill assessment sessions) (Farrow, 2010).

Australian football is played in an open environment. Within this setting expert players are constantly adapting to their changing environment to perform consistently (Araujo and Davids, 2011); however, current Australian football skill assessments are conducted in a static environment. These environments are not effective in assessing skill proficiency as they simulate behaviors different to that performed in match play (Pinder et al., 2011). Furthermore, these settings eliminate the ability of the athlete to demonstrate their competence in anticipation, problem solving and attention, which consequently affects their ability to execute their skill proficiently (Falk et al., 2004; Lidor et al., 2009). Skill assessments should create opportunities for players to trial moving in a variety of different patterns. This would demonstrate the player's ability to overcome constraints during match play in order to achieve the intended performance outcome (Davids et al., 2013a). Active opponents are integral to this concept as they assist in the environment being more dynamic and challenging for the players to perform within (Vilar et al., 2012). A significant gap therefore exists between current static assessment procedures used to identify talent in Australian football and the dynamic nature of match play. A new representative skill assessment in the Australian football draft combine, where behavior emulates competition (e.g., small-sided games), may assist in abridging this void.

SMALL-SIDED GAMES

Match play is unstable, dynamic, and unpredictable. There is a strong need for coaches to develop assessments and drills where the components of match play are more interconnected whilst replicating the most intense performance demands of competition without a decrease in running performance (Johnston et al., 2015). Well-designed open skill assessments not only provide a suitable amount of skill affordances but are more contextually relevant to the game setting (Farrow et al., 2008). When examining the skill and physiological demands of open and closed training drills, in elite junior Australian football players, it was highlighted how open skills were more physically and cognitively demanding than closed drills (Farrow et al., 2008). Australian football requires a high level of physical ability in combination with technical skill and decision making ability. The application of open skill assessments (e.g., small-sided games) are appropriate as they provide a suitable amount of skill affordances and are more contextually relevant to the game setting than traditional assessment methods (Farrow et al., 2008).

Small-sided games demand a greater cognitive effort (Lee et al., 1994) which is associated with greater decision making capabilities, skill execution (Turner and Martinek, 1999), and tactical awareness (Chatzopoulos et al., 2006). In addition, small-sided games challenge the athlete to make timely decisions whilst proficiently disposing of the ball in a simulated match environment (Davids et al., 2013a; Young and Rogers, 2014). Gabbett (2009) investigated the application of using small-sided games for improving skill and physical fitness in team sport athletes and found they were effective in developing technical and perceptual expertise. In addition, small-sided games have the ability to challenge a player's agility, speed, aerobic conditioning and power (Bujalance-Moreno et al., 2018). Small-sided games can be manipulated in a variety of ways to achieve the desired outcome. For example, coaches will vary environmental conditions such as the playing area, practice objectives, and rules of play to ensure players are performing enough skill executions (Davids et al., 2013a). Bonney et al. (2020a) investigated the influence of manipulating player numbers (i.e., 5v5, 5v6, 6v6, 7v7) in an Australian football small-sided game. They found different player numbers produced different technical and physical responses. For example, the 5v6 condition produced more technical events under more pressure situations, balanced numbers produced more contested possessions and lower player density conditions produced higher physiological responses.

Assessments of playing performance can be accurately assessed within match play situations. When a representative environment allows an athlete to display their tactical understanding and their ability to make timely and accurate decisions, combined with their ability to proficiently execute game related skills, players can be accurately identified as either higher skilled or lesser skilled (Piggott et al., 2019; Bonney et al., 2020d). Researchers have also investigated if small-sided games can discriminate perceptual-cognitive-motor capability and predict disposal efficiency in match performance of skilled Australian football players (Piggott et al., 2019). The participants played three small-sided games for 3 min with each disposal from only the attacking players scored for decision making and motor skill execution. The authors found the higher skilled players were able to make better decisions and obtain a higher scores than the lesser skilled players. Furthermore, only the higher skilled players scores were successful in predicting disposal proficiency in match performance (Piggott et al., 2019).

The use of constraints (e.g., two consecutive touches per possession) in small-sided games can enable the task to more accurately replicate match play (Almeida et al., 2012). Furthermore, the constraints applied can encourage players to explore solutions to problems (Cronin et al., 2017) highlighting player's strengths and areas of improvement. It is important for players to develop their ability to impact match play as player and team impact scores have been shown to not only have a significant correlation with winning but also as a valid method of assessing game performance (Heasman et al., 2008). Interestingly, the main indicator correlating with the derived team impact score was effective long kicks (Heasman et al., 2008) with previous research finding similar results (Stewart et al., 2007). It is important therefore, this type of kick is accurately assessed within any future Australian football talent identification battery assessment.

The size of the small-sided game perimeter is varied in the literature. In Australian football playing areas such as 30 × 20 m, 45 × 30 m, 23.2 × 20 m, 30 × 40 m, and 40 × 50 m have all been used to compare the physical and technical demands of small-sided games in elite Australian football (Davies et al., 2013; Fleay et al., 2018). Davies et al. (2013) demonstrated how a reduction in players resulted in increased amounts of variability seen during training combined with small increases in total agility maneuvers. In another Australian football study, Fleay et al. (2018) found "large" small-sided games generated fewer technical errors and tackles, more bounces and a greater physical activity profile in comparison to "small" and "medium" dimensions. An earlier futsal study found similar results (Duarte et al., 2009). The authors noted when there was a decrease in the number of players from 4v4 to 2v2, with a pitch size of 20 × 20 m, player intensity increased and more frequent tactical actions occurred. It was hypothesized this was due to more surface area being available per player (Duarte et al., 2009). In contrast to these two studies, a rugby league study analyzing the effect of field size on the physiological and skill demands of players involved in small-sided games noted no significant skill involvement differences when using a 10 × 40 m playing area vs. a 40 × 70 m playing areas (Gabbett et al., 2012). Increases in meters traveled and distances covered at moderate, high and very high intensities were; however, noted in games played on the larger field size, with senior elite players recording higher amounts than junior elite players. The authors suggest the difference in small-sided game field size in rugby league may have a greater impact on physical output than volume or quality of skill executions (Gabbett et al., 2012). These results suggest when implementing a small-sided game, as a method of talent identification, careful consideration should be given to the area afforded to players to ensure the technical and physical outputs produced are appropriate to the task goals.

Small-sided games are commonly used as a method of assessing and preparing players for match play. Coaches; however, should be mindful of how the constraints manipulated in these games compare to match play. When comparing an Australian football 5v6 small-sided game to Australian football match play, small-sided games have been shown to produce higher kicking proficiency, number of kicks executed, meters traveled per minute and percentage of high intensity running (Bonney et al., 2020b). In comparison, players had less time affordance to execute a kick and achieve higher maximum running velocities during match play (Bonney et al., 2020b). In soccer, researchers have found match play to produce greater player total distance covered per minute, total number of duels and lost ball possessions (Dellal et al., 2012). Furthermore, fewer ball touches (i.e., 1 or 2) increased the difficulty for players to perform technical actions. The authors continued to suggest if one or more of the physical, tactical, technical components can be developed simultaneously rather than in isolation, coaches would have the opportunity to maximize their contact time with players and increase efficiency of their training sessions (Dellal et al., 2012).

Overall, these studies indicate by changing the pitch area, the amount of players participating and constraints by which the players are abiding by, the intensity of the game can be modified. For example, a smaller number of players (lower player density) can produce higher external and internal loads (Randers et al., 2018). Furthermore, when fewer player numbers are used with a large pitch size players work at a higher exercise intensity (Hill-Haas et al., 2011). Considering small-sided games are the closest representation of match play conditions from a physiological, tactical, and technical perspective and player performance should be analyzed from within a simulated, competitive environment it appears small-sided game testing is the best solution (other than actual match play) for assessing competition skill performance (Bonney et al., 2019).

CONCLUSION

As the focus on the elite Australian Football League competition becomes greater so too does the demand for success. Clubs are scrutinized for their draft selections and as such are taking more interest in the younger levels of competition in an attempt to identify and monitor talent. This article discussed the current assessments used in the Australian football talent identification pathway and provided future directions and considerations to more accurately and efficiently identify talent. Currently, a significant gap exists between static and isolated assessment procedures used to identify talent in Australian football and the dynamic nature of match play. Future assessments need to consider the effect of maturation and fatigue on the performance outcome. The addition of a valid and reliable technical skill assessment (e.g., small-sided game) to the current Australian Football League draft combine was recommended. Such assessments may provide greater insights into match play kicking proficiency as players can be assessed on their ability to obtain possession of the ball, make decisions and execute a skill. Results from player performance can then provide critical information to coaches regarding a player's technical skill performance during match play, rather than specific details on how a player will execute the skill.

AUTHOR CONTRIBUTIONS

NB: conceptual idea and writing of article. PL and KB: conceptual idea and reviewer. All authors contributed to the article and approved the submitted version.

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Pilot Study on the Reliability of the Coach's Eye: Identifying Talent Throughout a 4-Day Cadet Judo Camp

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A typical assumption found in talent identification literature is that different coaches, given the same athletes and circumstances, will identify the same subset of athletes as "talented". However, while coaches play a major role during talent identification in practical sport settings, there is limited empirical research exploring the processes which underpin this. The purpose of this study was to explore the reliability of "the coach's eye" during the assessment of talent in a group of athletes. Specifically, this project compared inter-coach agreement between nine judo coaches (ages 35.8 ± 10.6 years) with varying levels of experience (12.9 ± 8.9 years) in the evaluation of 24 talented cadet judo athletes (13–15 years) at seven timepoints throughout a 4-day development training camp. Without discussion of their scores with other coaches, coaches provided a single score representing each athlete's "potential for future performance" on an 11-point Likert scale at each timepoint. Scores from each coach were converted into rankings from 1 to 24 to create a normalized scale to facilitate comparison of athletes. Based on their rankings at each timepoint, athletes were placed into one of three evenly distributed groups (high, medium, and low rank). Inter-coach agreement at each timepoint was determined by the number of coaches who ranked each athlete in the same group, categorized at three levels: 50, 75 or 100% agreement. Overall results showed that at completion of the camp, coaches reached 100% agreement on only two athletes, both of whom were in the high rank group. When inter-coach agreement was set at 50%, 15 athletes (62.5%) were placed into like groups. The first timepoint at which coaches were able to differentiate between the majority of athletes was Timepoint 3 (end of day 2). The findings suggest that, in isolation, coaches do not agree on the talent or potential of athletes. This indicates that the "coach's eye" is subjective and variable, and, given the same context, there is poor inter-coach agreement in the identification of talented athletes. In turn, these findings may have significant implications for both future talent identification research and athlete selection processes by sport organizations.

Keywords: talent identification, coach, selection, inter-rater agreement, combat sport, potential, reliability – reproducibility of results, coaching (performance)

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INTRODUCTION

Talent is rare, as only a small minority of people are talented (Baker and Wattie, 2018) and the forecasting aspect of talent identification makes the process of choosing who will succeed in the future challenging and relatively subjective (Johnston and Baker, 2020). Although historically, talent identification has been performed by coaches and/or scouts (Christensen, 2009; Bergkamp et al., 2019), in the last few decades there has been a shift toward creating evidence-based (i.e., empirically measurable) talent identification procedures in many sports. Interestingly, in measuring the effectiveness and accuracy of this empirical research, subjective coach decisions are often relied upon as the gold standard metric to which their results are compared (Roberts et al., 2019). This reliance on coaches within scientific investigations, along with the multifaceted and dynamic nature of talent (Vaeyens et al., 2008), indicates that coaches do, and will continue to play a significant role in the identification of sporting talent, both in the laboratory and on the field. In fact, the forecasting of future athlete performance is considered a major part of the coach's role, evaluating all aspects of an athlete (on and off the field) to forecast, or predict, who has the potential to be a high performer within a given sport (Tromp et al., 2013; Johansson and Fahlén, 2017; Roberts et al., 2020). However, the validity of coach decisions during talent identification is extremely difficult to determine due to the prognostic nature of these decisions, and the inherent de-selections that occur as part of the talent identification process. Without a formal assessment of coach accuracy and reliability, evaluating success or measuring talent identification methods over time will always be limited (Till and Baker, 2020). Despite anecdotal discussions, a fundamental unanswered question is; If viewed in the same context, would multiple coaches deem the same athlete(s) as "talented" and "untalented" when assessing their future potential?

There is limited understanding of how coaches determine an athlete's talent. Recent research has found that experiential knowledge plays a significant role in coach decision-making in strength and conditioning coaching and periodization (Till et al., 2019), during competition and training (Collins and Collins, 2016; Almeida et al., 2019), in return-to-play scenarios (Dawson et al., 2017) and talent identification (Roberts et al., 2020). If experience plays a role in these decisions, then it follows that coaches may identify and/or select athletes differently based on their own experiences. In many talent identification settings, decisions are made in short periods of time (days or hours) and are made by coaches with varying levels of expertise and experience, particularly at lower levels of performance and/or competition.

The inter-rater reliability, or agreement, of coaches has lacked attention in empirical research. The inherent assumption made when relying on coaches to perform talent identification is that a group of (relatively homogenous) coaches, when selecting from the same group of athletes under the same circumstances, will mostly agree on the evaluation of talent. That is, although "the coach's eye" (i.e., what coaches "see" when identifying talent) is understood to be subjective (Jokuschies et al., 2017), it will still result in similar decisions regarding the identification of talent. With this understanding, it is not expected that coaches would rank the athletes exactly the same, however, it is expected that coaches will reach a satisfactory level of agreement on the placement of athletes into like groups (for example, those with "low," "medium" or "high" levels of potential). This study aimed to determine the level of agreement (i.e., inter-coach reliability) between a group of coaches throughout the course of a Cadet (youth) judo camp. Practically, given the same athletes, under the same circumstances, do coaches at a similar level (i.e., junior pathway coaches) come to the same assessment of athlete talent after 4 days? Specifically, did coaches agree on athlete placement within one of three ranked groups (high, medium, low) by the end of the camp.

METHODS

Participants

Nine Australian judo coaches, four females and five males, of varying age ($M = 35.8 \pm 10.6$ years); and experience ($M = 12.9 \pm 8.9$ years) participated in this study (see **Table 1** for full coach demographic information). All coaches have been identified by the National Sporting Organization as being skilled, up-and-coming coaches. Seven coaches were of Australian background, with one coach Japanese and one Brazilian. Ethical approval was obtained from the relevant Human Research Ethics Committees. All coaches gave their consent to be involved in the study and as no athlete data was collected, the Ethics Committees waived the need for informed consent from the athletes.

Procedure

This study was conducted at a 4-day "Judo Futures" development camp run by Judo Australia, consisting of skill/drill training, randori (sparring), recovery sessions, educational lectures, team-building activities and group meals. Fifty athletes were invited to be part of the camp based on their performance at the most recent National Championships. Twenty-five of the athletes at the camp were randomly selected for inclusion in the study as following pilot testing and coach comments about the practical process of identifying talent in unfamiliar athletes, this was deemed the maximum they could "evaluate" during the camp. Coaches were also assigned a mixture of coaching duties throughout the camp. Athletes were randomly assigned a number between 1 and 50, and the athletes that were evaluated in this study were those numbered between 1 and 25. For identification throughout the camp numbers were visible on their hands, feet and gi (jacket). The athlete designated as #3 did not attend the camp at the last minute, so the final number of athletes evaluated was 24. This included 13 male and 11 female judo cadets with a mean age of 13.88 ± 0.69 years. Athletes were unaware that the research was occurring to prevent potential observation-related behavior changes.

Coaches were asked to rate each athlete on an 11-point Likert scale, with 1 being "limited potential – unlikely to have a competitive future in sport"; 6 being "average potential – no

TABLE 1 | Coach demographic information, including playing, coaching and education levels.

Coach identifier	Gender	Age (years)	Judo coaching experience (years)	Judo playing experience (years)	Primary coaching level	Judo coaching accreditation	Other relevant education
A	F	22	3	10	Cadets	JA Coach Judo (Level 2)	B Health Science (Fitness)
B	M	43	20	10	Seniors	None	
C	M	53	30	20	Seniors	JA Senior Coach (Level 3)	
D	F	45	5	17	Cadets	IJF Academy Instructor Certificate (Level 1)	
E	F	24	9	7	Cadets	JA Coach Judo (Level 2); IJF Academy Coach Certificate (Level 2)	B Physiotherapy
F	F	21	1	4	Cadets	JA Assistant Coach (Level 1)	
G	M	41	15	25	Cadets	IJF Academy Coach Certificate (Level 2)	
H	M	35	13	18	Juniors	JA Coach Judo (Level 2)	B Physical Education
I	M	38	20	25	Seniors	JA Senior Coach (Level 3)	B Sports Science
Totals (Range)	5 F;5 M	35.8 ± 10.6 (21–53)	12.9 ± 8.9 (1–30)	15.1 ± 7.3 (4–25)	5 Cadets; 1 Juniors; 3 Seniors		

JA, Judo Australia; IJF, International Judo Federation.

more or less likely than peers to have a competitive future" and 11 being "extremely high potential – good potential to be a future Olympic medalist." An 11-point scale was chosen to increase the generalizability and sensitivity of results when compared to smaller scales and is considered more appropriate for statistical analyses (Chyung et al., 2017; Wu and Leung, 2017). Having an odd-numbered scale (i.e., the inclusion of a mid-point) allowed coaches to express neutral opinions. All ratings were collected electronically using Qualtrics (Version January 2019, Qualtrics, Provo, Utah, USA).

The 4-day duration of the camp provided seven measurement opportunities. The first rating was made the conclusion of Day 1 (8 p.m.), with subsequent measures made in the morning prior to commencement of the first session of each day (∼6–8 a.m.) and following the last session of each day (∼8–10 p.m.). At each timepoint coaches received both an email and a text message with a link to the relevant survey which presented each athlete with their name, ID number and a photograph to facilitate recall. The athletes were presented one-by-one in a randomized order to remove any potential order biases. At each timepoint, coaches were instructed to "rate the athlete based on your *current overall* opinion of the athlete." They were deliberately instructed to not base their score off the most recent session, but of their overall impression of the athlete up to that point. Coaches were provided the option of selecting "N/A" to indicate that they did not yet have enough information to rate a given athlete. This option was provided in order to avoid "misuse" of the midpoint as a "dumping ground" for those athletes they had not yet formed an opinion of, as recommended by Chyung et al. (2017). Importantly, coaches were blinded to their previous ratings for each athlete, and to the ratings provided by other coaches. Coaches were asked to provide their ratings independently of other coaches at each timepoint and to avoid discussions of scoring and athlete comparisons throughout the camp.

Data Analysis

Data were analyzed descriptively using SPSS V26 (IBM Corporation, 2017). As coaches were given the option to use N/A if they did not have enough information to provide a rating for that athlete at that timepoint, coaches were included for statistical analysis at each timepoint if they rated 12 (50%) or more of the athletes. To standardize scores across coaches, the Likert score for each athlete was used to rank the athletes from 1 to 24 for each coach at each timepoint. If a coach rated two athletes with the same Likert score, they were given the same ranking.

Coaches were asked to score each athlete, rather than rank them or place them into the three groups, so as to avoid creating an artificial divide between groupings of athlete "potential." By having coaches score the athletes over time, the organic emergence of separate groups allowed the research team to capture the time it took for coaches to discriminate between athletes of different potential levels.

For group analysis, rankings were used to sort athletes into three categories to conceptualize the talent identification process (Roberts et al., 2020). Therefore, the athlete rankings are presented in three groups – High ranking (athletes ranked from 1 to 8), medium ranking (9–16) and low ranking (17–24). The level of inter-coach agreement was determined by the percentage of coaches who placed the same athletes into the same groups, with three confidence levels used - 50% agreement (in which five or more coaches agreed on athlete placements), 75% agreement (seven or more coaches) and 100% agreement (all nine coaches).

RESULTS

This study sought to determine the level of inter-coach agreement between 9 coaches throughout the course of a 4-day judo camp. A total of 1,252 athlete ratings (out of a possible 1,512) were obtained over the 4-day camp (83%). The absence of ratings at several timepoints were due to selection of the "N/A" option, rather than a lack of response. **Table 2** presents, for each timepoint, the number of coaches who rated more than 50% of the athletes (and were thus included in analysis for that timepoint). At no timepoint were all athletes able to be rated by each coach and for many coaches it took until the third session until they were able to rate the majority of the athletes.

Inter-Coach Reliability

At T7 (end of day 4), there was a large range in the rankings for each athlete as presented in **Figure 1**. Coaches were able to reach 50% or higher agreement in the placement of athletes within their respective group (high, medium, low ranking) for 15 athletes (62.5%), 75% agreement on 5 athletes (20.8%), and 100% agreement on only 2 athletes (8.4%). It can be seen that even for athletes where the minimum agreement of 50% was reached there was considerable range in the rankings across coaches. For example, Athlete 6's rankings ranged from 1 to 13 and was therefore placed in the "high" rank group by six coaches (66% agreement), with the remaining three coaches ranking them in the "medium" (two coaches) and "low" (one coach) rank groups.

Figure 2 presents the number of athletes included at each of the three levels of inter-coach agreement (50, 75, 100%) over the seven timepoints for all athletes rated at that timepoint.

TABLE 2 | Number of coaches who rated more than 12 athletes (50%) for each timepoint.

Timepoint	T1	T2	T3	T4	T5	T6	T7
# Coaches	5	4	9	8	9	9	9

Sensitivity of Coach Judgments

When the inter-coach agreement was analyzed according to the three groups of athletes (high, medium, low rank), it was not until T3 that the coaches agreed on placing athletes in all three groups (**Figure 3**). T4 was the first time there was 100% inter-coach agreement for a single athlete and by T7, all coaches agreed on the placement of two athletes.

DISCUSSION AND CONCLUSIONS

The purpose of this investigation was to test the assumption that different coaches within the same sport, given the same athletes and circumstances, will identify the same subset of athletes as

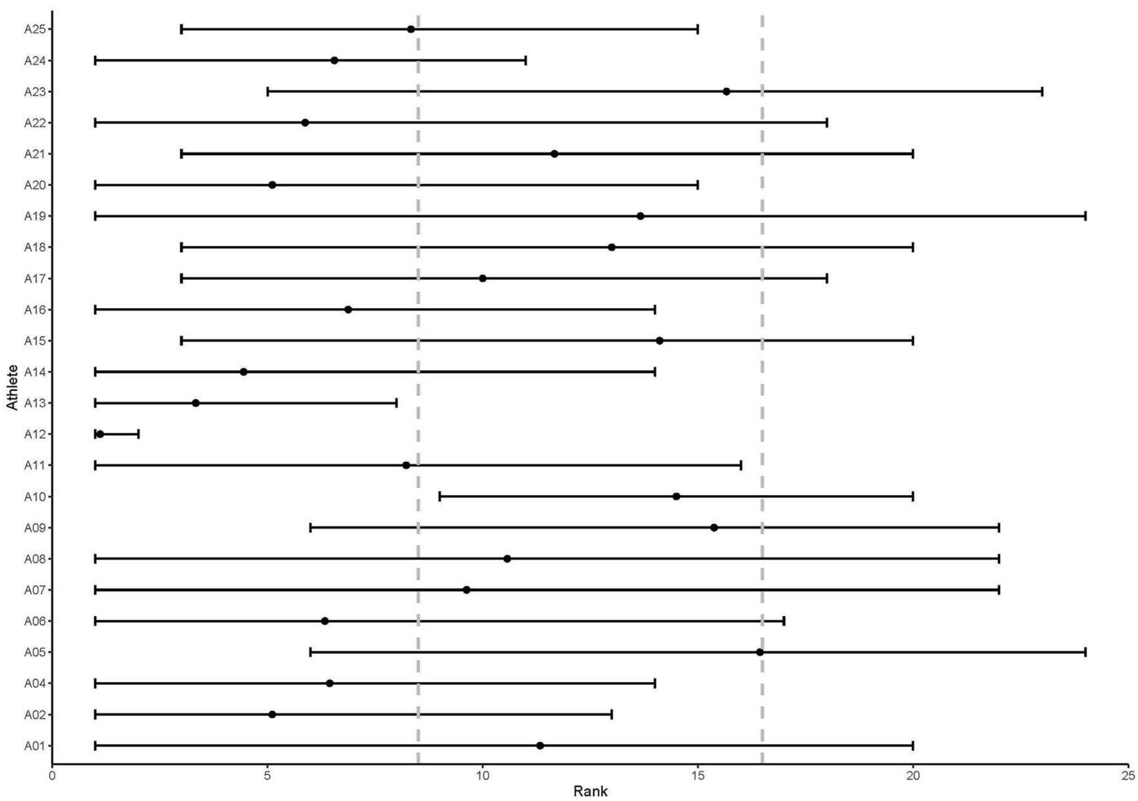

FIGURE 1 | Range of athlete rankings by coaches at Timepoint 7. The range of each athlete's score is represented by the black horizontal line; dot on each horizontal line represents the mean rank for each athlete at Timepoint 7; gray vertical dotted lines depict the cutoff ranks for high-ranked (1–8), medium-ranked (9–16) and low-ranked (17–24) groups.

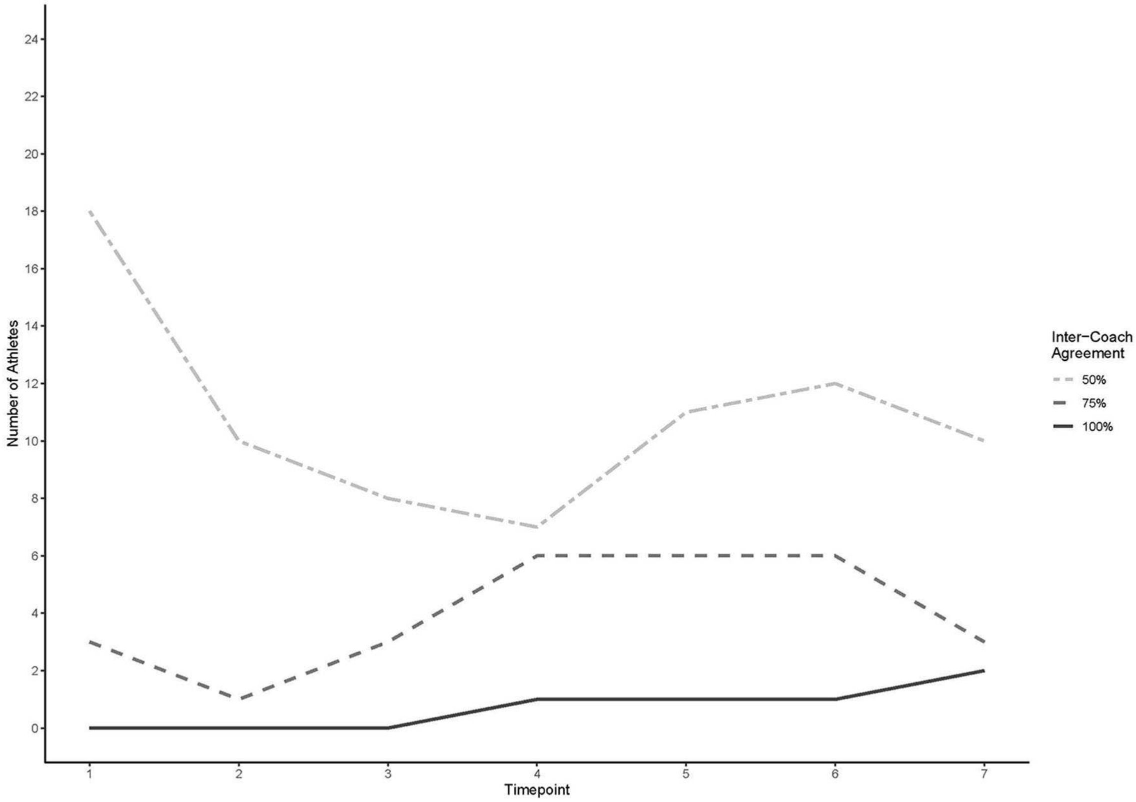

FIGURE 2 | Number of athletes placed into like groups by coaches at three levels of inter-coach agreement.

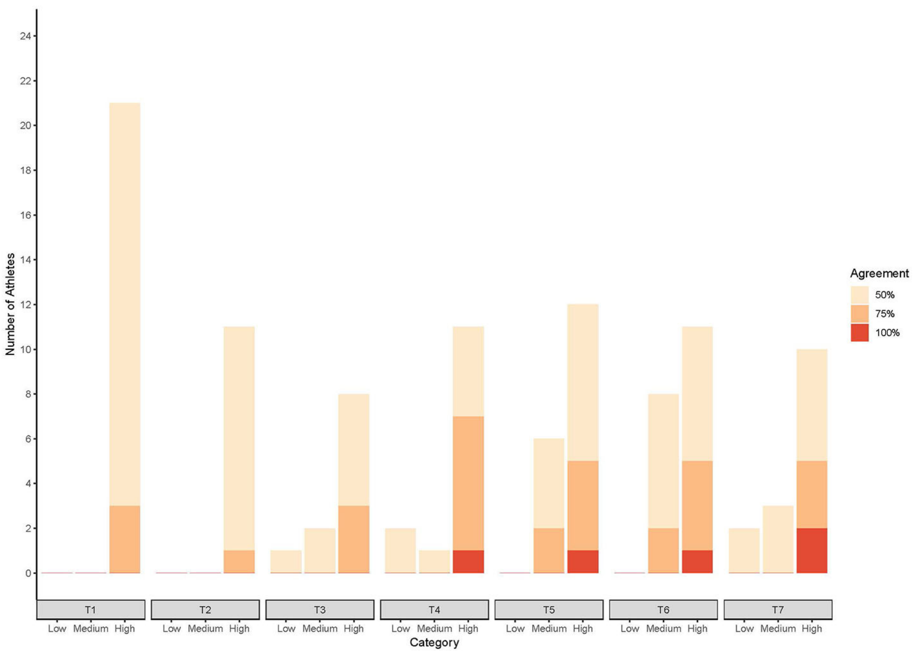

FIGURE 3 | Number of athletes classified by group for each level of agreement across the seven timepoints.

being talented. Inter-coach reliability was measured through the level of agreement between a group of coaches in their assessment of athlete talent throughout and at the completion of a 4-day talent camp. Our key finding was that, given the same athletes, context and time, coaches did not assess talent in the same way. Specifically, a maximum of two athletes were placed into the same ranked group by 100% of the coaches at only one point throughout the seven measured timepoints.

The current findings emphasize the inconsistencies and a lack of reliability between coaches when identifying talent in cadet judo athletes. These results demonstrate that identifying talent is not as straightforward and reliable between talent arbiters as has been previously assumed. Using what could be considered a relatively low level of sensitivity (50% agreement) and placing athletes into one of three groups, coaches were unable to agree on athlete rankings, implying an absence of consensus among coaches as to which athletes should or should not be identified as talented.

Despite the homogeneity of athletes which were involved in the study, or perhaps because of it, it is apparent that coaches disagree about what a "talented" athlete looks like. This is in alignment with the findings of both Wiseman et al. (2014) and Tromp et al. (2013), in which experienced ice hockey coaches and scouts could not agree on rankings of athletes after a single tryout and eight games, respectively. Wiseman and colleagues state that traits such as "coachability" and "character" are important considerations during athlete selection that are unable to be observed in short, one-shot tryouts. From the current research, data showed that it was not until the end of the second day (T3) that coaches were able to distinguish between those with comparatively more or less potential. Prior to this, is appears that coaches were not able to sufficiently differentiate between athletes enough to sort them into three different groups. The current results highlight that even with extended exposure to athletes, in this case 4 days, the level of agreement between coaches on the evaluation of athlete's future potential was not necessarily "better" than in a one-off observation. It appears that it is easier for coaches to agree on the placemement of athletes in the "high rank" group, suggesting that athletes with more potential are more easily differentiated from their peers with less potential.

Interestingly, coaches either chose not to, or were not able to, rate every athlete at every timepoint, with coaches rating as few as four athletes at some timepoints, however for those included in the analysis they rated between 13 and 23 athletes per session. At no timepoint was every coach able to rate every athlete suggesting a "bandwidth" limit to the observational capacity of a coach during the identification process. This indicates that having a single coach evaluate multiple athletes is not an ideal scenario, as coaches are unable to form a consistent opinion of an athlete's talent that they are comfortable with. This finding supports previous research by Roberts et al. (2020), who found that coaches require time to get to know athletes before forming a confident evaluation of the athlete's future sporting potential. In this study, although the coaches had 4 days in which to evaluate the athletes, it appears that the number of athletes inhibited the coaches' capacity to survey the athletes in as much detail as they would require to make confident judgments and decisions.

This study captured the level of agreement between coaches with limited external influences, such as discussion with other coaches, providing a "natural" setting which, according to Stewart et al. (1997) is ideal for the study of judgment and decision-making. This is an important element of the current research, highlighting that without a discussion process consensus among coaches is all but impossible. This highlights why coaches may disagree with others' evaluations when selecting teams and why this can be such a point of friction within sporting organizations. The challenge of having multiple coaches decide on selection processes is clear from this research, demonstrating why many head coaches like to have the "final say" when identifying or selecting athletes. An important question for future research is to examine why is there such a difference in athlete evaluations between this group, and why in the past have we assumed that coaches will identify the same athletes under the same circumstances.

Coaches were not provided with any guidance as to what "talent" is defined as, nor what attributes may contribute. As such, the ratings provided their interpretation and application of the Likert scale, and subsequent rankings are entirely subjective based on the coaches' own knowledge and experience. While guidance could have been provided, previous research highlights that providing coaches with checklists or similar items does not necessarily increase inter-rater agreement (Wiseman et al., 2014), as judgments of performance are believed to be intrinsically subjective (Jako and Murphy, 1990). As such in the current study, coaches were instructed to score athletes based on their own perceptions of talent, rather than on specific guidelines or alignment with a given coach, thus providing a more ecologically valid identification scenario.

The AM and PM ratings provided evaluation of athletes on 12-h cycles. Interestingly, results show that different ratings were evident for the same athletes during the "overnight" cycles, when coaches had no interactions with the athletes. While one could argue that with no additional information gained overnight their assessment of each athlete should not have changed, these results highlight that there may be a reflective practice that the coach goes through, or a reduction in the effect of most recent interactions that occurred immediately prior to their evening evaluation, thus changing their assessment of talent. While outside of the scope of this paper, this finding aligns with the judgment and decision-making literature in that emotions (including tiredness) can affect evaluative judgments, as can age and gender (Weber and Johnson, 2009). These considerations will be important future steps in coach reliability research and in the practical talent identification processes adopted by sport organizations. The amount and experience of coaches present at these camps is always a limitation in this type of research, but the difference in perceptions between expert and novice coaches would also be an important research question. Investigation into the agreement of coaches of varying experience levels would be a valuable continuation of this research. Finally, an important question for future research is to examine why there is such a difference in athlete evaluations between coaches, and why in the past it has been assumed that coaches will identify the same athletes under the same circumstances.

A limitation of this study was that the camp used for data collection was not designed as a "true" talent identification or selection camp, as there was no official selection made following the camp. Rather, it was a development camp with pre-selected athletes and the coaches' primary responsibilities during the camp were to actively coach and develop the athletes, rather than to observe and evaluate. Their coaching responsibilities varied each day, and may have contributed to the low level of agreement at each timepoint and their inability to rate each athlete at each timepoint – on days when coaches were responsible for running sessions, they may not have been able to observe as many athletes as they otherwise would have. Coaches may also not have dedicated the same level of analytical thinking to these ratings as they would have if it had been a "real" identification scenario with athlete selection outcomes.

In conclusion, the process of talent identification, and the subsequent athlete selections, is undoubtedly complex. This research has added to the area by demonstrating that different coaches, when given the same athletes and circumstances, do not identify the same subset of athletes as being talented. Continuing to enhance our understanding of how coaches make talent decisions will help both coaches and practitioners become more aware of the necessary time and information needed for coaches to make confident, reliable decisions. This finding that coaches do not agree on the future potential of these athletes indicates that talent identification is not strictly related to athlete qualities which can be objectively measured. Instead, it is heavily dependent upon coach factors – possibly the "coaches eye" or "gut instinct" that are often spoken about in coaching literature. Exactly what these factors are is a question that remains for future research.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Human Research Ethics Committee, Edith Cowan University. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ARo, DG, CH, and ARa contributed to the design of the work, interpretation of the data, and revised the work critically. ARo acquired the data and drafted the work. All authors approved the final version to be published and agreed to be accountable for all aspects of the work.

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Biological Maturity Status in Elite Youth Soccer Players: A Comparison of Pragmatic Diagnostics With Magnetic Resonance Imaging

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The influence of biological maturity status (BMS) on talent identification and development within elite youth soccer is critically debated. During adolescence, maturity-related performance differences within the same age group may cause greater chances of being selected for early maturing players. Therefore, coaches need to consider players' BMS. While standard methods for assessing BMS in adolescents are expensive and time-consuming imaging techniques (i.e., X-ray and MRI), there also exist more pragmatic procedures. This study aimed to evaluate commonly used methods to assess BMS within a highly selected sample of youth soccer players. A total of $N = 63$ elite male soccer players (U12 and U14) within the German Soccer Association's talent promotion program completed a test battery assessing BMS outcomes. Utilizing MRI diagnostics, players' skeletal age (SA_{MRI}) was determined by radiologists and served as the reference method. Further commonly used methods included skeletal age measured by an ultrasound device (SA_{US}), the maturity offset (MO_{MIR}), and the percentage of adult height (PAH_{KR}). The relation of these alternative BMS outcomes to SA_{MRI} was examined using different perspectives: performing bivariate correlation analyses (1), modeling BMS as a latent variable (BMS_{lat}) based on the multiple alternative diagnostics (2), and investigating individual differences in agreement (3). (1) Correlations of SA_{MRI} and the further BMS variables ranked from $r = 0.80$ to $r = 0.84$ for the total sample and were lower for U12 ($0.56 \leq r \leq 0.66$), and U14 ($0.61 \leq r \leq 0.74$) (2). The latent structural equation modeling (SEM) ($R^2 = 51\%$) revealed a significant influence on BMS_{lat} for MO_{MIR} ($\beta = 0.51$, $p < 0.05$). The additional contribution of PAH_{KR} ($\beta = 0.27$, $p = 0.06$) and SA_{US} ($\beta = -0.03$, $p = 0.90$) was rather small (3). The investigation of individual differences between the reference method and alternative diagnostics indicated a significant bias for MO_{MIR} ($p < 0.01$). The results support the use of economical and time-efficient methods for assessing BMS within elite youth soccer. Bivariate correlation analyses as well as the multivariate latent variable approach highlight the measures' usefulness. However, the observed individual level differences for some of the utilized procedures led to the recommendation for practitioners to use at least two alternative assessment methods in order to receive more reliable information about players' BMS within the talent promotion process.

Keywords: talent development, youth football, talent identification, biological maturation, MRI

INTRODUCTION

In the context of competitive sports, major sports organizations invest considerable financial resources and work in the promotion and development of youth players (Johnston et al., 2018), meaning a huge commitment for the organizations as well as for the players. For instance, upon being drafted (to a selection squad), promising players are removed from their familiar environment at an early stage (Baker et al., 2018). While this separation can be valuable from a performance-oriented perspective, it can also represent a serious interruption in the personality development of young players (Fraser-Thomas et al., 2008). Therefore, a fair (and optimal) selection process must take into consideration the viewpoints of both competitive sports and pedagogical development. However, several studies point out that such selection processes within talent development programs are challenging in youth soccer (Gouvêa et al., 2017; Cumming, 2018).

A major reason for this problem is separating youth players into chronological age (CA) groups (e.g., U10, U11, and U12) based on an annual cutoff date (Helsen et al., 2005; Deutscher Fußball-Bund, 2020). These classifications lead to CA differences of players within an age group of up to 1 year (Malina et al., 2019). Players born early in a given year (i.e., first birth quarter) generally have a physiological advantage in their development in contrast to their younger counterparts (i.e., those born in the fourth quarter). This leads to the well-known relative age effect (RAE), which occurs especially in soccer talent identification (Deprez et al., 2013). Votteler and Höner (2017) emphasize the importance of this effect by demonstrating that significantly more players are born in the first rather than last quarter in German youth national teams. Moreover, this problem is further reinforced when a player's biological maturity status (BMS), regardless of his CA, is neglected. Johnson et al. (2017) point out that BMS has a stronger impact than RAE when selecting players. Especially in the pubertal stages (i.e., 11–16 years; Deprez et al., 2015), in which rigorous and important selection processes take place, the difference in players' BMS can reach up to 5 years (Malina et al., 2004). In practice, this leads to the phenomenon where coaches and talent scouts often prefer early maturing players due to a currently better performance level based on more developed physical attributes (Unnithan et al., 2012). At the same time, late maturing players show lower performance levels, especially in physiological predictors, and therefore are often overlooked (Cumming et al., 2017). Hence, those players often do not receive access to a comprehensive talent promotion program with more qualified coaches and better resources. Furthermore, they also receive less playing time in competitive matches, less team responsibility, and less emotional support, which undermines their holistic soccer education (Malina et al., 2015). In the worst case, even highly talented players are deselected due to the time-delayed biological development in comparison with their on-time or early developing peers. Therefore, sports scientific research on talent has long shown that a player's individual BMS should be taken into account within talent promotion, particularly in selection processes (Romann and Javet, 2018).

As a result, there have been recent initial approaches that have tested the classification of players according to their biological maturity rather than CA. This classification strategy is currently referred to as bio-banding (Cumming et al., 2017). Bio-banding can be considered in different domains, such as conducting new competition formats and grouping players in strength and conditioning training to prevent injuries or in talent identification with respect to selecting players for promotion programs (see Cumming et al., 2018a,b). To date, only a few pilot studies have evaluated bio-banding, e.g., within tournaments initiated by United States Soccer Federation or as a part of the Elite Player Performance Plan by the English F.A. (Bradley et al., 2019).

These studies indicate that bio-banding offers potential benefits for talent promotion programs (Malina et al., 2019). However, in order to obtain the benefits of implementing bio-banding in soccer practice and research, appropriate methods are needed that meet ethical and economically pragmatic criteria and undergo a sound psychometric evaluation.

To determine BMS in youth players—both in research and in practice—various methods are proposed that can objectively assess different dimensions of biological maturity (e.g., skeletal age or somatic age; Lloyd et al., 2014) or qualitatively through a morphological, subjective examination of the maturity status by experts (Romann et al., 2017). In the research literature, measuring skeletal age radiographically is currently regarded as the gold standard method (Lloyd et al., 2014). In various international talent studies, an image of the left hand is taken by using an X-ray (Gouvêa et al., 2017; Holienka et al., 2017). However, some researchers have figured out that even in different assessment methods based on X-rays (i.e., Fels method vs. Tanner–Whitehouse 3 method; Malina et al., 2007a), no satisfying agreement in the determination of skeletal age could be achieved. Furthermore, due to the radiation exposure, there are ethical concerns that make routine implementation very difficult, especially with youth and adolescent players (Focardi et al., 2014). In fact, in competitive sports in many European countries, there is currently no legal basis for using X-ray examinations to estimate the ages of healthy youth players (Timme et al., 2017). In this context, several studies mention that, in addition to the X-ray method as the gold standard, an image of the hand-wrist can also be reliably produced by radiation-free magnetic resonance imaging (Dvorak et al., 2007; Dvorak, 2009; George et al., 2012; Bolívar et al., 2015; Urschler et al., 2016; MRI). Going further, there is also evidence that MRI that does not use ionizing radiation is fundamentally more accurate than X-rays due to its high contrast resolution (Serinelli et al., 2015). Therefore, currently—from the authors' point of view—MRI is the most established method for determining skeletal age and can be used without ethical consequences.

In general, the MRI method is associated with economic disadvantages (e.g., high costs and long acquisition time) for practical use. Therefore, there appears to be a need for less costly and less technical methods to measure the biological maturity based on skeletal age. One promising alternative method involves a newly developed ultrasound diagnostic device (SonicBone, Rishon Lezion, Israel). Currently, however, this method has been only sufficiently validated for children, but not in a sport-specific context (i.e., Rachmiel et al., 2017; Utczas et al., 2017), and a validation of this method in the field of youth competitive sports is still pending. This validation is necessary given the fact that moderator variables have to be considered in talent research (e.g., performance level, age groups, gender, see Murr et al., 2018).

To date, practitioners from diverse talent promotion programs mainly use alternative assessments and determine biological maturity by somatic age (Cumming et al., 2018b). In this context, two commonly utilized methods are the calculation of the maturity offset (MO) based on the estimation of individual age at peak height velocity (APHV; Mirwald et al., 2002) and calculating the percentage of predicted final adult height (PAH; Khamis and Roche, 1994). More specifically, the Mirwald method estimates the players' MO based on various parameters (CA at the time of measurement, weight, height, sitting height, and leg length), while the Khamis–Roche approach predicts the adult height from weight and height of the individual as well as the height of the biological parents. However, considering the influence of moderator variables, researchers emphasize that these methods have inaccuracies depending on which age group was studied (Myburgh et al., 2019).

Within the constraints of talent promotion programs, empirical knowledge of appropriate diagnostics for determining BMS is needed. However, in practice, such methods have to be both acceptable with regard to costs and ethical issues for bio-banding strategies and scientifically sound in terms of psychometric properties.

Indeed, in prior studies, researchers aimed to validate different diagnostics to assess BMS in youth players in different sports (e.g., Malina et al., 2007 in American football; Malina et al., 2012 and Romann et al., 2017 in soccer; Myburgh et al., 2019 in tennis). Malina et al. (2007b) found a correlation of $r_s = 0.52$ between skeletal age measured by left hand-wrist radiographs and PAH in their study with 143 male American football players (9.27–14.24 years). By utilizing the same method as Malina et al. (2007b), similar results were detected by Myburgh et al. (2019) in an investigation with 40 male, British junior tennis players (12.5 $\pm$ 1.8 years). Apart from PAH, this study also used predicted APHV (Mirwald et al., 2002) for BMS assessment and found lower correlations between various assessment methods (PAH: $r_s = 0.35$; predicted APHV: $r_s = 0.37$). In comparable studies in soccer, Romann et al. (2017) and Malina et al. (2012) found similar correlations ($0.26 \leq r_s \leq 0.47$) between skeletal age and PAH, as well as predicted APHV in 11- to 14-years-old male soccer players. However, these studies mainly used bivariate, correlative approaches to analyze the relationship between the gold standard and further BMS diagnostics.

Therefore, special focus should be given to an accurate and comprehensive investigation of diagnostics' reliability and validity by comparing alternative diagnostics with a well-established reference method (i.e., MRI) from different perspectives. Here, *correlational analyses* (*perspective 1*) give insight into the association between possible appropriate diagnostics and the reference method. Furthermore, a multivariate consideration of the alternative diagnostics' coherence with the *theoretical construct of BMS* (*perspective 2*) may facilitate a more comprehensive view of diagnostics' psychometric properties. Therefore, a structural equation modeling (SEM) approach may be beneficial to define BMS as a latent variable by utilizing the reference method as the measurement model. Consequently, this makes it possible to accurately analyze the degree of the theoretical construct's correspondence with further alternative and more pragmatic diagnostics (e.g., Bollen, 1989). More specifically, one can investigate whether the multiple alternative BMS diagnostics may be utilized in combination to represent BMS in a satisfying manner. Since the consideration of manifest variables as indicators implies neglecting potential measurement errors, SEM could take this problem into account and enable more exact calculations (e.g., Skrondal and Rabe-Hesketh, 2004). However, perspectives 1 and 2 fail to examine absolute differences between two measures (Bland and Altman, 2003). In order to go beyond such an examination of the relationship of the considered diagnostics for criterion validation, the *absolute agreement* (*perspective 3*) between the reference method and the alternative diagnostics should be taken into account by analyzing individual differences and systematic biases in agreement between the various methods (Bland and Altman, 1999; Giavarina, 2015).

THE PRESENT STUDY

The aim of the present study is to evaluate pragmatic diagnostics for assessing biological maturity in a representative sample of elite youth soccer players by comparing their applicability for the assessment of skeletal age, which is currently considered the gold standard method (Lloyd et al., 2014). In doing so, the reference method MRI was set as the criterion to determine skeletal age (e.g., Serinelli et al., 2015; Urschler et al., 2016). The MRI approach was chosen in order to avoid possible health risks for players due to unnecessary radiation exposure (i.e., X-ray method). In addition to fulfilling economic, ethical, and pragmatic criteria, the study focuses especially on the criterion validation of different diagnostics to assess BMS. Therefore, the study's main purpose was to investigate the agreement between the radiation-free MRI diagnostics and the alternative (e.g., in terms of setup and cost), more economical and practical methods of measuring BMS by

(a) Skeletal age using a quantitative ultrasound-based device and
(b) Somatic age utilizing estimates of MO (Mirwald et al., 2002) and PAH (Khamis and Roche, 1994).

These BMS outcomes were related to the reference method MRI using three perspectives of analyses:

- Bivariate correlation analyses of MRI with the alternative BMS diagnostics,
- Multivariate modeling of BMS as a latent variable (measured by MRI) based on alternative BMS diagnostics, and
- Investigation of individual differences and systematic bias in agreement between MRI and alternative BMS diagnostics.

METHODS

Participants

The study sample consisted of male youth soccer players (N = 63) who were part of the German talent promotion program. Players were born between 2006 and 2008 and belonged to either the U12 (n = 32, 11.3 ± 0.3 years old) or U14 age group (n = 31, 13.4 ± 0.3 years old). For the estimation of an appropriate sample size in each age group, statistical a priori power analyses were performed utilizing G*Power Version 3.1.9.4 ($\alpha = 0.05$, $1 - \beta = 0.85$, two-tailed). In order to detect at least large effect sizes within the correlational analyses (i.e., $r \geq 0.50$; Cohen, 1988), a sample size of at least 30 players in each age group (i.e., U12 and U14) was indicated.

As the talent promotion program comprises two important levels of promotion in early to middle adolescence (i.e., competence centers and youth academies), the sample included a balanced amount of competence center (U12: n = 16; U14: n = 16) as well as youth academy players (U12: n = 16; U14: n = 15). All players' legal guardian/next of kin provided informed written consent for the collection and scientific use of the data. With respect to the MRI diagnostics, players and their parents were informed about the examination in advance and had to sign a study participation agreement. The research was approved by the ethics committee of the Faculty of Medicine at the University of Frankfurt and the scientific board of the DFB Academy.

Measures

The entire investigation was conducted within 2 weeks at Frankfurt University Hospital and was predetermined in a strict protocol. Testing for one player, including MRI, ultrasound, and anthropometric data, took about 25 min and took place between 12 and 4 p.m. at the day of assessment. Before every measurement, all players were informed about the detailed assessment procedure by the respective investigators.

Criterion

To assess the reference method for BMS, an MRI of each player's left hand was taken. A 3.0-Tesla MRI (MAGNETOM Prisma, Siemens, Erlangen, Germany) using a dedicated wrist coil was implemented for the native MRI examination. Players were examined in the prone position with the left arm extended (super-man position). In the coil, the middle finger was positioned in the same axis as the radius to avoid ulnar or dorsal deviation. The MRI data of the bones of the left hand were evaluated by three certified clinical radiologists with different experience levels (1 = specific pediatric radiologist, 2 = more than 20 years, and 3 = more than 3 years of experience in clinical radiology) independently from each other. The conventional Tanner–Whitehouse 2 method (TW2; Tanner et al., 2001; Satoh, 2015) was used to determine the skeletal age to the nearest 0.1 years. Inter-rater reliabilities were found to be excellent for the total sample (ICC = 0.988, 95% CI = [0.980; 0.992]) as well as for each age group separately (U12: ICC = 0.978, 95% CI = [0.958; 0.989]; U14: ICC = 0.979, 95% CI = [0.961; 0.989]). The average of all three raters served as players' skeletal age according to MRI (SA_{MRI}).

Predictors

To determine the *skeletal age* based on the ultrasound examination, the BAUSport™ instrument was used (Rachmiel et al., 2017). The ultrasound device is a small, portable, bone sonometer (SonicBone, Rishon Lezion, Israel). It analyzes three sites of the left hand [(1) the distal radius and ulna's secondary ossification centers of the epiphyses at the wrist; (2) the growth plate of the third metacarpal and the shaft of the proximal phalange; and (3) the distal metacarpal epiphysis at the metacarpals]. The device measures the speed of propagation through bone of inaudible high-frequency waves of a short ultrasound pulse (m/s) and the distance attenuation factor (decay rate). With the use of these parameters, skeletal age was calculated (to the nearest 0.01 years) by an algorithm integrated into the software of BAUSport™ using the scoring method designed by Tanner and Whitehouse (TW2 method; Tanner et al., 2001; Rachmiel et al., 2017). All ultrasound examinations were conducted by a trained person according to the BAUSport™ user manual's instructions. All subjects underwent two measurements. Correlation analyses showed excellent retest reliability for the two measurements (r_{tt} = 0.98). The mean of both measurements comprised players' skeletal age according to ultrasound (SA_{US}).

For anthropometric data assessment, all players were barefoot and wore only shorts. Weight was measured with calibrated scales (seca 213 portable stadiometer) to the nearest 0.1 kg. Height and sitting height were determined to the nearest 0.1 cm with a fixed stadiometer (seca 813 electronic flat scale). Here, players had to stand with feet together and arms relaxed. For sitting height, the players sat on a table with an upright trunk and back against the stadiometer. Leg length was indirectly calculated as the difference between standing height and sitting height. In both measurements, the players' head was aligned with the Frankfurt horizontal plane (Malina and Koziel, 2014). Two measurements were taken for each anthropometric variable by the same trained research assistant. Retest reliabilities for all anthropometric measurements were excellent ($r_{tt} \geq 0.99$). If the results differed by more than 0.4 kg for weight, or 0.4 cm for height, or 0.4 cm for sitting height, a third measurement was conducted (Mirwald et al., 2002). The findings for each anthropometric measurement were averaged.

In order to determine the BMS by *somatic age*, two well-known methods utilizing these anthropometric data were applied. First, players' MO from their PHV (MO_{MIR}) was computed based on Mirwald's equation (Mirwald et al., 2002):

MO_{MIR} (in years) = −9.236 + [0.0002708 × (leg length × sitting height)] + [−0.001663 × (CA × leg length)] + [0.007216 × (CA × sitting height)] + [0.02292 × (weight by height ratio × 100)], where the leg length was estimated by subtracting sitting height from height.

By additionally recording the body sizes of the biological parents (collected by a questionnaire), the somatic age was also estimated using the Khamis–Roche method (Khamis and Roche, 1994). The method enables prediction of players' adult height based on the regression formula:

predicted adult height (in cm) = $\beta_0 + \beta_1 \times$ height + $\beta_2 \times$ weight + $\beta_3 \times$ mid-parent height,

where β_0, β_1, β_2, and β_3 represent age and gender-specific regression coefficients defined by Khamis and Roche (1994) (for more details, see this original research). In order to control for a potential overestimation of the self-reported heights by parents (Maukonen et al., 2018) and in line with former research (Cumming et al., 2018b), parents' heights were adjusted according to the recommendations of Epstein et al. (1995) before calculating the mid-parent height parameter. By utilizing this adult height prediction, players' PAH (in %) (PAH_{KR}) was calculated by the ratio (height/predicted adult height).

Data Analysis

Data were analyzed utilizing IBM SPSS version 26 and Mplus Version 8.4. In order to compare the reference method (SA_{MRI}) and the alternative diagnostics for assessing BMS (SA_{US}, MO_{MIR}, and PAH_{KR}) according to the three perspectives of analyses, the following statistical procedures were applied.

Bivariate Correlation Analyses

Pearson's r served as the measure for the correlations between SA_{MRI} and the alternative BMS diagnostics (SA_{US}, MO_{MIR}, and PAH_{KR}) for the total sample as well as for each age group separately.

Multivariate Latent Structural Equation Modeling

A SEM approach was used to model BMS as a latent construct. Within the measurement model, three different evaluations of SA_{MRI} by the independent clinical experts were defined to load on the latent variable BMS_{lat}. The alternative diagnostics SA_{US}, MO_{MIR}, and PAH_{KR} served as predictors for BMS_{lat}. In accordance with Muthén and Muthén (2010), R^2 was examined to quantify the amount of variance within BMS_{lat} explained by the utilized predictors within the latent regression model. As the sample sizes within each age group were too low to specify a model for U12 and U14 separately, the SEM was only computed for the total sample. However, in order to also adjust for the classification to an age group for this perspective, all variables were z-standardized within each age group before the model was run.

Investigation of Individual Differences and Systematic Bias in Agreement

In addition to the correlative approaches in perspectives 1 and 2, Bland–Altman analyses (Bland and Altman, 1999) were utilized to investigate individual differences as well as systematic biases in agreement between SA_{MRI} and each of the three alternative measures SA_{US}, MO_{MIR}, and PAH_{KR}. Since a comparison between two methods is only reasonable when two measurements are of the same unit, some measurements had to be converted before the analysis. In particular, MO_{MIR} was converted into skeletal age (i.e., SA_{MIR}) based on the mean individual APHV for boys (i.e., 13.8 years; Malina et al., 2004) via the equation $SA_{MIR} = MO_{MIR} + 13.8$. With respect to PAH_{KR}, there was no possibility for a transformation into skeletal age. For this reason, SA_{MRI} was transformed into values of achieved percentage of adult height (i.e., PAH_{MRI}) by a conversion tool BoneXpert, 2020 validated by Thodberg et al. (2009). Finally, players' PAH_{MRI} was determined as the ratio of their current height and their predicted adult height. As the BoneXpert conversion is restricted to individuals where the absolute difference between their skeletal and CA is <3.5 years, three players had to be excluded from this part of the analyses.

In accordance with Bland and Altman (1999), the average of two measures to be compared (i.e., SA_{MRI} and SA_{US}, SA_{MRI} and SA_{MIR}, and PAH_{MRI} and PAH_{KR}, resp.) constituted the x-axis, whereas the differences between the measures (SA_{MRI} – SA_{US}, SA_{MRI} – SA_{MIR}, and PAH_{MRI} – PAH_{KR}, resp.) were depicted on the y-axis of the plots. Additionally, the mean difference and the corresponding 95% limits of agreement were computed and marked within the graphs according to Bland and Altman (2003). Finally, one-sample t-tests were utilized in order to examine whether there was a significant systematic bias between two measurements, which was indicated if the average of the differences between measurements deviated significantly from zero.

RESULTS

Descriptive statistics for all maturity-related outcomes for the total sample as well as separated by age group are displayed in **Table 1**.

Bivariate Correlation Analyses

The results of the correlation analyses with respect to various BMS outcomes are presented in **Table 2**. All correlations were found to be significant ($p < 0.001$). With respect to the total sample, correlation coefficients of SA_{MRI} and the further BMS variables are ranked from $r = 0.80$ (SA_{MRI}, SA_{US}) to $r = 0.84$ (SA_{MRI}, MO_{MIR}). When looking at the age groups U12 and U14 separately, correlations for U14 were higher for BMS variables ($0.61 \leq r \leq 0.74$) than those for U12 ($0.56 \leq r \leq 0.67$).

Multivariate Latent Structural Equation Modeling

The analysis of the SEM for the total sample indicated excellent model fit [$\chi^2_{(6)} = 1.98$, $p = 0.92$, root mean square error of approximation (RMSEA) (90% CI) = 0.00 ([0.00; 0.06]),

TABLE 1 | Descriptive overview of BMS diagnostics' outcomes.

Outcome		Age group		
		U12 ($n = 32$)	U14 ($n = 31$)	Total ($n = 63$)
		$M \pm SD$		
Anthropometry	Height (cm)	150.06 ± 5.48	164.86 ± 10.23	157.35 ± 11.01
	Weight (kg)	39.13 ± 4.33	51.37 ± 8.88	45.15 ± 9.25
Chronological age	CA (years)	11.33 ± 0.28	13.41 ± 0.29	12.35 ± 1.09
Skeletal age	SA_{MRI} (years)	12.06 ± 0.88	13.86 ± 1.17	12.95 ± 1.37
	SA_{US} (years)	11.75 ± 0.89	14.06 ± 1.44	12.89 ± 1.66
Somatic age	MO_{MIR} (years)	−2.11 ± 0.37	−0.22 ± 0.79	−1.18 ± 1.13
	PAH_{KR} (%)	83.40 ± 1.78	91.64 ± 2.82	87.45 ± 4.76

SA_{MRI}, skeletal age determined by magnetic resonance imaging; SA_{US}, skeletal age determined by mobile ultrasound device; MO_{MIR}, maturity offset according to Mirwald et al. (2002); PAH_{KR}, percentage of adult height according to Khamis and Roche (1994).

TABLE 2 | Correlation analyses between SA_{MRI} and alternative diagnostics for the total sample and each age class separately.

	Method	Pearson's *r*		
		SA_{US}	MO_{MIR}	PAH_{KR}
U12 ($n = 32$)		0.56***	0.63***	0.66***
U14 ($n = 31$)	SA_{MRI}	0.65***	0.74***	0.61***
Total ($n = 63$)		0.80***	0.84***	0.81***

****$p < 0.001$.*
SA_{MRI}, skeletal age determined by magnetic resonance imaging; SA_{US}, skeletal age determined by mobile ultrasound device; MO_{MIR}, maturity offset according to Mirwald et al. (2002); PAH_{KR}, percentage of adult height according to Khamis and Roche (1994).

comparative fit index (CFI) = 1.00, Tucker Lewis index (TFI) = 1.00, standardized root mean square residual (SRMR) = 0.01] and revealed $R^2 = 0.51$, indicating that 51% of BMS_{lat} variance could be explained by the model.

Figure 1 presents the estimated model including factor loadings and standardized regression coefficients. First, the manifest MRI evaluations of skeletal age [$SA_{MRI(1)}$, $SA_{MRI(2)}$, and $SA_{MRI(3)}$] loaded particularly highly on BMS_{lat} ($0.97 \leq \lambda \leq 0.98$; $p < 0.001$).

The latent SEM revealed a significant influence on the latent factor BMS_{lat} for the variable MO_{MIR} ($\beta = 0.51$, $p < 0.05$). Due to high correlations between MO_{MIR} and the other alternative diagnostics PAH_{KR} ($r = 0.78$) and SA_{US} ($r = 0.87$), the additional contribution of PAH_{KR} ($\beta = 0.27$, $p = 0.06$), and in particular of SA_{US} ($\beta = -0.03$, $p = 0.90$) within the regression model was rather small and not significant.

Investigation of Individual Differences and Systematic Biases in Agreement

The results from the Bland–Altman analyses are shown in **Figure 2**. When regarding the range of differences between SA_{MRI} and the other diagnostics with increasing mean values between two measurements, differences did not seem to correspond with the mean value. Furthermore, the investigation at an individual level showed that nearly all differences between the reference method (SA_{MRI}) and each alternative BMS diagnostics were within the 95% limits of agreement for the mean value. In total, five individuals were identified as outliers (i.e., players whose differences fell outside of the 95% limits of agreement) by at least one of the three comparisons between the reference method and the pragmatic BMS diagnostics. All three outliers identified by SA_{US} were also detected by at least one further comparison. However, both SA_{MIR} and PAH_{KR} found one outlier each that was not recognized by another comparison. Moreover, while the average of the differences for the comparison of SA_{MRI} and the SA_{MIR} deviated significantly from zero [$M = 0.32$ years, $t_{(62)} = 3.45$, $p < 0.01$], no systematic bias was found for the comparisons of SA_{MRI} with SA_{US} [$M = 0.06$ years, $t_{(62)} = 0.45$, $p = 0.65$] as well as with PAH_{KR} [$M = -0.35\%$, $t_{(59)} = -1.30$, $p = 0.20$]. However, considerable variation with regard to the individual differences was found for all three comparisons ($SD = 0.74$ years for SA_{MIR}, $SD = 2.06\%$ for PAH_{KR}, $SD = 1.00$ years for SA_{US}, respectively).

DISCUSSION

In addressing the demand of both practitioners and researchers to integrate information about players' BMS within the processes of talent promotion, the present study evaluated various BMS diagnostics within a representative setting. Highly talented adolescent players (i.e., U12 and U14) from the two main institutions of the German talent promotion program (i.e., competence centers and youth academies) underwent a test battery consisting of the (costly and time intensive) reference method (SA_{MRI}) as well as additional, more pragmatic diagnostics (SA_{US}, MO_{MIR}, and PAH_{KR}) that could be applied, among other things, in an area-wide setting. Following the idea of a comprehensive evaluation, diagnostics were related to the reference method from three different perspectives (i.e., bivariate correlation analyses, multivariate latent SEM approach, and investigation of individual differences and systematic deviations). The comparison between the reference method and the alternative diagnostics (*perspective 1*) revealed strong correlations for the total sample ($r > 0.80$) and, as expected due to a lower variance in age, slightly lower correlations regarding U12 ($r \geq 0.56$) and U14 ($r \geq 0.61$) separately. The multivariate SEM approach (*perspective 2*) allowed for an accurate investigation (adjusted for age group) of the alternative diagnostics' conformity with BMS as a latent construct free of measurement errors (BMS_{lat}). BMS_{lat} was measured by three evaluations of the reference method by independent experts. Overall, the three alternative BMS outcomes (in combination) predicted significant BMS_{lat}. *Perspective 3* added value to the diagnostics' evaluation by considering differences and systematic deviations at the individual level. The procedures' average difference exposed a systematic bias for SA_{MIR}. Furthermore, the comparisons revealed high standard deviations for the differences between the reference method and the pragmatic diagnostics. With respect to detected outliers, a high degree of agreement was achieved among comparisons.

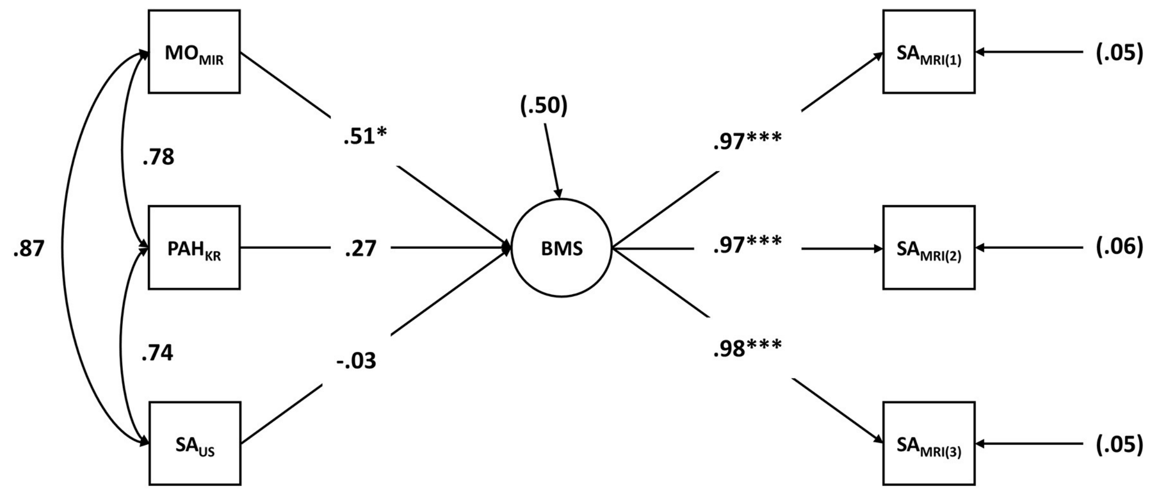

FIGURE 1 | Latent structural equation modeling (SEM): biological maturity status (BMS) as a latent construct predicted by the alternative BMS diagnostics. BMS_{lat}, biological maturity status as a latent construct; $SA_{MRI(i)}$, evaluation of skeletal age based on magnetic resonance imaging by rater *i*; SA_{US}, skeletal age determined by mobile ultrasound device; MO_{MIR}, maturity offset according to Mirwald et al. (2002); PAH_{KR}, percentage of adult height according to Khamis and Roche (1994).

Former research that aimed to validate different diagnostics to assess BMS in youth players mainly utilized correlative approaches, that is, *perspective 1* (e.g., Malina et al., 2007b in American football; Malina et al., 2012 and Romann et al., 2017 in soccer; Myburgh et al., 2019 in tennis). While the players in those studies were of similar CA as were participants of the present study, all authors used maturity categories (early, on time, and late) instead of continuous outcomes to define players' BMS. This may limit the comparability to the present study, which utilized continuous BMS variables (e.g., skeletal age) in order to differentiate more precisely between diagnostics. Nevertheless, the results of categorical classifications were compared with the results of the current study to establish a reference to existing literature. In general, the correlations between diagnostics were found to be higher in the present study. In a study of 143 male American football players (9.27–14.24 years), Malina et al. (2007b) found lower correlations ($r_s = 0.52$) between the skeletal age measured by left hand-wrist radiographs (evaluated by the Fels method) and PAH_{KR} compared with the results of this investigation ($r = 0.84$). Similar (even lower) results were found by Myburgh et al. (2019) in a study with 40 male, British junior tennis players (12.5 ± 1.8 years). Utilizing the same method as Malina et al. (2007b), this study evaluated PAH_{KR} as well as the predicted APHV (Mirwald et al., 2002) and found limited agreement between various assessment methods (PAH_{KR}: $r_s =$ 0.35; predicted APHV: $r_s = 0.37$). With respect to comparable studies in soccer, Romann et al. (2017) found only moderate rank correlations ($r_s = 0.42$) between skeletal age (measured by X-ray) and predicted APHV in male Swiss soccer players (13.9 ± 1.8 years), while SA_{MRI} and MO_{MIR} highly correlated within this investigation ($r = 0.81$). A similar pattern holds true for a study of 11- to 12-years-old ($n = 87$) and 13- to 14-years-old ($n = 93$) male soccer players evaluating the relationship among indicators (i.e., skeletal age based on the Fels method, predicted APHV, and PAH_{KR}) of BMS (Malina et al., 2012). While results showed small to moderate Spearman rank correlations for both age groups (11–12 years:.26 $\leq r_s \leq$ 0.43; 13–14 years: 29 $\leq r_s \leq$ 0.47), Pearson coefficients of the present study for the corresponding age groups (U12:.56 $\leq r \leq$ 0.67; U14:.61 $\leq r \leq$ 0.74) were large. These higher correlations could be explained by the more differentiated assessment of BMS outcomes (i.e., categorized vs. continuous), which might be indicated when evaluating potential alternative BMS diagnostics.

Moreover, the research analyzing multivariate correspondence between diagnostics is scarce. An exception is the study of Malina et al. (2012), which evaluates the relationship among BMS indicators in young soccer players. The authors found that the chosen indicators (i.e., skeletal age based on radiographs, APHV, PAH_{KR}, and stage of pubic hair) showed one principal factor (i.e., one dimension) within a principal component analysis for 13- to 14-years-old players. This finding is in line with the results of the present study where the three alternative diagnostics significantly predicted BMS_{lat} (*perspective 2*). This provides evidence that, in a realistic setting of highly selected, male youth soccer players, alternative diagnostics, such as SA_{US}, MO_{MIR}, and PAH_{KR} may be used to assess BMS more pragmatically and efficiently in order to incorporate players' BMS as an important criterion within the talent promotion process (i.e., in terms of selections and bio-banding; Cumming, 2018). However, it was particularly MO_{MIR} ($\beta = 0.51$) that predicted BMS_{lat} within the regression model. The influences of SA_{US} as well as PAH_{KR} were rather small ($\beta \leq 0.27$) because of the high correlations ($r \geq 0.78$) within the three alternative measurements (i.e., collinearity). Perhaps the use of similar information to compute BMS (i.e., CA and anthropometric measurements) within those measurements, among other factors, may have led to these high correlations. On the one hand, this may lead to the conclusion that the use of only one measurement may be

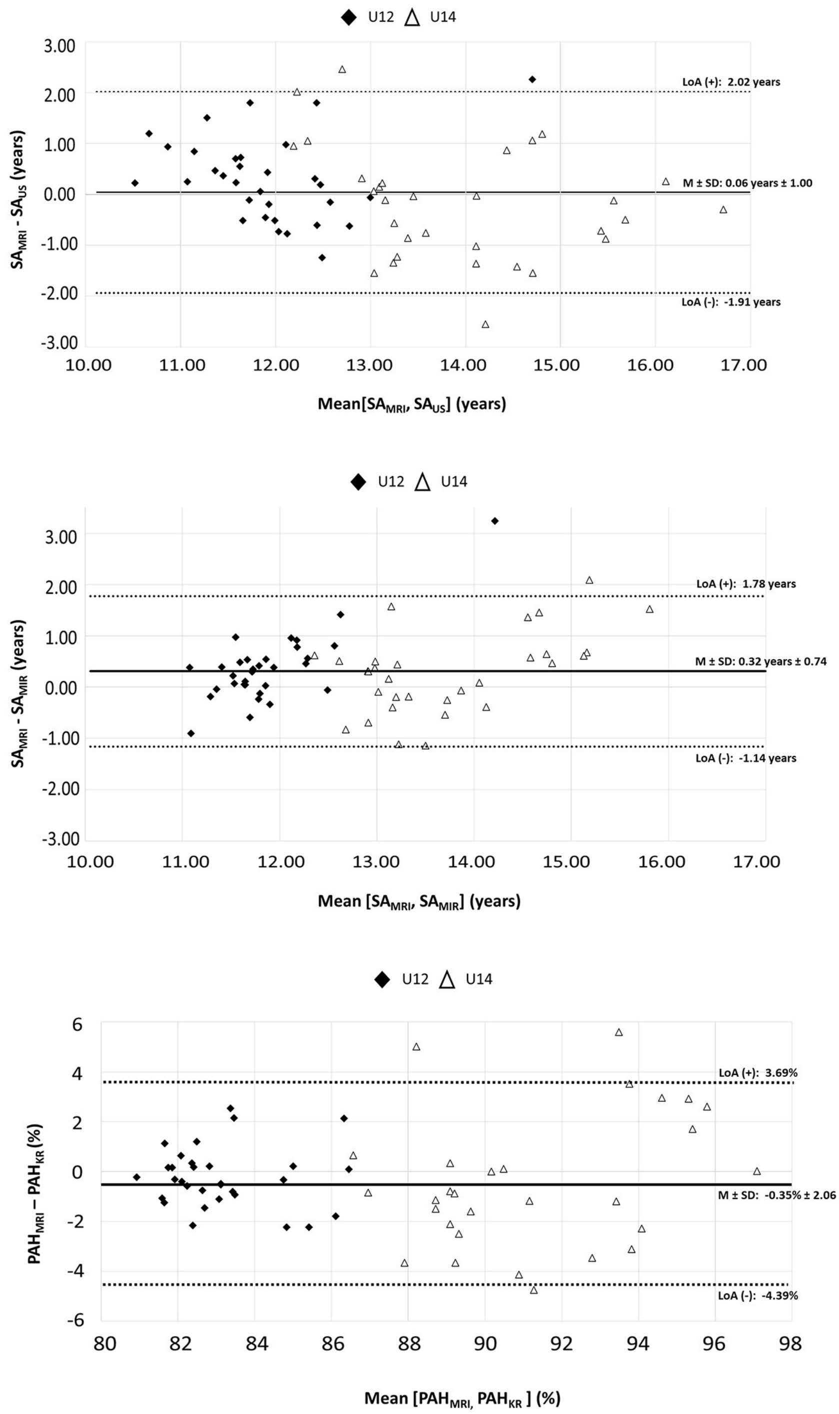

FIGURE 2 | Bland–Altman plots: individual differences of SA_{MRI} and the alternative BMS diagnostics. SA_{MRI}, skeletal age determined by magnetic resonance imaging; SA_{US}, skeletal age determined by mobile ultrasound device; SA_{MIR}, maturity offset (Mirwald et al., 2002) transformed to skeletal age according to Thodberg et al. (2009); PAH_{KR}, percentage of adult height according to Khamis and Roche (1994); PAH_{MRI}, skeletal age determined by magnetic resonance imaging converted to percentage of adult height according to Thodberg et al. (2009).

sufficient. On the other hand, the use of the combination of the three alternative methods leads to a higher degree of explained variance without overly magnifying the efforts that come with the assessment.

A further benefit of such a combinatory approach could be obtained from the investigation of individual differences between the various diagnostics providing a more comprehensive view of players' BMS (e.g., to detect systematic bias between two diagnostics). As demonstrated in *perspective 3*, systematic bias was found between the reference method and the measurement SA_{MIR}. Although these pragmatic diagnostics may be easily utilized within an area-wide setting (e.g., a huge number of players within a nationwide promotion program), their use at the individual level must be considered with caution. The systematic bias for the comparison with SA_{MIR} as well as the slightly high variance (e.g., $SD = 0.74$ years for SA_{MIR}) indicates considerable deviations between the alternative diagnostics and the reference method. These distinct differences seem problematic when using one of the alternative diagnostics in practice in order to get reliable BMS information at an individual level. Instead, the use of at least two alternative diagnostics may be helpful in order to adjust for the deviations between the pragmatic and reference method diagnostics.

Consequently, the findings from the present study may help practitioners aiming to integrate information about players' BMS within talent promotion. *Perspective 1* showed that all considered alternative diagnostics correlate highly with the reference method and, therefore, may be used as more economic assessment methods for BMS. Similarly, *perspective 2* revealed that a combined, multivariate use of the alternative measurements significantly predicted BMS and led to slightly higher explanatory power. Even though MO_{MIR} provided the highest impact on BMS, the strong correlations between the pragmatic diagnostics did not allow the conclusion of which diagnostics should be preferred. In contrast to perspectives 1 and 2, *perspective 3* was able to detect individual differences and systematic deviations that might be controlled for by using more than one pragmatic BMS diagnostics in practice.

Limitations and Perspectives

While the main focus within the present study was the investigation of BMS, further aspects of the maturation process, namely, "maturity timing" and "maturity tempo," may be considered to determine the biological maturity of youth players in sports (Malina et al., 2019). The maturity timing approach describes specific maturational events that occur at a certain point of time at a different CA for every player (Swain et al., 2018). Such events include the estimated APHV (te Wierike et al., 2015), menarche status (Lloyd et al., 2014), or the age of first ejaculation (Mattila et al., 2008). In addition to these objective diagnostics, further approaches in talent research exist that determine maturity timing morphologically by holistic, subjective expert judgments (Romann et al., 2017). In those assessments, responsible coaches evaluate players independently according to certain characteristics (e.g., morphology). From an economic perspective, such a method offers advantages; however, a certain level of experience is essential, and comprehensive evaluation of the reliability and validity of these expert judgments is still pending. For both objective and subjective approaches, individuals are categorized in early, on-time, and late maturing players (e.g., Romann et al., 2017; Myburgh et al., 2019). Maturity tempo examines how fast/slow a child develops biologically (Mendle et al., 2019) and refers to the rate at which maturation progresses between (at least) two measurement points (Howard et al., 2016; Malina, 2017; Radnor et al., 2018). As with BMS and maturity timing, various approaches to determine maturity tempo exist in the literature (e.g., rate between beginning and end of the adolescent growth spurt; Wormhoudt et al., 2017).

However, there is disagreement in the literature with regard to the inconsistency of definitions (Cheng et al., 2020) and which indicators are assigned to which approaches (BMS vs. maturity timing vs. maturity tempo). For example, several authors use APHV (Buchheit and Mendez-Villanueva, 2014; Deprez et al., 2015) as an indicator of BMS, despite the fact that the review by Swain et al. (2018) argues that APHV reflects an indicator of maturity timing. To the authors' best knowledge, both approaches are possible but investigate different aspects; a more precise consideration of this issue is needed. While MO_{MIR} should be used as an indicator of BMS (as in the present study), the difference of a player's individual APHV to the general APHV for boys (i.e., 13.8 years; Malina et al., 2004) provides an indicator of maturity timing. For instance, Mirwald's equation (Mirwald et al., 2002) calculates both BMS and maturity timing. Consequently, future research should carefully choose the right approach for determining an indicator that corresponds to the specific aspect of the maturation process to be investigated. While the present study analyzed BMS outcomes, maturity timing and maturity tempo outcomes—ideally in a longitudinal research design—would be of future interest.

As a limitation of the present study and of the pragmatic assessment of indicators of somatic age in general, it has to be considered that both MO_{MIR} and PAH_{KR} appear to be very sensitive for parameters, such as leg length and standing height. Therefore, in order to ensure precise measurement of these parameters, practitioners should—beyond the use of calibrated measurement devices—control for potential physiological confounding variables. For instance, height and weight might vary at different times of the day (e.g., in the morning/evening or before/after practice; Orsama et al., 2014). For this reason, practitioners should try to maintain a standardized measurement procedure by determining consistent time slots for measuring their players. In addition, concerning the PAH_{KR} method including a mid-parent height parameter, it has been remarked that people tend to overestimate their own height (Maukonen et al., 2018). This, in turn, may falsify the PAH_{KR} values for the respective player and indicates the need for an objective assessment by an independent observer. However, research investigating the measurement errors of PAH_{KR} values between self-reported parents' height and objectively assessed parents' height by researchers is scarce. To the authors' best knowledge, only one equation exists in which the self-reported height is adjusted, developed by Epstein et al. (1995). While this equation was used in the present study as well as in some current studies (e.g., Cumming et al., 2018b), more research is needed for finding an accustomed correction formula to reduce measurement errors based on overestimating self-reported height.

Moreover, players' ethnicity status was not taken into account in this study. Researchers controversially discuss a potential influence of ethnicity on skeletal age. While Timme et al. (2017) emphasize that no impact of ethnicity exists, current studies found significant differences in skeletal age between African and

European population (e.g., Grgic et al., 2020). However, the focus of the present study lays in the comparison of different pragmatic methods with the MRI diagnostics, not least because of the effort in terms of time and costs associated with the MRI diagnostics, and the study's sample size was too small to examine the impact on different ethnic groups. Thus, comprehensive validation studies are needed to investigate potential differences when determining BMS for several ethnic groups. Therefore, future studies—ideally in a longitudinal design—should control for a possible impact of ethnicity when examining BMS, and the use of an ethnicity-specific formula might be helpful for this issue. However, to date, there is no formula that could account for ethnicity-specific assessment of BMS.

CONCLUSION

The results suggest that the use of SA_{US}, MO_{MIR}, and PAH_{KR} for measuring BMS is more pragmatic in terms of cost and time as compared with MRI diagnostics. Based on a general agreement between these pragmatic diagnostics and the reference method MRI in all three perspectives, the alternative methods can be used to determine BMS among (male) elite youth soccer players. Since caution is required with respect to the precision of the measurements at the individual level, the simultaneous use of at least two alternative diagnostics is recommended in order to get a more reliable BMS outcome. Further research is needed that evaluates both the implementation of BMS' diagnostics in practice and their usefulness in terms of bio-banding in youth soccer (e.g., Romann et al., 2020).

DATA AVAILABILITY STATEMENT

A de-identified version of the raw data supporting the conclusions of this article the findings of this study will be made available by the authors upon reasonable request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics committee of the Faculty of Medicine at the University of Frankfurt. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

OH, DLe, and DM: conceptualization and methodology. OH: data curation and supervision. DLe: formal analysis. OH and TH: funding acquisition. OH, DLe, DM, GS, MR, DLü, LB, and KE: investigation. OH, MR, and KE: project administration. DLe and DM: validation, visualization, and writing ± original draft. DLe, DM, OH, LB, KE, TH, DLü, MR, and GS: writing ± review and editing. All authors contributed to the article and approved the submitted version.

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Game Insight Skills as a Predictor of Talent for Youth Soccer Players

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Perceptual–cognitive skills are found to be important factors for soccer players. The aim of this study was, therefore, to find within-group differences for game insight in an elite group of youth soccer players by means of a Game Insight inDicator (GID). In addition, the prospective value of perceptual–cognitive skills was examined by following the trajectory of the participants. The GID consisted of film clips that show game situations. The task of the players was to predict the trajectory and destination of the ball and move toward the correct position to receive the pass of a teammate. The film clips stopped 80 ms before, at, and 80 ms after the football contact of a teammate. We also sought to validate the GID against game performance. Participants were talented soccer players 11–13 years old and playing at the elite level for their age. Based on eight independent elite-coach judgments, two groups were created: highly talented players (HT) and less talented players (LT). The coach ratings were supported by a significant difference between the two groups based on the objective notational analysis of their game performance in 4 vs. 4 and 11 vs. 11 matches. With respect to the GID, a significant interaction effect for the groups (HT vs. LT) by occlusion time (−80, 0, and +80 ms) was found, showing that the HT performs better than the LT in 0 and +80 ms condition. In addition, GID scores were compared with soccer levels at the mean age of 19 years. Longitudinal data did not show significant differences between elite and sub-elite. Overall, the GID was found to be a valid and useful indicator for players anticipating the ball's trajectory and destination at age 11–13 years but failed to predict the players' level at age 19 years. The latter indicates how difficult it is to predict talent development.

Keywords: perceptual-cognitive skills, game insight indicator, talent identification, youth elite soccer players, occlusion task, anticipation, decision making

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INTRODUCTION

Most ball sports require the ability to intercept or pass the ball. To succeed, one has to be capable of anticipating the ball's trajectory and destination. When visual information available for players is limited, they have to rely even more on their capability to extract relevant cues from the limited amount of visual information available. This skilled perception is found to be a valid differentiator between expert and less-expert players. Major findings from several studies have shown that expert athletes can extract more relevant information from pre-ball flight cues than their less-expert counterparts (Mann et al., 2007; Savelsbergh et al., 2010). Thereby occlusion of sport-specific video, occluded at or near-final ball contact, can differentiate between expert and less-expert soccer players when the players are asked to follow the direction of the ball in the video (Savelsbergh et al., 2002).

The research paradigm using the temporal occlusion of visual information was first introduced by Abernethy and Russell (1987) in squash to investigate the level of anticipation between expert and non-expert players. Later studies have reported that the discrepancy of anticipation capacity between expert and non-expert players also holds in many other ball sports such as tennis, baseball, cricket, and soccer (Houlston and Lowes, 1993; French et al., 1995; McPherson, 2000; Savelsbergh et al., 2002).

Perceptual–cognitive skills are reported to be crucial factors for soccer players (Roca et al., 2012). Furthermore, the literature on the occlusion paradigm suggests that perceptual–cognitive skills might be highly relevant for talent identification (TID). TID aims to recognize players in sports who will be successful in the future (Williams and Reilly, 2000). Literature has shown that this "talent" is something that does not remain stable and evolves with experience or expertise (Abbott and Collins, 2004; Vaeyens et al., 2008). Consequentially, the use of physiological measures such as height or sprint speed for TID might be affected by improper judgment. These improper judgments are developed by pitfalls in TID, such as the relative age effect and selection biases (Vaeyens et al., 2008; Christensen, 2009). Shifting toward psychological predictors of talent relatively less affected by latter pitfalls is more promising (Mann et al., 2017; Murr et al., 2018). For instance, as players increase with age, the general standard of skills and technical ability keeps getting better. This would mean that the technical skills of the successful players who reach the top would be extremely high, and the distinguishing factor of experts and novices on that level might not be in technical expertise but expertise in the mental aspect of the game (Woods et al., 2016a).

Perceptual–cognitive skills are typically measured with verbal or notational measures (Abernethy and Russell, 1987; Savelsbergh et al., 2002; Kannekens et al., 2009; Woods et al., 2016b). Earlier research found, for instance, that soccer players who scored high on the Tactical Skills Inventory for Sports positioning and deciding scale (procedural knowledge) had more chance to reach professional soccer than players who scored low on those scales (Kannekens et al., 2011). In another study, participants watched an occlusion video clip regarding a certain game situation and responded accordingly by circling a decision on a paper. The study consisted of 25 talented and 25 non-talented Australian football players, and the results showed that the talented participants made more accurate decisions (Woods et al., 2016b). These results should be highly relevant for TID in soccer. However, it was found that self or verbal reports measure individual processes, whereas tactical behavior is based upon the interaction between an organism and the environment (Araújo et al., 2010). According to the ecological approach, perception and action continuously interact (Gibson, 1979). Moreover, an athlete during a match, training, or when tested will continuously adapt to the environment and make decisions accordingly. In that regard, the process of identifying talented athletes should take into account an environment in which perception and action are related (Araújo et al., 2009).

In an attempt to create a setting in which perceptual–cognitive skills are measured in a "natural" setting, the Game Insight inDicator (GID) was developed (Savelsbergh et al., 2006, 2010). During the GID, participants react to a positional soccer game shown on a screen in front of the participant. The positional game is occluded before a pass is given toward the participant. The participants move as fast as possible to the position they perceive to intercept the ball after the video was occluded. Savelsbergh et al. (2010) found that skilled amateur youth soccer players were more accurate in moving toward the correct position to intercept the ball than the less skilled players (Savelsbergh et al., 2010). However, the validity of video-based decision making is questioned (Bennett et al., 2019). The latter study underlined the use of sport-specific response actions and a realistic view without removing key contextual information for decision making in a test setting. In addition, the study concluded that within-group differences should be found with a TID tool for practical relevancy.

With current knowledge regarding TID and video assessment tools, the GID should be further examined for practical relevance. Validation of GID could be improved, as no research has examined the GID in relation to *in situ* game insight and game performance. Furthermore, coaches' judgment in regard to perceptual–cognitive skills should be further examined, as it can be highly relevant for TID to know whether coaches can differentiate better and lesser perceptual–cognitive players. In addition, a within-group analysis rather than a between-group analysis should be conducted, as it might reveal more detailed information for successful performance determinants and practical use (Savelsbergh et al., 2005; Bennett et al., 2019). Additionally, the GID was proposed as a TID indicator; nevertheless, no study has been conducted to examine the prospective value of the GID. Therefore, the current experiment expands that of Savelsbergh et al. (2010) by adding four elements: (1) Independent coaches ranked players according to their game insight abilities during a 4-vs.-4 small-sided game (SSG); (2) participants were ranked in both 4-vs.-4 and 11-vs.-11 games using an objective rating system; (3) all participants were elite rather than skilled amateur youth soccer players, all playing at a Dutch elite soccer club; and (4) current soccer level was compared with GID data.

This study frame is different from previous literature, as it examines elite players in their youth and at the expertise level. To our knowledge, this is the first study that examines the prospective value of perceptual–cognitive skills—measured with an interactive video assessment tool—while also taking the judgment of coaches into account. Thereby, the aim of the present study is 2-fold: (1) to establish within-group differences for game insight in elite youth soccer players; thereby, validation of the GID could be improved by examining both subjective as objective perceptual–cognitive skills; (2) prospective value of perceptual–cognitive skills is examined by following the trajectory of the participants.

According to previous literature, expert athletes can extract more relevant information than less-expert athletes (Mann et al., 2007; Savelsbergh et al., 2010). Research also showed that early recognition of visual information could lead to better anticipation on the part of experts during given situations (Abernethy and Russell, 1987; Helsen and Starkes, 1999; Williams and Elliott, 1999; Savelsbergh et al., 2002, 2005; Vaeyens et al., 2007). Therefore, it is hypothesized that the GID can differentiate between talented and less-talented players, even within a highly homogenous elite group and at a later age.

MATERIALS AND METHODS

Participants

Fourteen youth soccer players playing in the U12 or U13 team (mean age 12.2 years, SD = 0.5) for an elite youth academy in the Netherlands participated in the study. The self-reported mean age, height, and body weight were, respectively, 12.2 years (SD = 0.13), 149 cm (SD = 2.0), and 37.8 kg (SD = 1.5). Their self-reported soccer experience was 6.8 years (SD = 1.0) and experience at an elite youth academy (M = 3.6 years, SD = 2.3). Coaches associated with the club but independent from the players were asked to watch and rank the players for game insight. This minimized the prior knowledge the coaches had about the players. All coaches were qualified trainers working with elite level players. Before the research, trainers and club management received an explanation of the measurements, the risks, and the benefits of the study. Parents or guardians were asked to sign an informed consent before the measurements. The study was conducted in agreement with the local university's ethics committee.

Materials

Video cameras recorded the clips for the GID, the regular games, and the SSGs. Video footage was projected on a 2.4 by 2.4 m screen with a video projector (Benq MX 717). An artificial turf mat was placed on the floor in front of the screen, enabling the players to wear their regular soccer shoes. The participant's positions were recorded using a Microsoft Xbox 360 Kinect sensor with coordinates saved on a laptop (HP EliteBook 8570W). The Kinect has been validated for large body movements (Geerse et al., 2015). All measurements were performed in one of the change rooms within the club's facilities (**Figure 1**).

Game Insight inDicator Clips

GID footages were recordings of a position game played on an 18.3 by 18.3 m field by 4-vs.-4 peer-aged players with additional two wildcard players. Both wildcard players were lined up on opposite sidelines, returning the ball to the team originally playing the ball. This created a 6 vs. 4 advantage for the team in ball possession. Four games of 5 min each were recorded by two cameras positioned on a wildcard's sideline (see **Figure A1**). Video clips were eligible for the GID if the ball was played in the general direction of one of the cameras, without any obstruction by a player. Based on previous research, three different occlusion types were specified (Abernethy and Russell, 1987; Savelsbergh et al., 2006):

- Clip occludes 80 ms before football contact (−80 ms) (screen turns black)
- Clip occludes at football contact (0 ms) (screen turns black)
- Clip occludes 80 ms after football contact (+80 ms) (screen turns black)

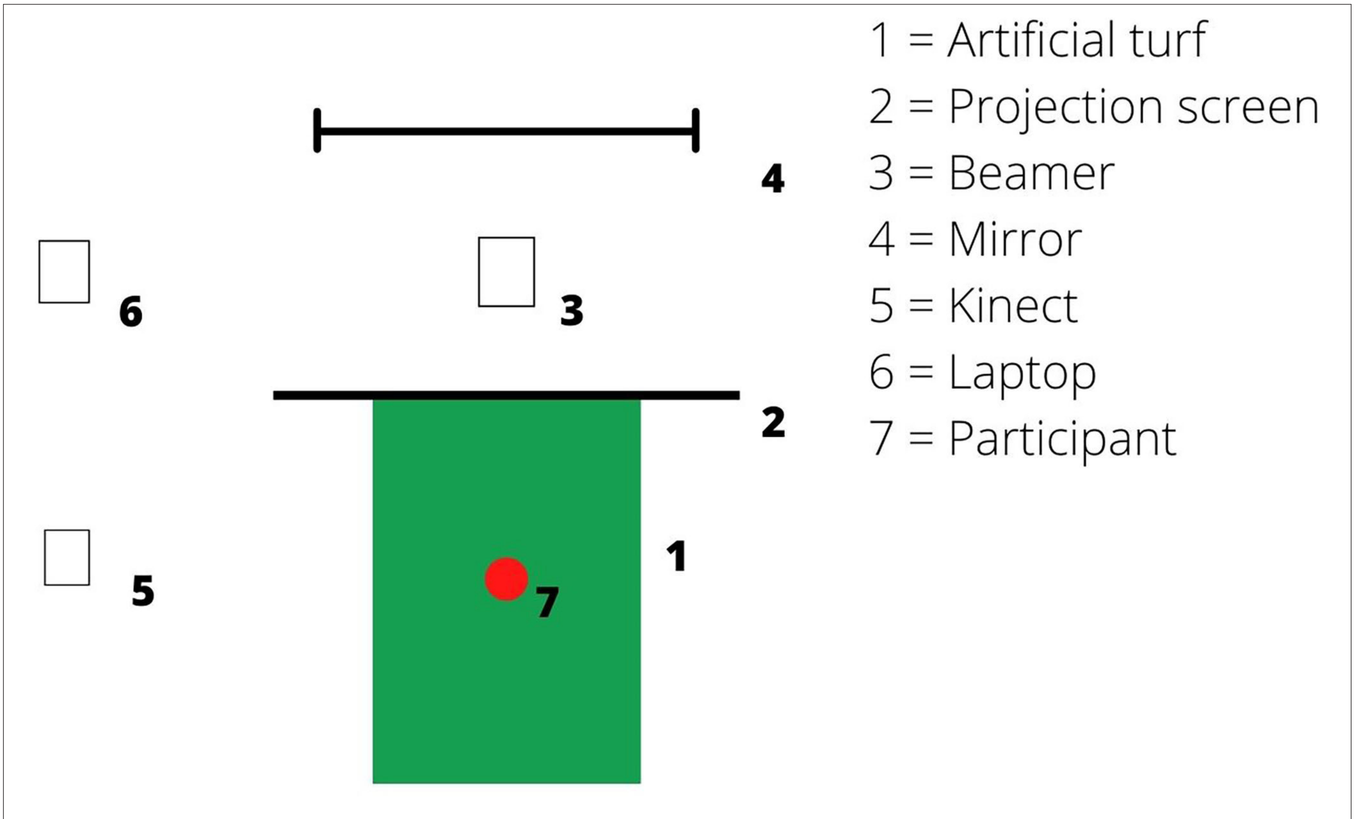

FIGURE 1 | Bird-eye view of the video task setup.

Questionnaire

Participants self-reported anthropometrics (height and weight), soccer experience (at the current and previous clubs), time participating in other sports, and time spent playing outdoors. The questionnaire consisted of the following questions:

- Date of birth?
- What are your height and weight?
- Which position do you play? (goalie, defender, midfielder, or forward)
- How many years have you played soccer in general?
- How many years of those have you played at this club?
- How many hours a week do you practice for soccer?
- How many hours a week do you spend playing outdoors?

Procedure

Rating Game Insight Abilities

Participants were involved in five 6-min SSGs with 2-min breaks between the games. SSGs are shown to replicate situations and skill requirements of regular match play (Owen et al., 2004; Rampinini et al., 2007). Thereby, varying the pitch size or amount of players can provide different training responses for physical, physiological, or perceptual loads. For instance, reducing the number of players results in a significant increase of ball contacts and tactical decisions performed by a single player (Owen et al., 2004; Jones and Drust, 2007; Duarte et al., 2009). There is, however, a lack of consistent use of SSG design (Hill-Haas et al., 2011). The current study uses the SSG design 4-vs.-4 with five 6 min SSGs and 2 min breaks in between, as it was part of the training to increase physiological demands. This 3:1 work/rest ratio is within the range of previous research regarding SSG (Hill-Haas et al., 2011). All teams consisted of four players, and the composition of the teams was shuffled every game to prevent social preference bias. The field measurements were 20 by 40 m with a small goal placed on either side. Compared with previous literature, this pitch size was relatively long for an SSG (Hill-Haas et al., 2011). This caused increased physiological demands without affecting the technical demands (Owen et al., 2004). In addition, this longer and narrow pitch was assumed to increase longitudinal inter-team distance and decrease lateral inter-team distance (Frencken et al., 2013). Therefore, it was assumed that there would be more longitudinal space and, thereby, more situations to play the ball forward or backward. These *in situ* situations were examined with the GID videos.

For both the U12 and U13 teams, four independent coaches viewed the video of the five SSGs and separately ranked the players. In total, eight coaches ranked the players according to their game insight abilities. The definition used for game insight is "to act appropriately with the given situation." Coaches gave participants a score on a scale from one to three, one for performing best and three for performing worst. All coaches judged every player in their allocated age group at least twice, with a maximum of four times. All participants were ranked 10 times. The participants rated a "1" 70% or more were placed in the *highly talented* group. The participants rated a "1" 30% or less were placed in the *less talented* group. This rating was used as the gold standard of game insight in this study. Accordingly, the performance of participants on the GID and for other variables was analyzed when comparing the highly and less talented group.

Video Occlusion Task

The GID consisted of 60 occlusion clips, proportionally distributed for three occlusion conditions (Côté et al., 2003). The first three trials were disregarded to allow the participants to familiarize themselves with the setup. The task required participants to anticipate the trajectory of the oncoming ball when visual information was occluded. Before the task, the participants received a brief explanation about the experimental setup and instructions regarding the GID. The task was to be considered a (real-)life-size video game instead of a scientific experiment. In each trial, the ball was played toward the participant or to their left or right. The participants were instructed to receive or intercept the ball, which could be achieved through lateral movements in front of the screen. Before each trial, participants were instructed to return to the center of the screen to prepare for the next trial. When the video clip ended, the participants' positions were recorded with the Kinect for an additional 3 s to capture any movement after occlusion. No feedback was given about performance, but continuous supportive comments were made to aid the participant in maintaining their focus. The occlusion score was determined by calculating the percentage of correct responses to receive or intercept the ball. For each condition (19 trials per condition), the maximum score was 33%. So, for instance, at one condition, 12 correct responses correspond with 21%.

Game Performance

Game performance was analyzed during SSGs and regular games. The same footage in which the coaches viewed and ranked the players for game insight was used for analyzing the game performance. Footage of regular competition games was acquired during regular games, which were held in accordance with the Royal Dutch Soccer Association rules on a 60 by 100 m field. The first 30 min of each half was analyzed independently by two notation analysts. Any additional time was excluded from the analysis. **Table 1** consists of all variables and the definitions for which the players were rated. The mean percentage of the sum of successful actions was used as an indicator for game performance. Whether the pass, pass reception, or interception was successful depended on the outcome. An action was deemed successful if the team remained in possession or regained possession from the opponent.

Dependent Variables, Data Analysis, and Statistics

To conduct analyses for the GID, all x,y,z-coordinates and frame numbers were extracted from the Kinect data. The starting position was determined by determining the participants' mean position over the first 50 frames. Participants' position at the moment of occlusion was used as the final position. A movement of more than 15 cm from the relative starting position was arbitrarily chosen to differentiate among a left, right, or middle response. The dependent variable for GID was the percentage of correct responses. The dependent variable for the SSG and competition game was the mean percentage of the sum of successful first touches, passes, forward passes, and interceptions.

TABLE 1 | Definition of parameters used for the rating of game performance.

Parameter	Definition
Receive	Player gains or attempts to gain control of the ball to retain possession
Well-received	The player successfully gains or attempts to gain control of the ball to retain possession
Defensive pressure/interception	Preventing an opponent's pass from reaching its intended destination or put pressure on a player in possession of the opponent
Successful defensive pressure/interception	Successfully preventing an opponent's pass from reaching its intended destination or put successfully pressure on a player in possession of the opponent
Number of passes	Pass: Player in possession sends the ball to a teammate (e.g., using the foot, thigh, or chest; using various techniques such as ground, lofted, chip, flick, or volley; over short or long distances)
Number of passes correct	Amount of successful passes given by a player in a match
Number of passes forward	Amount of passes forward given by a player in a match
Number of passes forward correct	Amount of successful passes forward given by a player in a match

Statistical analyses were performed with SPSS (IBM SPSS Statistics 26.0). An independent *t*-test was used to compare the highly and less talented groups for rating by coaches, rating game performances, and the questionnaire. A mixed analysis of variance design, with between-subject factor groups, was performed to evaluate coach rating for the group [highly talented (HT) vs. less talented (LT)] and occlusion time (−80 vs. 0 vs. +80). If Mauchly's test was not significant ($p > 0.05$), the sphericity assumption was accepted; if not, a Greenhouse–Geisser correction was used. *Post hoc* pairwise comparisons were done with independent *t*-tests to examine if there was a significant interaction effect.

RESULTS

Coach Rating

Based on the mean coach ratings, HT and LT participant groups were created. The HT group consisted of five players rated a "1" 70% or more ($N = 5$). The LT group consisted of eight players who were rated a "1" 30% or less. This excluded one player from further analysis. The overview per coach and player is found in **Table 2**.

A significant difference ($p < 0.001$) was found for the ratings of the players across the HT group (M = 1.2, SD = 0.16) and LT group (M = 2.25, SD = 0.52) (**Table 3**). Also, significant differences were detected in the game performance for both the 4v4 and the 11v11 games between the HT group (M = 85.84, SD

TABLE 2 | (A) Overview coach ratings U12 players. (B) Overview of coach ratings U13 players.

	Trainer 1					Trainer 2					Trainer 3					Trainer 4						"1"%
Players U12	L1	L2	L3	L4	L5	L1	L2	L3	L4	L5	R1	R2	R3	R4	R5	R1	R2	R3	R4	R5	Mean	
A																						
A	2					2						3	3	3	3		3	3	3	3	2,8	0
B	3		3	3	3	3		3	3	3		3					3				3	0
C				3					2		1	2	1		3	2	2	2		1	1.9	30
D		2	1		1		2	1		1	3			1		1			1		1,5	70
E		3		3	3		3		2	3	2		2			3		1			2,5	10
F	1					1						2	1	1	1		1	1	1	1	1,1	90
G	1		1	1	1	1		1	1	1		1					1				1	100
H	2	2				2	2						2	2	1			2	2	2	1,9	10

	Trainer 5					Trainer 6					Trainer 7					Trainer 8						"1"%
Players U13	L1	L2	L3	L4	L5	L1	L2	L3	L4	L5	R1	R2	R3	R4	R5	R1	R2	R3	R4	R5	Mean	
B																						
I		1			1		2			2	2		3	3		2		3	3		2,2	20
J		1	1	2			3	1	1		1				1	2				1	1,4	70
K	3	3	2		2	3	3	2		1			2					2			2,3	10
L			1	1	1			1	1	1	1	2				1	2				1,2	80
M	1	2				2	2						1	1	1			1	1	1	1,3	70
N	1			1		2			2			1	1		2		1	1		2	1,4	60

TABLE 3 | Relevant variables between HT and LT group, *significant ($p < 0.05$).

Variable	HT Group (*N* = 5) Mean (SD)	LT Group (*N* = 8) Mean (SD)	*T*-value (*p*)
Rating by the coaches	1.2 (0.16)	2.25 (0.52)	4.3 (<0.000)*
Game performance in 4v4	85.84 (8.2)	69.7 (5.8)	−4.2 (<0.001)*
Game performance in 11v11	86.82 (6.8)	63.26 (9.3)	−4.9 (<0.005)*
Hours spent playing outdoors	10.2 (2.8)	7.3 (3.8)	−1.5 (0.152)

= 8.2; M = 86.82, SD = 6.8) and the LT group (M = 69.7, SD = 5.8; M = 63.26, SD = 9.3).

The group (HT vs. LT) × Occlusion (−80 vs. 0 vs. +80) testing was carried out. The sphericity assumption was accepted due to non-significant Mauchly's test ($p > 0.05$). For the main factor of the group, no significant effect was found $F_{(2, 11)} = 2.8$, $p = 0.106$. The main effect of occlusion was significant $F_{(2, 22)} = 5$, $p = 0.016$, $\eta_p^2 = 0.313$, whereas the analysis revealed a significant interaction between group and occlusion $F_{(4, 22)} = 3.4$, $p = 0.025$, $\eta_p^2 = 0.385$ (**Figure 2A**). An independent *t*-test for GID score showed a significant difference, $t(11) = -3.2$, $p = 0.009$, between score on 0-ms clips for talented (M = 19, SD = 6.4) and less talented group (M = 9, SD = 5). Also, a significant difference, $t(11) = -2.3$, $p = 0.04$, was found between score on +80-ms clips for talented (M = 21, SD = 6) and less talented group (M = 12, SD = 7). For total occlusion score, there was also a significant effect ($p < 0.05$) found for HT group (M = 48.2 SD = 12.6) compared with the LT group (M = 28.4, SD = 13.6).

Seven Years Later

Seven years after the original measures, 9 of the 14 players still played soccer at a high level (i.e., in the first league for their age). The playing levels of the participants (mean age of 19 years) are reported in **Table 4**.

Three out of the six original HT players were playing at the highest level (1), one was performing at the third-best level (3), one at the fourth-best level (4), and one player, unfortunately, had to quit soccer due to reasons other than his soccer skills and was therefore excluded for further analysis. Five of the seven players—originally classified as LT players by the coaches—also played at the highest level. Additional analysis found no significant effect on the main factor group ($p = 0.568$) between sub-elite and elite players (**Figure 2B**). Also, no significant effect was found for interaction effect between group and occlusion ($p = 0.634$) between the elite ($N = 9$) compared with sub-elite ($N = 4$).

DISCUSSION

The purpose of this study was to verify and expand findings by Savelsbergh et al. and improve the validation of the GID. In previous research, the GID was validated as a differentiator between skilled amateur youth players (Savelsbergh et al., 2010). However, the capabilities of video-based decision-making have been questioned (Bennett et al., 2019). The current findings confirm our hypothesis that talented and less-talented youth participants can be identified on the basis of their performance on the occlusion task. Within a highly homogenous elite group, the HT group outperforms the LT group for occlusion task and game performance (**Table 3**, **Figure 2A**). This also indicates that independent elite coaches can differentiate HT players and LT players within only 30 min of SSG play. Further, these coach ratings are supported by the significant difference between the two groups revealed by objective notational analyses of the 4-vs.-4 and 11-vs.-11 game performance.

A significant interaction effect for occlusion and group was found. A clear difference was observed visually between the HT and LT groups (**Figure 2A**). This is in line with earlier literature stating that expert athletes can extract more relevant information than less-expert athletes (Mann et al., 2007; Savelsbergh et al., 2010; Roca et al., 2012). In the current study, the −80 and +80 ms occlusion scenarios do not (quite) differentiate between the HT and LT groups. From the literature, it is well-known that adult experts are capable of extracting relevant cues at 160 ms before final ball contact and that −80 ms occlusion trials show to be a good occlusion scenario to discriminate within expert adults (Abernethy, 1990; Mann et al., 2007). The current study showed that the −80 ms occlusion trials were too difficult for the young participants. Explanations that may account for this: (1) the cognitive functioning of the young brain has not been fully developed and lacks the processing speed; (2) the participants do not have the amount of experience of adults and lack a reference framework to compare the current situation with; (3) It may yet not be necessary for youth players to make anticipation for that time constraint (Weissensteiner et al., 2008). In addition, it has been suggested that children need more time to decide during an occlusion task (Savelsbergh et al., 2010). The +80 and 0 ms occlusion scenarios seem to be good methods to discriminate within a highly talented youth soccer group between HT and LT players. The uptrend in **Figure 2A** for LT players at +80 ms trials reflects the elite level of the participants. Future research should indicate whether +80 ms scenarios discriminate more between sub-elite and elite.

By using both subjective and objective measurements, the current study presents a broad view of game insight. Elite coaches created both the HT and LT groups on their game insight abilities. Between both groups, a significant difference in game performance, measured by objective analysis, was observed. Current findings, therefore, note the importance of game insight during a game performance, whereas game performance depends on multidisciplinary skills (Larkin and O'Connor, 2017). GID might, therefore, be an important tool to indicate game insight and game performance. Nevertheless, there might be a

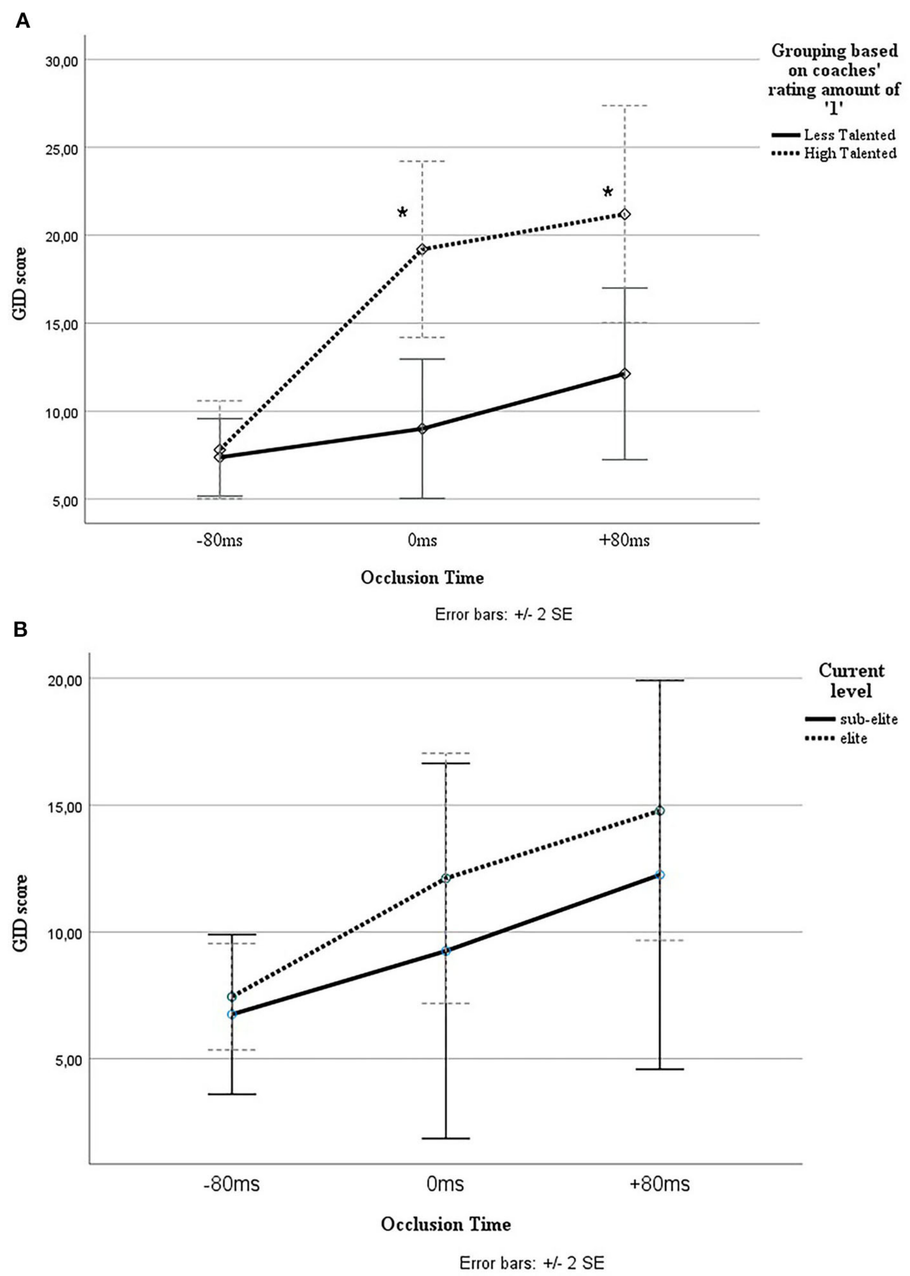

FIGURE 2 | (A) Interaction effect for the Group *Occlusion for groups based on coaches rating. *Significant ($p < 0.05$). **(B)** Interaction effect for the Group * Occlusion for groups based on current level.

discrepancy between the GID and real gameplay. Game insight during gameplay is suggested to be characterized by explorative behavior, which increases the rate of successful actions of soccer players (Jordet et al., 2013; McGuckian et al., 2018). A recent study, thereby, proposes that players who have knowledge regarding their surroundings can make better actions accordingly (McGuckian et al., 2018). GID measures perceptual–cognitive skills in the frontal plane and, therefore, might require less explorative behavior than the *in situ* gameplay, which requires a three-dimensional view (Vaeyens et al., 2008). The latter suggests that the GID is less representative of real gameplay and, therefore, might not be suitable for TID regarding perceptual–cognitive skills (Shim et al., 2005; Bennett et al., 2019). However, identifying talent should be executed in an environment with an intact coupling between perception and action (Araújo et al., 2009). In addition, the task should be representative of soccer matches and require the execution of sport-specific skills (Travassos et al., 2013; Bennett et al., 2019). During the GID, participants are

TABLE 4 | Current soccer level 2019/2020.

Participant	Group	Current soccer level
F	HT	1
L	HT	3
M	HT	1
G	HT	Quit
D	HT	4
J	HT	1
A	LT	3
B	LT	1
C	LT	1
E	LT	1
H	LT	5
I	LT	1
K	LT	1
N	MT	1

Playing level 1 is the highest possible level—still playing in a premier club at the highest division—whereas level 5 is playing in the fourth division.

tasked to receive the ball and not give a pass afterward or make a certain action. Therefore, the GID creates a decision-making situation that is encountered by players during regular games. In addition, the GID provides environmental information such as teammates and task requirements, which decision-making tasks should consist of Araújo et al. (2006) and Mann et al. (2007). The GID also contains decision and processing speeds required during a competition, which should be reflected during practice sessions (Farrow and Raab, 2008). Overall, the GID gives a representative view of decision making and might be a more suitable tool to measure tactical decision making than verbal or written tests (Van Der Kamp et al., 2008; Araújo et al., 2009, 2010; Travassos et al., 2013). The latter is supported by the findings that *in situ* performance of SSGs did not relate to self-reported procedural data (Nortje et al., 2014). This is in line with the idea of Van Der Kamp et al. (2008) that an experimental study regarding decision making should require participants to act rather than to write or communicate. The GID, however, is performed in a controlled laboratory setting. A limitation, therefore, is the presence of a discrepancy of perception–action coupling between *in situ* and the controlled setting. The perception in a laboratory setting is found to be different, whereas the player in the natural setting has to perform the required action according to the perceived information (Dicks et al., 2010). The intention with the GID is only to move toward a position to intercept the ball without performing the interception. Current results, however, indicate that occlusion scores differentiate for *in situ* game insight. Nevertheless, further research should be undertaken to compare occlusion scores with explorative behavior during real gameplay to increase the validity of the GID and *in situ* decision making.

Seven Years Later

Longitudinal data show that five of the seven players—which were originally classified as LT players by the coaches—played at the highest level at mean age 19 years. This indicates how difficult it is to predict talent development. Current data show that trainers should not base their decision on (de)selecting exclusively on GID score. Nevertheless, although there was no significant difference for longitudinal data, GID is still very promising as the elite group scored better than the less group (**Figure 2B**). The improvement of the less group might be caused by the nature of the soccer club, i.e., having a long-distance plan with their youth players. During the years of training, the "less talented" players could have increased their perceptual–cognitive, and other skills, with the number of training hours at the elite level. GID could, therefore, be a valuable tool for measuring and evaluating the development of perceptual–cognitive skills. Future research should examine longitudinal data for the GID with a larger sample size to indicate the usefulness of the GID for talent prediction.

Additional Information

This section contains findings that are outside the scope of this study. Nevertheless, it contains important and useful information for TID and development. A growing body of evidence arises that children and young adolescence are spending more time indoors and becoming more sedentary (Hallal et al., 2012; Tremblay et al., 2014, 2016). A recent study by Anselma et al. (2020) found that the decrease of physical activity results in a decrease of movement speed, flexibility, and trunk, leg power for children of 10–12 years compared with 10 years before. Another recent study with 2,543 children showed that the physical activity of children with mean a mean age of 10 years was 9.06 hours per week (SD = 5.10) (Rodriguez-Ayllon et al., 2020). In comparison, the physical activity per week of the soccer players in the current study was considerably higher. With organized sports hours per week and hours playing outside taken into account, the self-reported total physical activity of the talented players was 14.7 h and, for the lesser counterparts, 11.8 h per week. The discrepancy with the non-expert peers might result in an ongoing advancement for elite players, whereas a decrease in physical activity decreases characteristics needed for soccer (Anselma et al., 2020). In addition, outdoor play improves responses to new and challenging environments and social skills (Pellegrini and Smith, 1998; Pellegrini et al., 2007). Furthermore, the extra hours of practice could play a significant role in the development of the players (Côté et al., 2003; Memmert et al., 2010). The motor development of future athletes could, therefore, be hindered and as a consequence the gap between expert elites and novices increases. Future research should take the latter into account and examine whether the gap between novices and expert athletes increases as this might be concerning for the overall level of future athletes.

Overall, the current findings indicate that the GID is a useful indicator for anticipating the ball's trajectory and destination at age 11–13. Although no clear relationship with future performance was found, the GID can be a valuable tool to measure and evaluate perceptual–cognitive skills to examine the process of talent development. Yet, *in-situ* game insight measurement and coaches evaluation had some limitations. Future research should, therefore, evaluate game performance by taking explorative behavior into account. Furthermore, the current findings point to the need to consider the subjective opinions of expert coaches for talent identification. This is in line with recent literature that the judgment of coaches regarding soccer skill rating discriminates between different skill groups (Hendry et al., 2018). Although there is a growing body of literature regarding objective talent predictors, coach judgments are still important and should not be neglected in the selection and deselection of soccer players (Höner and Votteler, 2016). Nevertheless, coaches' evaluations of game insight might be biased. Therefore, it is suggested that future research should implement the actuarial judgment of coaches to improve the evaluation of game insight performance *in situ*. The actuarial judgment gives more rules for the judgment and decreases the chance of biased judgments (Christensen, 2009; Den Hartigh et al., 2018). Combining both actuarial judgments and the GID could provide a broader understanding of the game insight of soccer players.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. Written informed consent was obtained from the minor(s)' legal guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

GS conceptualized the study. DT and TdJ contributed to the software and data collection. TdJ contributed to the methodology and writing of the original draft. GS reviewed and edited the manuscript and supervised the study. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

APPENDIX

A. Set-Up for Footage for the GID Clips

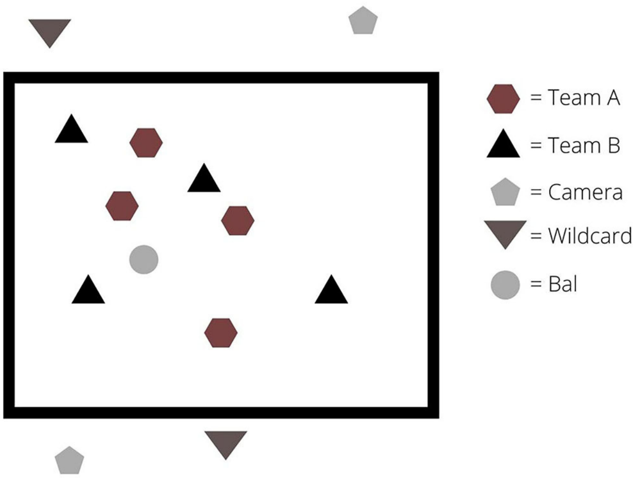

FIGURE A1 | A 4-vs.-4 position game played by peer-aged players with two wildcard players at the side. It was played on an 18.3 by 18.3-m field. Four games of 5 min each have been recorded by two cameras positioned on a wildcard's side line.

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More Success With the Optimal Motivational Pattern? A Prospective Longitudinal Study of Young Athletes in Individual Sports

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It is widely recognized that motivation is an important determinant for a successful sports career. Specific patterns of motivational constructs have recently demonstrated promising associations with future success in team sports like football and ice hockey. The present study scrutinizes whether those patterns also exist in individual sports and whether they are able to predict future performance levels. A sample of 155 young individual athletes completed questionnaires assessing achievement goal orientations, achievement motives, and self-determination at t_1. The person-oriented method linking of clusters after removal of a residue (LICUR) was used to form clusters based on these motivational constructs in order to analyze the relations between these clusters and the performance level 2.5 years later (t_2). Similar to the studies in team sports, four motivational patterns were observed at t_1. The *highly intrinsically achievement-oriented athletes* were much more likely to compete internationally [odds ratio (*OR*) = 2.12], compared to the *failure-fearing athletes* (*OR* = 0.29). Although team and individual sports differ in many respects, they nevertheless are characterized by similar and thus generalizable career-promoting motivational profiles: Regardless of the type of sport, the *highly intrinsically achievement-oriented* athletes consistently have the best potential for success.

Keywords: person-oriented approach, motivation, pattern analysis, predicting success, individual sports

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INTRODUCTION

Current empirical research on motivation in sport has examined a broad range of theoretical constructs, including achievement motivation (e.g., Coetzee et al., 2006; Elbe and Beckmann, 2006; Sagar et al., 2010), achievement goal orientations (e.g., van Yperen and Duda, 1999; Reilly et al., 2000; Domínguez-Escribano et al., 2017), or self-determination (e.g., Sarrazin et al., 2002; Gillet et al., 2009, 2012), and highlighted their importance for sports performance. However, most of these studies systematically considered the different motivational variables in isolation. The failure to take the multidimensional nature of the motivational subsystem into account, results in neglect of compensation mechanisms as well as interactions between different variables, which are assumed by talent research (e.g., Bartmus et al., 1987). Thus, to offer tailored and person-oriented psychological assistance to youth elite athletes, it seems essential to understand the emerging dynamics within the motivational subsystem, and to examine the developmental consequences (e.g., prognostic value) of different combinations of motivational variables (or so-called patterns). Therefore, the use of a holistic and dynamic-interactionistic research paradigm seems to be appropriate (Bergman et al., 2003; Bergman and Andersson, 2010). One possibility is the application of a person-oriented approach, which provides a view of the system as a whole with its components forming a pattern that is considered indivisible (Bergman and Wångby, 2014). This pattern has to be understood and analyzed in its entirety and cannot be broken down into independent variables (Bergman and Wångby, 2014). So far, only three studies combined different motivational constructs with a person-oriented approach and the goal of identifying predictive patterns of future athletic performance (Zuber et al., 2015, forthcoming; Zuber and Conzelmann, 2019b). Zuber et al. (2015) used the Linking of Clusters after removal of a Residue (LICUR) method to form motivational patterns out of achievement goal orientations (i.e., win orientation and goal orientation), achievement motives (i.e., hope for success and fear of failure), and self-determination in young talented football players. Those patterns were relatively stable over the span of 1 year in early adolescents and effectively predicted future success in football after 1 (Zuber et al., 2015) and 5 years, respectively (Zuber et al., forthcoming). It was found that the *highly intrinsically achievement-oriented players* were significantly more likely to end up in the highest performance level after 5 years (*OR* = 3.5; Zuber et al., forthcoming). Those athletes showed high win and goal orientations, hope for success, and self-determination but low fear of failure. Conversely, the *non-achievement-oriented failure-fearing players* showed the opposite pattern and were, as a result, significantly less likely to compete at the highest performance level (*OR* = 0.4; Zuber et al., forthcoming). In young ice-hockey athletes, structurally similar motivational patterns demonstrated great relation with success over 6 months (Zuber and Conzelmann, 2019b).

These results suggest that, despite the differences related to the inherent specificity of these team sports, a promising motivational pattern labeled *highly intrinsically achievement-oriented players* seems to emerge on a recurrent basis. The pattern's repeated association with a higher probability of future success not only makes it worth striving for, but also supports the possible generalization of its joined benefits beyond team sports. Because person-oriented studies were only conducted in male football and ice hockey until now, the extent of their generalizability is underexplored. Investigation of the applicability of this approach in national talent development programs will require the thorough examination of their generalizability to a more diverse range of environments, such as individual sports and athletes of both sexes (e.g., Johnston et al., 2018). With regard to the generalizability from team to individual sports, several empirical findings suggest differences in terms of motivational processes (e.g., Hollembeak and Amorose, 2005; Hanrahan and Cerin, 2009; Jonker et al., 2010; van de Pol and Kavussanu, 2012). The higher controllability and responsibility of the behavior in individual sports may change the optimal motivational pattern required to reach the highest performance level (e.g., Hanrahan and Cerin, 2009). For example, it was found that athletes competing in individual sports have higher ego orientation than those of team sports (Hanrahan and Cerin, 2009), as well as higher level of intrinsic motivation (Hollembeak and Amorose, 2005) and different self-regulatory skills (Jonker et al., 2010).

In order to identify career-promoting or impeding motivational profiles in individual sports, the present study aims to replicate the results that Zuber et al. (2015) found in team sports with a sample composed of athletes from individual sports. By doing so, not only the reproducibility but also the generalizability of the results will be investigated.

MATERIALS AND METHODS

Participants

With the help of Swiss Olympic and several sports federations, 76 coaches were contacted, who in turn suggested 263 athletes to participate. With a response rate of 62.7%, the overall sample consisted of 165 young athletes from Switzerland. Complete data sets were available for a total of 155 athletes (60 females and 95 males) with a mean age of 16.47 years (*SD* = 2.21). These athletes were competing in badminton (n = 7), biathlon (n = 1), curling (n = 7), freestyle skiing (n = 3), golf (n = 7), judo (n = 15), artistic cycling (n = 3), track and field (n = 12), wheelchair athletics (n = 2), mountain biking (n = 5), sledding (n = 1), rowing (n = 65), swimming (n = 7), alpine skiing (n = 5), shooting (n = 9), tennis (n = 1), or equestrian vaulting (n = 5).

Measures

As a replication study of Zuber et al. (2015, forthcoming) and Zuber and Conzelmann (2019b), identical measures were used to assess the different motivational characteristics of the athletes. The achievement goal orientations were assessed through the German version (Elbe, 2004) of the Sport Orientation Questionnaire (SOQ; Gill and Deeter, 1988). The two scales win orientation (e.g., "I have the most fun when I win") and goal orientation (e.g., "I try hardest when I have a specific goal") were used and displayed acceptable to good internal consistencies (α_{WO} = 0.84; α_{GO} = 0.77).

The achievement motivation was measured by using the German version of the short scale of the Achievement Motives Scale – Sport (AMS-Sport; Wenhold et al., 2009) with its two dimensions of hope for success (e.g., "I enjoy athletic tasks that are slightly difficult for me") and fear of failure (e.g., "I am even afraid of failing at athletic challenges that I believe I can accomplish"). The internal consistencies were within a good range (α_{HS} = 0.80 and α_{FF} = 0.84).

The self-determination was determined with the Sport Motivation Scale (SMS; Burtscher et al., 2011). Similar to Vallerand (2001) and Zuber et al. (2015), the seven subscales of motivation (intrinsic motivation toward knowledge, accomplishment and stimulation, identified, introjected, external regulation, and amotivation) were combined to form a self-determination index. The scale displayed good internal consistencies with $\alpha = 0.83$.

Procedure

A longitudinal research design was applied to assess the motivational characteristics and the future athletic success of the participants. At the first measuring point (t_1), the athletes were asked to complete the self-assessment questionnaires. Their initial performance level was assessed through the allocation of Swiss Olympic Cards (SOCs). The type of card assigned (none, regional, national, and international/elite) mainly reflects three aspects: the results in annual multidimensional tests carried out by the federations, the systematic estimation of each athlete's potential carried out by their coach, and the achievement reached in competitions. At t_1, the performance level of these athletes ranges from regional to international (i.e., competing at youth world championships), which corresponds to levels T1–T4 in the Foundations, Talent, Elite, and Mastery (FTEM) framework (Gulbin et al., 2013). Two and a half years later (t_2), the performance levels of the athletes (1 = international level; 2 = national level and lower; and 3 = dropout) were identified through their results at national or international competitions. At t_2, 50 athletes participated in international competitions, whereby several athletes were ranked on the podium at junior or U23 world championships and one athlete had won an Olympic medal. The remaining athletes either participated in national competitions ($n = 83$) or were no longer found in the result databases and had dropped out ($n = 19$).

Formal ethical approval was granted from the authors' institutional review board before conducting the study. All athletes and their legal representatives (for athletes younger than 16 years) provided their written informed consent.

Data Analysis

The LICUR method (see Bergman et al., 2003) was used to analyze the motivational subsystem. This person-oriented approach has already proven its usefulness in various talent studies, as the multi-dimensional nature of sports performance and athlete development seeks for holistic and dynamic-interactionist approaches (Zibung and Conzelmann, 2013; Sieghartsleitner et al., 2018). Within the person-oriented approach, "the individual is seen as an organized whole with elements operating together to achieve a functioning system where the involved elements interact in the process" (Bergman and Andersson, 2010, p. 157). Consequently, the interacting variables of a system are described as operating factors (Bergman et al., 2003).

The following statistical analyses were carried out according to the guidelines of Bergman et al. (2003). In a first step, the dataset was checked for outliers (residues), because such rarely occurring cases would otherwise distort the cluster solution. A threshold value of 0.8, measured by the squared average Euclidean distance computed on standardized variables, was chosen as distance to identify multivariate outliers. In a second step, a hierarchical cluster analysis (Ward method with average squared Euclidean distance) was performed. In order to optimize the solution, a partitioning cluster analysis (k-means method) was executed. The optimal cluster solution was selected through content aspects and the criteria formulated by Bergman et al. (2003). Only the operating factors with z-scores ≥ 0.5 were used to label the different clusters. In a third step, the transitions (developmental paths) between the clusters and performance levels were checked for significance using a Fisher's exact test with a hypergeometric distribution ($p < 0.05$). By calculating the odds ratio (OR), the strength of association between clusters and performance level is quantified ($OR = 1.0$ as the expected value; $OR < 1.0$ means less and $OR > 1.0$ more transitions than expected by chance). Additionally, a one-way ANOVA was performed to test any cluster differences in age and years of training. Eta-square (η^2) was used to estimate the effect size (0.01 = small, 0.06 = medium, and 0.14 = large; Cohen, 1988). The distributions of sex and initial performance level (i.e., SOC type) across clusters were also checked with a Fisher's exact test. The described LICUR analysis was carried out with the statistics package ROPstat 2.0 (Vargha et al., 2015), all other analyses with IBM SPSS Statistics 26.0.

RESULTS

Three cases exceeded the squared average Euclidean distance to all of the other cases and were therefore excluded from further analysis, resulting in a total sample size of 152 athletes. The descriptive statistics of the five motivational constructs before z-standardization are presented in **Table 1**. The four cluster solution (see **Figure 1**) was found to fit best in terms of content aspects as well as statistical criteria with an explained error sum of squares (EESS) of 51.78%, a weighted homogeneity coefficient (HC_{mean}) of 0.99 (0.84; 1.25), and a silhouette coefficient (SC) of 0.58 (Vargha et al., 2016).

Cluster 1 (*highly intrinsically achievement-oriented athletes*) consists of athletes who display high goal orientation, hope for success, and self-determination, but low expression of fear of failure. Cluster 2 (*win-oriented athletes*) consisted of athletes with a particularly high win orientation. The athletes of the cluster 3 (*failure-fearing athletes*) are characterized by average values, apart from high fear of failure. Athletes with low win and goal orientation were grouped in cluster 4 (*non-achievement-oriented athletes*). There were no differences between the four clusters at t_1 regarding age [$F(3,148) = 0.22$, $p = 0.88$, $\eta^2 < 0.01$], years of training [$F(3,148) = 1.36$, $p = 0.26$, $\eta^2 = 0.03$], and sex ($p = 0.85$). Results of the Fisher's exact test revealed that the proportion of SOC types only differed in one cluster at t_1. Specifically, in cluster 4 (*non-performance-oriented athletes*) athletes with a regional SOC were underrepresented ($p = 0.01$). Athletes of different sexes were evenly distributed across clusters ($p = 0.85$).

Two significant paths emerged from the clusters at t_1 to the performance level t_2. While the *highly intrinsically achievement-oriented athletes* were more likely to be found in the highest performance level at t_2 [$OR = 2.12$ (1.03; 4.33)], the *failure-fearing athletes* were less likely [$OR = 0.29$ (0.11; 0.82)].

TABLE 1 | Descriptive statistics for the subsystem motivation.

	Win orientation (range 1–5)		Goal orientation (range 1–5)		Hope for success (range 0–3)		Fear of failure (range 0–3)		Self-determination (range -18–18)	
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Overall (*n* = 152)	3.97	0.75	4.49	0.47	2.23	0.49	0.56	0.59	7.82	3.24
Cluster 1 (*n* = 47) Highly intrinsically achievement-oriented athletes	4.14	0.68	4.72	0.30	2.78	0.21	0.14	0.22	9.94	2.74
Cluster 2 (*n* = 49) Win-oriented athletes	4.27	0.48	4.73	0.25	2.03	0.32	0.70	0.62	7.83	2.83
Cluster 3 (*n* = 33) Failure-fearing athletes	4.01	0.42	3.97	0.35	1.79	0.35	1.12	0.57	4.66	2.47
Cluster 4 (*n* = 23) Non-achievement-oriented athletes	2.67	0.58	3.92	0.41	2.13	0.39	0.40	0.27	7.07	2.61

Note that three cases have been classified as outliers and therefore were removed.

The two other clusters did not display any significant transitions to a specific performance level.

DISCUSSION

The purpose of the present study was to examine if the motivational patterns detected in the team sports football (Zuber et al., 2015) and ice-hockey (Zuber and Conzelmann, 2019b) can be observed in individual sports and demonstrate comparable developmental paths to a specific performance level. Overall, very similar but not identical clusters and developmental paths were discovered in the present study. It was shown that in individual sports, the *highly intrinsically achievement-oriented athletes* were more likely to reach the highest level. This cluster also displays many structural similarities to the most successful cluster in team sports (i.e., *highly intrinsically achievement-oriented players*). The three other clusters show slightly different patterns in comparison to the cluster solutions found in the previous team sport studies (cf. Zuber and Conzelmann, 2019b; Zuber et al., forthcoming). For example, no "average" cluster was identified. Athletes with the lowest prospects for future success in team sports were the *non-achievement-oriented failure-fearing players* (e.g., Zuber et al., 2015). This pattern did not emerge in individual sports; instead, the *failure-fearing athletes* displayed a significantly lower probability of competing on an international level at t_2. In an equivalent manner to the team sport studies, the trend illustrated by this pattern accentuates the negative consequences of an above-average *fear of failure* and as a result, seems to point to the possibility of a generalizable career-limiting motivational profile.

Two patterns (*highly intrinsically achievement-oriented athletes* and *failure-fearing athletes*) and developmental paths emerge recursively, one positively and one negatively associated with future success. Regardless of the sport examined, there seem to exist career-promoting/−limiting motivational patterns for athletes.

From an applied perspective, the potential of an athlete's person-oriented profiling and its implications in terms of coaching and selection must be critically reflected. Indeed, a careful evaluation of an athlete's profile can help to design targeted psychological interventions, which in turn may help them to create their own career-promoting motivational pattern. For example, it has been shown that coaches can trigger higher self-determined motivation and sport performance in athletes by increasing autonomy support, which would be an interesting intervention for athletes with low self-determination (Gillet et al., 2010). Furthermore, cognitive-behavioral intervention designed to promote a mastery-initiating motivational climate was found to lower the trait anxiety among youth athletes (Smith et al., 2007). Thus, future studies have an opportunity to examine whether those motivational patterns can be altered over time through sport psychological interventions.

Even if such a questionnaire-based procedure seems recommendable from a developmental point of view and its prognostic value is good, it is highly problematic to use it in the selection context because social desirability would quickly bias the results (Zuber and Conzelmann, 2019a). Therefore, it is recommended not to use self-reporting questionnaires for talent identification but only for talent development. In order to consider achievement motivation in the talent identification and selection process, an external rating scale for the assessment of the achievement-motivated behavior could be used (Schmid et al., 2020; Zuber et al., 2020).

The restricted comparability of different sports included in this sample should be mentioned as a primary limitation of the study. Even if they are all individual sports, there are major differences between these sports. For example, golf as a precision sport, judo as a martial art, or swimming as an endurance sport pose quite different demands on a person (physical capabilities, mental skills, etc.). Indeed, it remains unclear whether an unfavorable configuration of motivational variables can be compensated more easily in certain sports,

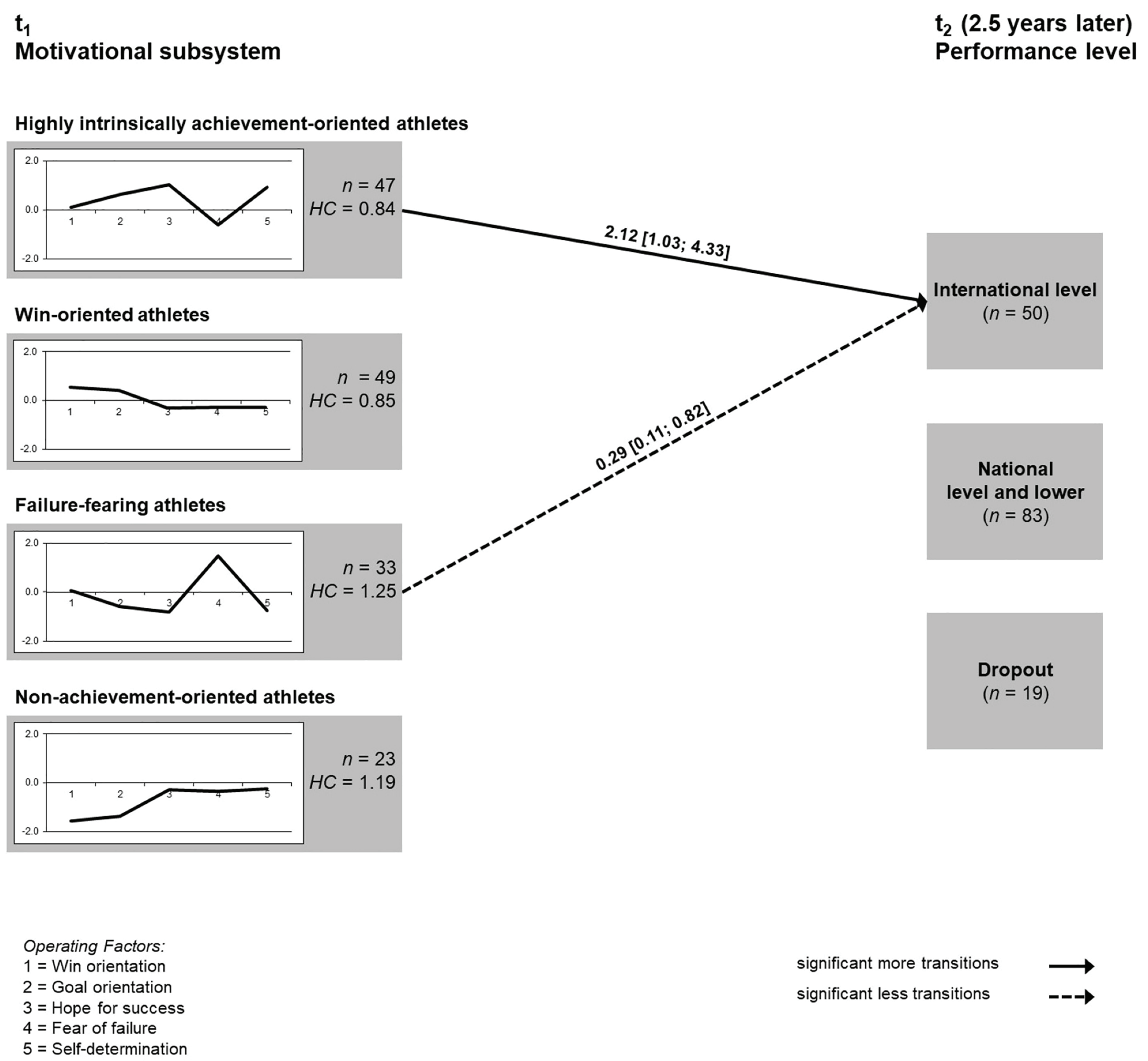

FIGURE 1 | Profiles of *z*-scores of the four clusters and transitions to the performance levels at t_2 (EESS = 51.78%). Operating factors: 1 = win orientation; 2 = goal orientation; 3 = hope for success; 4 = fear of failure; and 5 = self-determination index. Performance levels: 1 = international level; 2 = national level and lower; and 3 = dropout. HC, Homogeneity coefficient (mean square Euclidian distance within the cluster). The numbers next to the arrows represent the odds ratios (*ORs*) and 95% CIs (significant more transitions: *OR* > 1.0; significant less transitions: *OR* < 1.0).

as the motivational variables might not have the same importance (e.g., Vaeyens et al., 2008). Future studies in this area should therefore examine the degree of probation of the career-limiting and/or career-enhancing motivational patterns by using extensive samples within certain sports. Nevertheless, in terms of generalizability, it would be interesting to test whether these motivational patterns could be found in a larger sample that includes a wider range of individual and team sports.

Moreover, because the importance of the motivational subsystem may vary in relation to other multidimensional factors characterizing talent during the time span of talent development (Baker et al., 2019), it would be of particular interest to examine the development of the prognostic value (e.g., *ORs*) of the different motivational patterns in a dynamical manner (e.g., early, middle, and late adolescence). Indeed, as noted by Ivarsson et al. (2020), potential moderators (e.g., age) might affect the strength of the relationship between psychological factors and future performance.

In conclusion, despite minor limitations, this study replicates the findings of previous studies regarding the application of motivational patterns for success prediction in young athletes (Zuber et al., 2015, forthcoming; Zuber and Conzelmann, 2019b). The general applicability of the method was demonstrated across multiple individual sports as well as athletes of both sexes, thus underlining the importance of considering motivational variables in talent development.

DATA AVAILABILITY STATEMENT

The raw and anonymized data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics committee of the Phil.-hum. Faculty of the University of Bern. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MS, BC, AC, and CZ made significant contributions to the conception of the work, interpretation of the data, writing and revising the manuscript, and approved the submitted version. CZ and MS: data collection. MS: data analysis. All authors contributed to the article and approved the submitted version.

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ORIGINAL RESEARCH
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The Effect of Virtual Reality Technology on the Imagery Skills and Performance of Target-Based Sports Athletes

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The aim of this study is the examination of the effect of virtual reality based imagery (VRBI) training programs on the shot performance and imagery skills of athletes and, and to conduct a comparison with Visual Motor Behavior Rehearsal and Video Modeling (VMBR + VM). In the research, mixed research method and sequential explanatory design were used. In the quantitative dimension of the study the semi-experimental model was used, and in the qualitative dimension the case study design was adopted. The research participants were selected from athletes who were involved in our target sports: curling ($n = 14$), bowling ($n = 13$), and archery ($n = 7$). All participants were randomly assigned to VMBR + VM ($n = 11$), VRBI ($n = 12$), and Control ($n = 11$) groups through the "Research Randomizer" program. The quantitative data of the study was: the weekly shot performance scores of the athletes and the data obtained from the "Movement Imagery Questionnaire-Revised." The qualitative data was obtained from the data collected from the semi-structured interview guide, which was developed by researchers and field experts. According to the results obtained from the study, there were statistically significant differences between the groups in terms of shot performance and imagery skills. VRBI training athletes showed more improvement in the 4-week period than the athletes in the VMBR + VM group, in terms of both shot performance and imagery skills. In addition, the VRBI group adapted to the imagery training earlier than the VMBR + VM group. As a result, it was seen that they showed faster development in shot performances. From these findings, it can be said that VRBI program is more efficient in terms of shot performance and imagery skills than VMBR + VM, which is the most used imaging training model.

Keywords: virtual reality, imagery, target sports, visual motor behavior rehearsal, video modeling, PETTLEP, shot performance

INTRODUCTION

Imagery is the most popular field of research in sports psychology. According to a physical training, it has always attracted the attention of researchers and athletes due to its advantages, such as saving time and energy, being independent of the training environment, and no risk of disability (Jowdy et al., 1989; Ungerleider, 2005; Weinberg and Gould, 2015).

Imagery is the state of creating or re-creating our experiences in our minds, using all our senses (Suinn, 1985; Vangyn et al., 1990; Salmon et al., 1994). More broadly, imagery can be defined as human ability to access previously encoded perceptual information from memory (Kosslyn, 1980; Farah, 1993) to create a complex and sophisticated mental experience of objects, people, or places (Boccia et al., 2019). For effective imagery, the situation in the mind must be experienced with all sensory organs (Roure et al., 1999; Morris et al., 2005; Kehoe and Rice, 2016). Enough vivid, sharp, and clearly imagined situations create very realistic stimuli in our brain (Williams, 1993). As a result, the brain cannot distinguish whether this work is real or a dream, and it gives us the same physiological reactions as if the moment we are feeling in the mind is actually happening in real life (Martens, 1987; Cox, 2007). Thus, skill acquisition time is shortened when physical movement and imagery are combined together (Michalski et al., 2019).

Creating realistic images in the mind is one of the most important criteria that determines the quality of the imagery training. Naturally, the vast majority of research in the field of imagery so far has focused on the fact that an athlete can produce realistic images in his mind. In this context, one of the most widely used methods is the Physical, Environment, Task, Time, Learn, Emotion, Perspective (PETTLEP) approach, which is based on the functional equivalence hypothesis (Finke, 1979; Holmes and Collins, 2001; Smith et al., 2007, 2008; Moran, 2016). The PETTLEP model has been used across a wide range of domains such as sports psychology, cognitive psychology, and neuroscience (Holmes and Collins, 2001). An application that enhances the effect of the PETTLEP model is video modeling (VM). Watching yourself or others is known to have a positive effect on psychological variables such as performance, self-efficacy, and self-regulation (Murphy, 2012). Recent research has focused on the effects of VM on athletes' sports performance (Munzert et al., 2008; Ste-Marie et al., 2012). The combination of VM and imagery has attracted interest in both neuroscience and sports psychology literature (Rizzolatti and Craighero, 2004). The rationale behind the positive effects associated with VM and imagery is that neural networks (Holmes and Calmels, 2008; Battaglia et al., 2014). Imagery and VM share a number of mental operations and rely on common neural structures (Grezes and Decety, 2001). These structures are similar to some of those active during the preparation, anticipation and in some cases actual production of action. Imagery and VM cause neural responses similar to intracortical and subcortical plasticity that occur during the physical application of a task in the brain (Holmes and Calmels, 2008).

Another popular application developed to increase the effect of imagery is "Visual Motor Behavior Rehearsal (VMBR)." This technique, developed by Suinn, called VMBR, Suinn (1972a,b) combines both imagery and relaxation. Studies have shown that VMBR enhances the effect of imagery (Kolonay, 1977; Noel, 1980; Weinberg et al., 1981, 1982; Hall and Erffmeyer, 1983; Cauraugh and Lidor, 1992; Shipley and Baranski, 2002).

Despite all these developments, mental training is still seen as boring and a waste of time by many athletes (Gould et al., 1999; LeUnes and Nation, 2002; Gould and Maynard, 2009; Weinberg and Gould, 2015). This situation causes athletes and coaches to be biased toward sports psychology. Therefore, there is a need for innovation that can attract the attention of the athletes and shorten the time taken to reach the level of effective imagery. In this context, researchers exploring the possibilities of developing technology (wearable technologies, biomechanics, eagle-eye camera technology, etc.) in order to increase physiological performance, unfortunately did not go far beyond traditional methods in increasing psychological performance for athletes. Researchers have used progressive muscle relaxation (Kim et al., 2011; Boryri et al., 2019; Theologia et al., 2019), video (Smith and Holmes, 2004; Carbone et al., 2020; Meers et al., 2020), and audio (Smith and Holmes, 2004; Sesum and Kajtna, 2018) to enhance the effect of traditional imagery training. Although these innovations increased the effect of the mental training, they did not bring the desired level of success (Craig, 2013; Vignais et al., 2015; Bird, 2019). In this context, new applications are needed that can increase the effect of the imagery training.

In addition, another concept that determines the effect of imagery is perception. Imagery and perception cause similar neural activities in the brain (Dijkstra et al., 2017). If we can create realistic images in our minds, our brain will react as if we really see that image (Maier et al., 2020b). In addition, studies show that there is a positive correlation between perception in visual areas and vividness of imagery. According to these results, we need to enrich the perception in visual areas in order to increase the vividness of imagery (Dijkstra et al., 2017). It seems likely that we will improve our imagery performance by enriching our perception in visual areas. In the imagery training, much more is needed than 2D videos of sports environments, which were previously used to enrich the perception (Helsen and Pauwels, 1993; Williams et al., 1994). For this, there is a need for a virtual world where the athlete can perceive their surroundings actively with their head movements (Craig, 2013).

Virtual reality (VR) technology, which is the most popular product of developing technology today, has the feature to overcome these shortcomings in imagery applications. VR can deceive the human brain's predictive coding mechanism and create a real feeling of being present in the virtual body and space (Riva et al., 2019). VR has features similar to imagery in terms of the underlying mechanism. The underlying logic behind imagery and VR is to feel an unreal event, time, or environment as if it were actually happening. The most important feature that differentiates VR technology from other applications in the imagery process is that it gives participants the feeling of the experience being real.

In order to increase the sense of reality, desired items can be placed or removed in the VR environment to be created. In this respect, performance tests to be performed in VR environment will be different from classical laboratory tests. Many of the research done in sports psychology (imagery, VMBR, VM, self-talking etc.) tried to determine the pure effect of mental training performed by athletes by limiting external variables. However, sports competitions take place in highly variable and interactive environments. Therefore, measurements made by isolating from the external environment do not always reflect the correct results. The ecological approach, which is an alternative to the traditional one-way research model conducted in this way, advocates including the effects of the environment on the individual (Davaslıgil, 1997). According to the ecological approach, all factors affecting the individual (relationships, environment, social and cultural variables) should be addressed in a research process instead of examining the individual one way (Heft, 2012, 2013). The ecological approach has recently become popular in the field of sports psychology as well as in other fields. In this context, the methods in the researches in the field of psychological skill training started to be designed within the framework of ecological approach (Araujo et al., 2005; Jordet, 2005; Araujo and Kirlik, 2008; Seif-Barghi et al., 2012; Dicks et al., 2015). By integrating VR technology into mental training processes, tests can be organized within the framework of ecological approach. Variables such as type of surface (e.g., grass pitch), the objects involved (e.g., rugby ball) and the events taking place within it (e.g., a set-play) can also be included in the created VR environment (Riley et al., 2009). A virtual environment provides the researcher with an ecologically valid platform for presenting dynamic stimuli in a manner that allows for both the veridical control of laboratory measures and the verisimilitude of naturalistic observation of real life situations (Matheis et al., 2007; Jovanovski et al., 2012). VR environments proffer assessment paradigms that combine the experimental control of laboratory measures with emotionally engaging background narratives to enhance affective experience and social interactions (Parsons, 2015). In the literature review, it is seen that VR has started to be used in ecological approach-based researches in sports psychology (Ya, 2011; Parsons, 2015).

VR is widely used in many fields such as education (Lorenzo et al., 2020; McGarr, 2020; Radianti et al., 2020; Theelen et al., 2020), medicine (Bhattacharjee et al., 2020; Felipe et al., 2020; Maier et al., 2020a; Xin et al., 2020), computer games (Bapka et al., 2018; Yang et al., 2018; Allspaw et al., 2019), new motor skills acquisition (Prasertsakul et al., 2018; Ricca et al., 2018; de Moraes et al., 2020), virtual sights (Errichiello et al., 2019; Trunfio and Campana, 2019; Trunfio et al., 2019). VR studies in sports focused on three areas: performance analysis (Ouadahi et al., 2016; Neumann et al., 2018), simulation development (Pereira et al., 2018) and virtual training (Adamovich et al., 2009; Calabro et al., 2017; Akbas et al., 2019). VR used in the field of sports provides individualized training of technical-tactical as well as motor abilities regardless of the time and place, against a chosen opponent or situation (Akbas et al., 2019). VR minimizes disturbances in complex experiments involving multiple subjects or complex experiment protocols. VR simulation provides accurate control and synchronization of all items in the experiment and reproducibility and comparison among the different trials (Pereira et al., 2018). In addition, due to the immersion and presence in the virtual environment, user participation and motivation can be provided (Slater, 2009). Despite such a wide range of uses and advantage, has not been used with imagery training.

In this context, the aim of the study is to examine the effect of the VRBI training program on the shot performance and imagery skills of the athletes, and to compare it with the popular approach VMBR + VM used in imagery training. The main hypothesis for this study is that VRBI training will contribute more to the shot performance and imagery skills of athletes than VMBR + VM. To test this hypothesis, the athletes in the VRBI and VMBR + VM groups will be compared with the shot performances and imagery skills, as well as interviews with the athletes.

MATERIALS AND METHODS

Research Design

In this study where the imagery skills and shot performance of the athletes are examined, the mixed research method was used. Sequential explanatory design was used in the study. In this design, quantitative data is first collected and analyzed. Then, qualitative data is collected and analyzed to explain the quantitative results in depth (Sözbilir, 2017).

In the quantitative dimension of the research, semi-experimental design with repeat test VMBR + VM, VRBI, and control group was used. Then, a qualitative research design case study was used to examine the data obtained from quantitative results in more depth. In the case study, semi-structured interviews were conducted with the athletes.

Participants

GPower analysis was performed to calculate the sample size of the athletes who would participate in the research. According to the analysis, a minimum of 33 samples were required in order to have an effect size of 0.25 in 90% power and 95% confidence intervals. In this regard, because of the possibility of some abandoning the process, 39 athletes were included in the study.

According to Ryan and Simons (1981), imagery is more beneficial in sports involving simple cognitive processes and requiring concentration than it is sports involving complex motor skills and cognitive processes (Altıntaş and Akalan, 2008). In this context, curling, bowling and archery branches, which have high concentration and simple motor skills and are targeted sports branches, were selected.

A total of 39 participated in the study, but due to various reasons during the training period we worked with 34 athletes from curling (n = 14), bowling (n = 13), and archery (n = 7) branches completed (age = 21, 7 ± 4.33, weekly training time = 7.38 ± 3.59). Participants were divided into random, control (curling = 4, bowling = 4, archery = 3), VMBR + VM (curling = 4, bowling = 5, archery = 2), and VRBI (curling = 6, bowling = 4 Archery = 2) groups through the "Research Randomizer" program. The curling athletes were from the Turkey Curling First League, the bowling athletes were in the Ataturk University Bowling Team, and the archery athletes are from the national leagues. Detailed demographic information of the participants is given in **Table 1**.

Selection Criteria of Participants

- Not having professional mental training support before working,
- Not having chronic or acute disability problems,
- Being an elite athlete.

TABLE 1 | Demographic information of the participants.

Groups	Gender		Age (x̄ ± ss)	Weekly training time (x̄ ± ss)
	Female (n-%)	Male (n-%)		
Control	5-%45,5	6-%54,5	23,81 ± 5,17	7,63 ± 2,80
VMBR + VM	5-%18,2	6-%81,8	20,54 ± 4,76	7,36 ± 4,36
VRBI	7-%58,3	5-%41,7	21,08 ± 2,27	7,16 ± 3,76
Total	17	17	21,79 ± 4.33	7,38 ± 3,59

Performance and Scoring Scenarios

Performance scenarios were prepared by people who are experts in their branches and have coaching certificates. Performance scenarios were prepared in different ways for each branch. This included the freeze shot for the curling, the spinning throw for the bowling, and the shot from the distance of 30 m (target of 30 cm × 30 cm, with the classic bow) for the archery.

The prepared performance scenarios were converted to standard scoring by experts and scored over 10 points. The scoring system has been developed for each branch. Bowling athletes were asked to topple 10 pins with a single shot, i.e., to strike. One point is awarded for each topple pin. Archery athletes were asked to shoot at a target of 30 cm × 30 cm from a distance of 30 m with a classic bow. The archery shots are scored according to **Figure 1A**. Curling athletes were asked to shoot the freeze. The curling shots are scored according to **Figure 1B**.

Preparation of Successful Performance Video

The most successful athletes from each branch were selected to play in the shot video to be prepared. In the selection of athletes, being the first player in their teams, the number of national matches, the experience and the opinions of the trainers were determined as criteria. These athletes did not participate in the study. GoPro Fusion 360 camera with high resolution 360-degree video capability was used for performance video shot. The camera was attached to the head of the athlete with an apparatus, to allow the viewing athlete to watch the video from his own perspective and to imagine it from a point of view angle (**Figure 2**). The successful performance video continued from the locker room to the performance of the athlete. The recorded videos were prepared in 2D video format in computer format for the VMBR + VM group and in 3D video format integrated into the VR glasses for the VRBI group. GoPro Fusion Studio, Adobe Photoshop, Premiere and After Effect programs were used for video formatting.

Preparation of Progressive Muscle Relaxation Scenario

Progressive Muscle Relaxation Scenario for athletes was prepared with the support of two assistant professors who are experts in sports psychology.

Measures

Movement Imagery Questionnaire-Revised (MIQ-R)

This was developed by Hall et al. (1985) in order to determine the imagery ability of athletes. The scale was revised and simplified by Hall and Martin (1997). The scale consists of eight items that measure visual (four items) and kinesthetic (four items) imagery skills. The scale was adapted to Turkish by Akkarpat (2014).

Semi-Structured Interview Form

Face to face interviews were conducted with VMBR + VM and VRBI groups to better explain the quantitative data obtained in the study. At the beginning of the research process, the athletes were informed about the purpose of the training and they were reminded that their participation was on a voluntary basis. After the pilot application with an athlete, necessary corrections were applied, and the final shape was given for use in the study. Interviews with athletes in the VMBR + VM and VRBI groups, which took approximately 10 min, were recorded for analysis. Interviews were conducted with a total of six athletes; three from the VMBR + VM group and three from the VRBI group. After it was understood that the data had reached the saturation level, the data collection was terminated.

Process

The MIQ-R was filled by all participants to determine the imagery skill levels of athletes. In addition, 10 warm-up shots and 5 actual shots were made to determine the pre-test scores of the athletes. These shots were repeated on three different days of the week. The pretest score was created by taking the average of 15 actual shots (3 days * 5 shots). Then all participants were randomly divided into VMBR + VM group, VRBI group, and Control groups.

The VMBR + VM group performed progressive muscle relaxation exercise with 2D video guidance. At the end of the relaxation exercise, VM was done by watching the previously prepared successful 2D performance video from the laptop (**Figure 3**). Then the athlete imagined that he performed this performance within the framework of the imagery script. At the end of the imagery, performed the same performance that he had seen in the VM, performing 10 warm-up shots and 5 actual shots in the real training area. The daily performance score was recorded in the personal file of the athlete, taking the average of the 5 actual shots made.

Virtual reality based imagery group did progressive muscle relaxation exercise with 3D video guidance. Then, 3D-VM was done by watching the previously prepared successful shot video in 3D environment with VR glasses (**Figure 3**). After the imagery training was completed, the athletes were asked to take a successful shot similar to the shot in the VRBI training scenario. After 10 shots were made for practice, 5 real shots were made. All the shots made by the athletes in the VMBR + VM and VRBI groups were scored by the experts. In the control group, after the fun videos about the branch were watched, 10 warm-up and 5 main shots were made to record their daily performances. Imagery trainings, including warm-up trainings, were made for each branch, for approximately 2 h a day, 3 days a week, and for a total of 4 weeks. The weekly average of the daily performance scores obtained was taken. The MIQ-R applied at the beginning

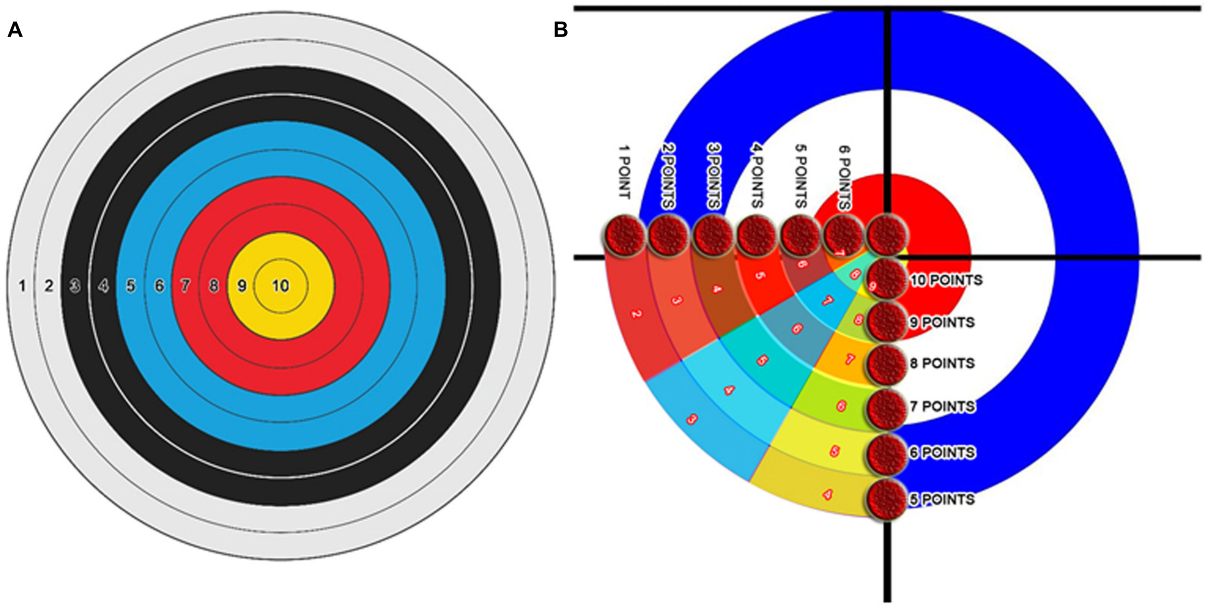

FIGURE 1 | Archery scoring **(A)** and curling scoring **(B)** system.

FIGURE 2 | 3D performance videos prepared.

FIGURE 3 | Watching performance videos.

of the study was reapplied to the athletes at the end of 4 weeks and the changes in the athletes were observed longitudinally. The quantitative data obtained after the application phase of the research has been analyzed. Accordingly, one-to-one interviews were conducted with the athletes within the framework of the interview form prepared by the researcher. The data obtained was recorded on the voice recorder.

Data Analysis

Normal distribution of continuous variables was evaluated with the Shapiro–Wilk test, Skewness and Kurtosis values. Since the number of participants in the study group is less than 35, Shapiro–Wilk normality test was used (Shapiro, 1985). The values obtained are presented in **Table 2**.

George and Mallery (2016) state that the skewness and kurtosis coefficients should be between −2 and +2 values accepted for social sciences, according to the 5% significance level, in order for the data set to be suitable for normal distribution.

In addition, Levene test was performed for the homogeneity of variances, another parametric test assumption (Pasin et al., 2016). The values obtained are presented in **Table 3**.

As a result of the tests, it was seen that the data met the parametric test assumptions. Mixed Measure Two Way ANOVA was performed to determine the effect of the imagery training program application on the dependent variable (shot performance, imagery skills). Mauchly's test was applied to identify the data sphericity. When the sphericity assumption was violated, the Greenhouse–Geisser correction was used. A significance level of $p \leq 0.05$ was taken for all results reported. *Post hoc* comparisons were conducted through Bonferroni significant difference tests. Qualitative data obtained in the study was analyzed with the content analysis method. SPSS was used for the analysis of quantitative data, and NVIVO programs were used for the analysis of qualitative data.

TABLE 2 | Normality analysis results of the participants.

	Group	Measurement	n	x̄	ss	S	K	SW
Shot performance	Control	Pre-test	11	5,74	1,91	−0,421	−0,905	0,575
		(1) Week	11	5,90	1,89	−0,350	−1,341	0,209
		(2) Week	11	5,60	2,37	−0,247	−0,535	0,837
		(3) Week	11	5,95	2,14	0,109	−0,516	0,946
		(4) Week	11	5,90	2,18	−0,144	−0,409	0,991
	VMBR + VM	Pre-test	11	5,21	1,02	0,933	0,528	0,102
		(1) Week	11	4,79	1,92	0,273	−1,197	0,408
		(2) Week	11	5,70	1,41	0,761	−0,797	0,122
		(3) Week	11	6,43	1,45	0,869	0,219	0,526
		(4) Week	11	6,60	1,47	0,932	0,138	0,124
	VRBI	Pre-test	12	4,68	0,98	0,296	−0,997	0,657
		(1) Week	12	4,22	2,17	0,882	0,117	0,157
		(2) Week	12	6,60	1,53	0,498	−0,585	0,567
		(3) Week	12	6,98	1,46	0,087	−1,165	0,383
		(4) Week	12	7,33	1,19	0,442	0,153	0,353
MIQ-R	VMBR + VM	Pre-test	11	3,97	0,63	0,183	−0,973	0,747
		Post-test	11	4,17	0,54	0,422	−1,727	0,052
	VMBR + VM	Pre-test	11	3,97	0,76	−0,907	−0,258	0,161
		Post-test	11	5,27	0,67	−0,318	0,190	0,987
	VRBI	Pre-test	12	3,57	1,03	−0,459	0,560	0,894
		Post-test	12	5,04	0,66	−0,030	-0,543	0,780

S, skewness; K, kurtosis; SW, Shapiro–Wilk(p).

TABLE 3 | Variance homogeneity (Levene) test results applied to GMDP + VM, SGTI, and control group scores obtained from repeated measurements.

	Measurement	n	df1	df2	F	p
Shot performance	Pre-test	34	2	31	3,076	0,057
	(1) Week	34	2	31	0,003	0,997
	(2) Week	34	2	31	1,496	0,240
	(3) Week	34	2	31	0,844	0,440
	(4) Week	34	2	31	2,303	0,117
MIQ-R	Pre-test	34	2	31	0,773	0,470
	Post-test	34	2	31	0,016	0,984

RESULTS

This section includes detailed results of the analyzes made in line with the hypotheses of the research. The main purpose of the research is to examine whether the newly prepared VRBI program is more advantageous than the widely used VMBR + VM today.

Weekly shot averages and standard deviation values of the athletes participating in the research are given in **Table 4**.

As observed in **Table 4**, weekly changes of the athletes in the control group are not significant; however, there is an increase in the weekly shot performance averages of the VMBR + VM and VRBI groups.

The results of (3 × 5) ANOVA regarding whether or not the weekly changes in the shot performances of athletes exposed to three different experimental procedures show a significant difference are given in **Table 5**.

When **Table 5** is examined, it is determined that there is no significant difference between the VMBR + VM, VRBI, and the athletes in the control group in terms of their scores in shot performance [$F(2,31) = 1.106$, $p > 0.05$]. When the athletes included in the research are compared regardless of which group they are, the difference between the pre-test, week 1, week 2, week 3, and week 4 performance scores was found to be significant [$F(2.875,89.136) = 36,590$, $p < 0.05$]. This result shows that the performance scores of athletes increased in the process. In order to see the effects of the process on the score differences between the groups, the measurement * group joint effect of the test results of the shot scores of the athletes was examined and this value was found to be significant [$F(5.751,89.136) = 8,508$, $p < 0.05$]. Therefore, it was determined that the imagery training applied had an impact on the athlete's performance scores.

Multiple comparison test results to determine which intergroups differ according to the process are given in **Table 6**.

TABLE 4 | Weekly average and standard deviation values of the shot performance scores of the athletes participating in the research by groups.

Groups	Pre-test		(1) Week		(2) Week		(3) Week		(4) Week	
	x̄	ss	x̄	ss	x̄	Ss	x̄	ss	x̄	ss
Control	5,06	1,36	4,97	1,55	5,00	1,56	5,35	1,47	5,37	1,44
VMBR + VM	5,21	1,02	4,79	1,92	5,70	1,41	6,43	1,45	6,60	1,47
VRBI	4,68	0,98	4,22	2,17	6,60	1,53	6,98	1,46	7,33	1,19

TABLE 5 | ANOVA results of the shot performance scores of the athletes participating in the research.

Source of variance	SoS	df	MS	*F*	*p*
Between subject	299,488	33			
Group	19,949	2	9,974	1,106	0,344
Error	279,539	31	9,017		
Within subject	189,009	97,762			
Measurement (weekly)	81,743	2,875	28,429	36,590	**0,000***
Measurement *Group	38,012	5,751	6,610	8,508	**0,000***
Error	69,254	89,136	0,777		

**p < 0,05; SoS, sum of squares; MS, mean square.*

TABLE 6 | Multiple comparison test results for shot performance points by group and measurement time.

Measurement time	Group		Mean difference (I–J)	*p*
Pre-test-(1) week	Control	VMBR + VM	0,333	0,511
		VRBI	0,367	0,463
	VMBR + VM	VRBI	0,031	0,950
Pre-test-(2) week	Control	VMBR + VM	−0,536	0,245
		VRBI	−1,971	**0,000***
	VMBR + VM	VRBI	−1,434	**0,003***
Pre-test-(3) week	Control	VMBR + VM	−0,925	0,030*
		VRBI	−2,016	**0,000***
	VMBR + VM	VRBI	−1,090	**0,010***
Pre-test-(4) week	Control	VMBR + VM	−1,068	**0,010***
		VRBI	−2,336	**0,000***
	VMBR + VM	VRBI	−1,268	**0,002***

**p < 0,017.*

When **Table 6** is examined, it is observed that there is no difference between the pre-test and 1st week shot performance scores between the groups. In the 2nd week, significant differences were observed between the VRBI group and VMBR + VM and the control groups, while no significant differences were found between VMBR + VM and the control group. When the measurement scores made at the end of the 3rd and 4th weeks were compared with the pre-test results, it was observed that there was a significant difference between the VMBR + VM, VRBI, and control groups. When the findings were examined, it was observed that the shot performances of the VRBI group started to rise earlier than those in the VMBR + VM group did. In addition, it was observed that the shot performances of the athletes in the VRBI group were better than the athletes in the VMBR + VM group, as well those in as the control group in the 2nd, 3rd, and 4th weeks. As a result, it can be said that VRBI training is more effective than VMBR + VM in shot performance and adaptation.

In **Figure 4**, the changes in the shot performances of the groups during the experimental process are shown graphically. When the figure is analyzed, it is seen in the measurements made at the end of the first week that the athletes in the VMBR + VM and VRBI groups experienced serious decreases in their shot performances, and this decline was replaced by an increase. No significant difference was observed in the shot performances of the athletes in the control group.

When **Table 7** is analyzed, it is seen that the pre-test scores of the athletes in the control and experimental groups from the imagery skills are close to each other, and that there are differences in the post-test scores.

When **Table 8** is analyzed, it is seen that there was no significant difference between the VMBR + VM, VRBI, and control group athletes in terms of imagery skill scores [$F(2,31) = 2,643$, $p > 0.05$]. Regardless of the group of athletes included in the study, the difference between the imagery pre-test and post-test scores was found to be significant [$F(1,31) = 35,771$, $p < 0.05$]. This result shows that the intervention of this process has increased the imagery skill scores of athletes. It is observed that the results of the imagery skill scores of the athletes have a significant effect on the measurement * group [$F(2,31) = 5,833$, $p < 0.05$]. As a result of this finding, it can be said that the types of imagery training caused a differentiation between the groups in terms of imagery skill scores.

Multiple comparison results made in order to understand between which groups this difference is are given in **Table 9**.

When **Table 9** is examined, it is seen that according to the pre-test/post-test results, the imagery skills of the VMBR + VM and VRBI groups improved significantly and positively. At the end of the process, it was observed that there were no significant difference between the VMBR + VM and VRBI groups in terms of imagery skill scores.

When **Figure 5** is examined, we can see there is an increase in the imagery skill scores of the VMBR + VM and VRBI groups in the pre-test/post-test results, while no significant increase was observed in the control group.

Content analysis results for determining the VRBI experiences of athletes are given in **Table 10**. The data obtained as a result of the interviews with the athletes are shown in **Table 10**. When the data in the table and the athletes' interviews were examined, the VRBI training program initially caused negative feelings such as stress, prejudice and concentration

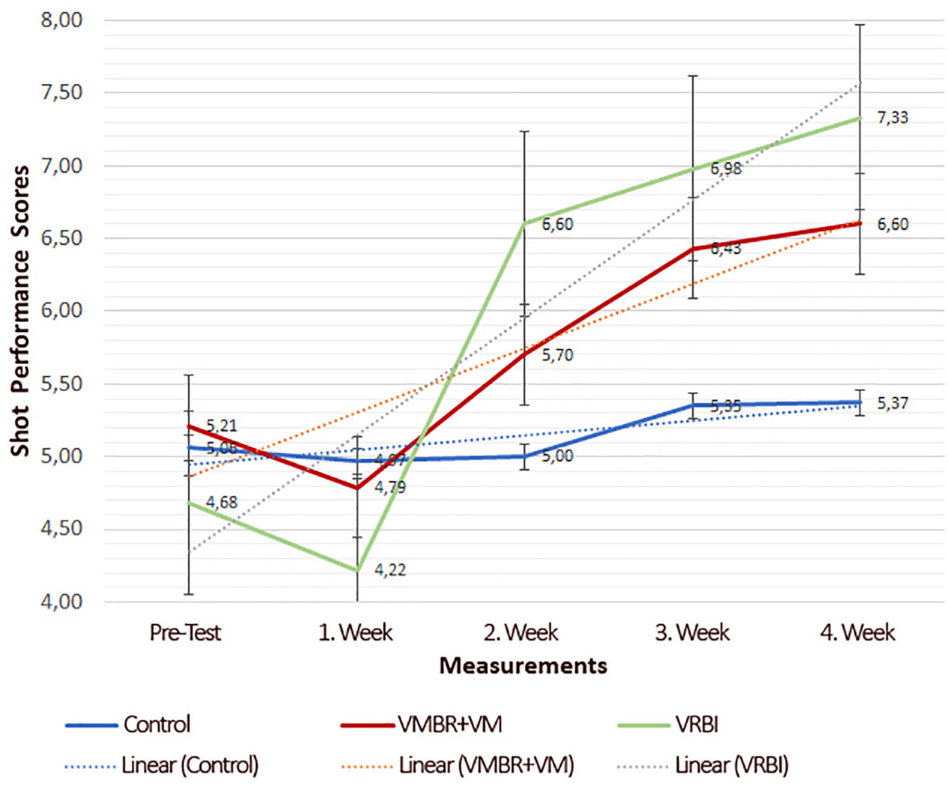

FIGURE 4 | Weekly result graphic of shot performance score by groups.

TABLE 7 | Weekly average and standard deviation values of the imagery skill points of the athletes participating in the study according to the groups.

Groups	Pre-test		Post- test	
	x̄	ss	x̄	ss
Control	3,97	0,63	4,17	0,54
VMBR + VM	3,97	0,76	5,27	0,67
VRBI	3,57	1,03	5,04	0,66

TABLE 8 | ANOVA results of the imagery skill points of the athletes participating in the research.

Source of variance	SoS	df	MS	*F*	*p*
Between subject	23,123	33			
Group	3,369	2	1,684	2,643	0,087
Error	19,754	31	0,637		
Within subject	36,165	34			
Measurement (weekly)	16,493	1	16,493	35,771	**0,000***
Measurement *Group	5,379	2	2,689	5,833	**0,007***
Error	14,293	31	0,461		

**p < 0,05; SoS, sum of squares; MS, mean square.*

TABLE 9 | Multiple comparison test results of imagery skill pretest and post-test scores by groups.

	Group		Mean difference (I–J)	*p*
Imagery skills	Control	VMBR + VM	−1,102	**0,011***
		VRBI	−1,275	**0,003***
	VMBR + VM	VRBI	−0,173	0,668

**p < 0,017.*

problems for the athletes. These negative emotions were replaced by positive emotions such as self-confidence and adaptation with the progress of the process. At the end of the process, it can be seen that the athletes could now immerse themselves in the VR environment and use this training method to increase their concentration before the competition.

Examples of answers given by athletes are given below.

A4: Since I used it for the first time in my life, I said to myself what effect it would have at first. I thought it would have no effect. I didn't feel any effect in the first weeks because I started this process biased.

A6: Initially, I thought this was ridiculous and would have no effect on my performance.

A5: I realized that when I started to get used to mental training and when I did it correctly, there was improvement and progress in my shots. This led me to begin to believe this workout, which I had initially found ridiculous.

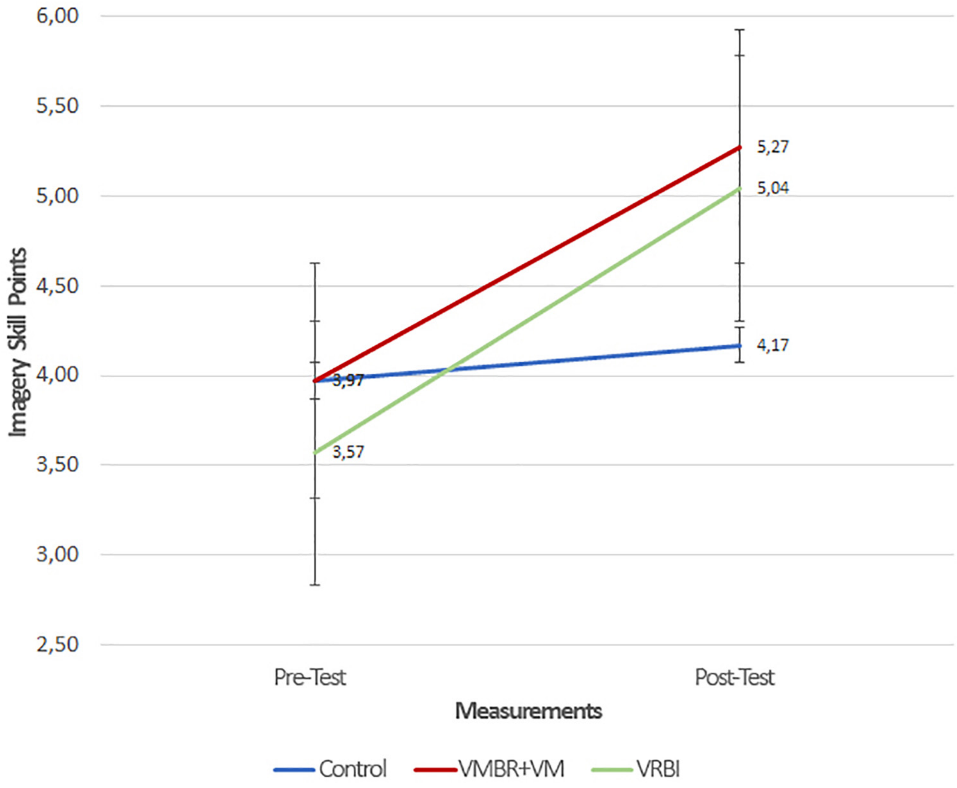

FIGURE 5 | Pre-test post-test result graphic of imagery skill score by groups.

TABLE 10 | Analysis results of VRBI experiences of athletes.

Theme	Code	f*
Emotional and mental responses	Stress	1
	Prejudice	4
	Concentration problem	2
	Excitement	2
	Frustration	1
Getting used to and believing	Adaptation	1
	Self-confidence	2
	Changing perspective	3
Successful imagery	Entering virtual reality environment	3
	Increased concentration	3
	Total	22

*Athletes stated more than one opinion.

The quantitative data obtained from the study was analyzed and it was observed that the shot performance of the athletes in VMBR + VM and VRBI decreased in the first weeks. Content analysis results for determining the cause of this decline are given in **Table 11**.

When **Table 11** is analyzed, it is seen that the reasons for the loss of performance in the first weeks of athletes were due to prejudice, stress and a new application, and this caused the athletes to change their habits.

Examples of answers given by athletes are given below.

TABLE 11 | Analysis results related to the causes of performance losses in the first weeks.

Theme	Code	f*
Negative emotions	Prejudice	3
	Stress	3
Changing habits	New training model	3
	Total	9

*Athletes stated more than one opinion.

A1: Initially, I thought this was ridiculous, so I had a bias.

A2: It didn't make any sense to me when I first put on the virtual reality glasses. It caused me to get worse rather than improve my performance. Because thinking that we should do a task given to us in the first training made me stressful. Somebody comes and makes you do something, and in return, it measures your performance. Due to this pressure, my shot performance decreased and my stress level increased.

DISCUSSION

The aim of this study was to examine the effect of VRBI training program on athletes' shot performance and imagery skills, and to compare it with VMBR + VM, which is the popular approach used in imagery training today.

Main Findings

The findings show that the new imagery model VRBI training program developed by the researcher gives more positive results in terms of shot performance when compared to the most popular imagery training program, VMBR + VM. In addition, it is seen that the athletes in the experimental group (VRBI and VMBR + VM) experienced performance loss in the first week of the research due to various reasons. Another important result of the study was that the athletes in the VRBI group adapted to the process faster and as a result experienced a rapid increase in performance. Finally, it was observed that the imagery skills of the athletes in both experimental groups increased during the research.

VR Technology, Imagery and Performance Improvement

Virtual reality is widely used in this field as it provides the opportunity to include or exclude the desired variables in the process and create replicable simulations to determine the performance of the athlete (Bideau et al., 2010). Thanks to the developing technology, real competition areas can be created in the VR environment. The athlete, who is in a realistic VR environment, act physical and psychological reactions (sweating, anxiety, etc.) as in the real competition (Stinson and Bowman, 2014). In this research, real competition environment is tried to be simulated in virtual environment. The improvement of the shot skills of the athletes who train in the virtual environment is one of the important findings of the research. In the literature, it is seen that VR training programs designed to improve the skills of athletes are effective (Neumann et al., 2018; Michalski et al., 2019).

Virtual reality has the potential to include PETTLEP components in the imagery training. The inclusion of PETTLEP components such as physical, environment, task, time, learn, emotion, and perspective in the imagery training enhances the effect of imagery (Smith et al., 2008, 2019; Wright and Smith, 2009; Battaglia et al., 2014; Anuar et al., 2018). In the mechanism underlying the VRBI program, all the components in the PETTLEP model are included in the process to maximize the effect of imagery. For this purpose, a new 3D model has been designed to include all the sensory organs in the imagery process and make the athlete feel as if the competition is happening in real life at that moment.

When creating vivid and clear images in the mind, more kinesthetic emotions are required than visual details (Smith et al., 2001). Thanks to the VRBI program, athletes can also activate their kinesthetic feelings by physically doing the same motion imagined, as they can move freely at the time of imagery and 3D VM. The kinesthetic ability associated with visual ability is crucial to improving motor performance (Ille and Cadopi, 1999). Pelgrims et al. (2009) argue that motor imagery is often more affected by action-related kinesthetic restrictions. Thanks to VRBI, this restriction has been eliminated.

The most important difference of the VRBI training model to the imagery training done so far is that the entire imaging process is done in 3D environment. In particular, the findings have shown that making VM in a 3D environment has important contributions. Particularly, athletes in the VRBI group reported that they were putting themselves in the place of the successful shooter in the video while modeling the video in a VR environment, thus increasing their self-confidence. In addition, athletes reported that they felt as if they had repeatedly done the same movement physically. It is the common idea of all the imagery theories that the imagery made close to reality has the highest impact on athletes. Another extension of the PETTLEP model is VM, which is of great interest in neuroscience (Holmes and Calmels, 2008; Battaglia et al., 2014). Watching themselves or others can not only improve the performance of the athlete, but also has a positive effect on psychological skills such as self-efficacy and self-regulation (Murphy, 2012). Nowadays, imagery and VM exercises are used in combination with each other to increase the psychological and physical performances of athletes. Research has shown that the combination of imagery and VM significantly improves performance (Smith et al., 2007; Wright and Smith, 2009; Battaglia et al., 2014; Buck et al., 2016).

The reasons for the positive effect of VM on athletes' performances have been studied in the research field for many years. Cognitively, an athlete observes the skill and encodes it symbolically and then uses this encrypted information as a guide for future action (SooHoo et al., 2004). This situation is based on symbolic learning theory.

The positive contribution of VM to athletes' performance can be explained neurologically with mirror neurons. Mirror neurons are neurons that activate when watching a movement (Demir and Gergerlioğlu, 2012). Mirror neurons differ from superior temporal sulcus neurons that only control visual processes, since the motor and visual responses are located in the same neuron (Herrington et al., 2011). It is thought that the superior temporal sulcus, activated by the observation of the biological movement, provides visual information to the mirror neuron system (Lange and Lappe, 2006; Molenberghs et al., 2010). The VR environment facilitates the activation of mirror neurons (Merians et al., 2006). Thus, it is easier and more effective to imitate the movements in a video when it is watched in a VR environment. In 3D VM in VRBI, it is thought that utilizing the 3D VR environment increases the activation of mirror neurons and causes the athletes in this group to perform more highly with their shot to outperform the athletes in the VMBR + VM group.

Whether there are differences in brain activation during actual and virtual actions is controversial. An fMRI study showed that the mirror neuron system was strongly activated by seeing both human and virtual (robotic) actions, without any significant difference between the two states (Gazzola et al., 2007). This shows that the region related to the movement in the brain may be more important than the way the action is performed. Recent research has shown that corticoline excitability increases during targeted VR mirror exercise when compared to true mirror exercise (Aziz-Zadeh et al., 2004; Kang et al., 2012).

In order to investigate the effect of the VR environment on mirror neurons, stroke patients were applied a virtual hand movement rehabilitation program in the VR environment (August et al., 2006). The findings obtained showed that the areas such as primary motor cortex, dorsal premotor cortex, where mirror neurons are found, were more active in the exercise program group who performed this in a VR environment. The findings obtained support the study. It is thought that the shot performances of the athletes in the VRBI group were better than the athletes in the VMBR + VM group, due to both the symbolic learning theory and the activation of mirror neurons.

Performance Loss in the First Weeks

An important point in the findings obtained is the decrease in shot performance of the athletes in the VRBI and VMBR + VM group during the first week of their imagery training. According to the qualitative research results regarding the causes of this decline, it was understood that the athletes in both the VMBR + VM group and the VRBI group developed negative emotions such as stress, excitement, and concentration problems at the beginning of the study. It is seen that athletes who had not received any of the psychological skill training professionally have developed negative feelings toward this new situation. Since high anxiety prevents the creation of successful images in the mind, the athlete cannot reach maximum performance (Suinn, 1972a; Morris et al., 2005). In addition, another result from the qualitative data is that athletes are biased toward VRBI and VMBR + VM training programs. The athletes thought that these exercises would not be useful because they had to change their habits with the new training program, and did not have enough experience and knowledge about the process. This situation adversely affected the shot performances. Whatever the reason, sports psychology suggests various psychological skills training in order to overcome the negative emotions that can occur in the athlete. Imagery, the most important of this skill training, can help athletes get rid of their negative emotions. In the literature review conducted in this area, it has been proved that the imagery exercises have benefits such as controlling emotions (Koehn et al., 2006; Jeong, 2012; Carter, 2013; Bayköse, 2014), reducing anxiety (Kolayiș, 2002; Erdoğan, 2009; Vurgun, 2010; Akkarpat, 2014; Güvendi, 2015), improving concentration (Uludağ et al., 2016; Tekin, 2018) and gaining self-confidence (Callow and Waters, 2005; Akkarpat, 2014). In the later days of the research, it is thought that athletes get rid of these negative emotions both by adapting to the process and by continuing their imagery training. It was observed that the shot performances of the athletes, who focused on their imagery training and performances by getting rid of negative emotions, increased significantly.

VR Technology Accelerates Adaptation to the Process

Another important finding obtained from the research is that for the athletes in the VRBI group, the increase in their shot performance and adaptation to the process was faster than the athletes in the VMBR + VM. In order to better understand why athletes in the VRBI group adapted faster to the process and increased their performance faster than the VMBR + VM group, the weekly changes in the shot performances of the groups are examined. An important result is the adaptation time of the athletes to the imagery training thanks to the VRBI intervention. In this way, the effect of the imagery training is seen in a shorter time. This effect occurs about a week (three workouts) before than VMBR + VM group. The results show that athletes in the VRBI intervention group adapt more quickly to their imagery training and that their imagery skills develop faster.

It is believed that isolation of the athletes in the VRBI group from the outside world through VR glasses and headphones and the inclusion of kinesthetic, visual and auditory senses in the process effectively helped to shorten the adaptation process in athletes. Information obtained from interviews with athletes confirms this idea.

In addition, using the 3D environment in the imagery process alleviates the cognitive load of the individual (Yiasemidou et al., 2017). This enables the athletes to adapt to the imagery training more quickly and to show a rapid performance improvement. In this study on rowing athletes, Parton and Neumann (2019) applied a VR protocol training program and examined the effect of this exercise program on the performance and motivation of athletes. According to the findings obtained in the study, it was found that VR-based training program was beneficial in increasing the motivation and performance of athletes. The findings are in line with the findings of this study. In this study, the effects of supporting the use of motor imagery with the VR program on corticomotor excitability were investigated (Im et al., 2016). Participants, consisting of 15 stroke patients and 15 healthy individuals were randomly assigned to control, motor imagery, SG-guided motor imagery and SG-guided motor imagery groups with task variability. According to the findings obtained as a result of the application, corticomotor excitability increased in all the subject groups. In addition, subjects in the SG guided imagery group were found to have greater central nervous system responses (motor arousal potential) given stimulus than subjects in the imagery group only. The findings clearly show the positive contribution of the VRBI training to the imagery skills of athletes, and these results overlap with the literature.

Improvement Imagery Skills

In addition to the improvement of the shot performances of the athletes in the VRBI and VRBI + VM groups, it was also found that the imagery skills showed a significant improvement when compared to the control group. When the findings obtained are examined, in terms of imagery skills there are significant differences between VMBR + VM and VRBI groups and control groups (VMBR + VM – control, VRBI – control). Another noteworthy situation here is the increase in the imagery skills of all groups, including the control group. Although there is no statistically significant increase, it is thought that the reason for this increase in the control group is that MIQ-R is an applied scale. Findings from neurophysiological and behavioral neuroimaging studies show that the application of motion has the potential to affect the imagery ability (Williams et al., 2011). In studies conducted using neuroimaging, it is shown that performing motion contributes to motor imagery by improving neural activity (Decety, 1996;

Fadiga et al., 1999; Buccino et al., 2001; Ehrsson et al., 2003; Clark et al., 2004).

The main hypothesis of the study was that VRBI training would contribute more positively to athletes' shot performance and imagery skills than VMBR + VM training. To test this hypothesis, the shot performances of the groups and the changes in their imagery skills were analyzed. In the findings obtained as a result of the 4-week study, it was seen that VMBR + VM significantly improved the shot performance and imagery skills of the athletes when compared to the control group. However, VRBI training seems to give much better results when compared to VMBR + VM.

Virtual reality based imagery includes all the sensory organs of the athlete, which uses the PETTLEP components, to the mental preparation process. In order to do this, athletes practice the imagery in a 3D environment. Training in a 3D environment not only allows the athletes to break away from the outside world, which negatively affects the imagery process, but also makes it easier for them to give their whole perception to the process of imagery. VRBI training program provides an excellent infrastructure for the PETTLEP model. The environment, which is one of the components in the PETTLEP model, is presented to the athlete as very close to reality thanks to VR. It helps the athlete create the competition area with more vivid and clearer images in his mind. At the moment of sports imagery and VM, instead of designing the competition area in his mind, he can give all his concentration to the movement. Thus, the athlete can reduce his cognitive load in his mind and give his full focus to the imagery. The timing component is also used effectively in imagery, thanks to the VRBI program. Researchers have found that doing the imagery at the actual speed of the movement will increase the quality of the imagery (Holmes and Collins, 2001). Thanks to the VRBI program, the performance in the shot mission is shown at its real speed. In different studies, it has been suggested to use an internal perspective in imagery exercises to develop psychological skills such as motivation, concentration and focus (Mahoney and Avener, 1977). The reason for this is that the person who makes the imagery dreams that he is the person who makes the movement. Since the VRBI training program takes place in a 3D environment, the athlete is provided with an internal perspective through VM and imagery processes, and this is done in the most realistic way possible.

The results obtained show that the VRBI program gave more positive results both in terms of performance and imagery skills when compared to the control group and VMBR + VM group. VR technology provided a great advantage in terms of the feeling of the imagery athlete in that environment and self-control of the process.

Limitations and Future Directions

There are a few limitations to the present study that should be addressed in future work. Since the athletes from three different branches participated in the research, the most important limitation of this study is that the expertise levels of the athletes in these branches are not exactly the same. Although the criteria for participants to be elite athletes are set in order to overcome this situation, the selection of athletes from the same branch may be preferred in similar studies to be conducted in the next. Another limitation of the study is that the participants are partially passive in the VR environment (can only move their heads) and cannot make hand and arm movements within the virtual world. A new study can be done by creating a fully interactive VR environment in future studies. In the study, a total of 15 shots, 5 shots per day and 3 days per week, were made and pre-test scores were created. Although the same method was used to create a pre-test score in similar studies (García-Herrero et al., 2016; Kehoe and Rice, 2016; Gray, 2017; Robin et al., 2019), more shots could be taken to avoid measurement errors. However, an important limitation here is that ice varies continuously in the curling branch. In the shots more than 15 shots (10 warm-up – 5 actual shots), the structure of the ice changes and the stone goes faster and more rotating. Therefore, the number of daily shots was limited to 15. As a result of the 4-week training program, it is seen that the performance increase continues in the experimental groups. By conducting longer studies, it can be seen how many weeks this linear increase will end. Moreover, in order to explain the effectiveness of this developed SGTI training program concretely, it should be supported with neurophysiological findings (EEG, fNIRS, fMRI, etc.).

DATA AVAILABILITY STATEMENT

All datasets presented in this study are included in the article/supplementary material.

ETHICS STATEMENT

This research was designed in accordance with the Helsinki Declaration and was approved by the Atatürk University Faculty of Medicine Ethics Committee (No: B.30.2.ATA.0.01.00/218, Date: 19.09.2009). All participants read and signed the voluntary consent form before starting the research.

AUTHOR CONTRIBUTIONS

DB and SE designed the experiments, commented on the data, wrote the original draft, and reviewed, edited, and prepared the article and approved the latest version. DB collected the data and carried out statistical analysis. Both authors contributed to the article and approved the submitted version.

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ORIGINAL RESEARCH
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A Multi-Block Multivariate Analysis to Explore the Influence of the Somatic Maturation in Youth Basketball

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The aim of this study was to examine the influence of somatic maturation in anthropometric, physical, and game-related variables in youth basketball age groups under-13 (U-13) and under-15 (U-15). One-hundred and eighty-five basketball players performed anthropometrical and physical tests during a non-official youth basketball tournament. Predicted maturity offset (MO) and game-related variables were also analyzed. Cluster analysis was used to analyze the between-maturation status differences in all parameters in each age group. Also, regularized generalized canonical correlation analysis (RGCCA) was used to assess relative contributions of maturational, physical, and game-related variables within each age group. Based on MO, two different clusters were identified within each age category. Greater differences in MO were identified among U-13 clusters than among U-15 clusters. No significant differences were observed between clusters in terms of physical and game-related variables. High correlations between maturational, physical, and game-related variables (i.e., points scored, field goals attempted, and rebounds) were found for boys. In girls, different trends in terms of correlations were observed. The strongest association between blocks was observed between physical tests and game-related variables in all age categories, except for U-15 girls. Knowing and identifying performance profiles according to biological age is of upmost importance since it allows the coach to create challenging situations adjusted to the individual's needs.

Keywords: talent, development, puberty, performance analysis, identification, growth, maturation, adolescence

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INTRODUCTION

Maturation refers to the developmental process toward the adult or mature state and can be defined in terms of status, tempo, and timing (Malina et al., 2004; Malina et al., 2015, Malina, 2016). The study of this individual's variation effect in growth and maturation has contributed to a better understanding of its influence in different areas of development, such as physical and technical parameters (Malina et al., 2004; Baxter-Jones, 2009; Coelho e Silva et al., 2010; Sherar et al., 2010). One of the best ways to improve the understanding about players' development is based on the establishment of different maturity timing categories, according to the age of peak height velocity (APHV), in comparison to average of population (Sherar et al., 2005), but also on different maturity status based on years to APHV [i.e., maturity offset (MO)]

(Carvalho et al., 2017). During adolescence, body mass and physical abilities play a decisive role in performance, and may positively influence the participation in youth competitions (Malina et al., 2004). However, evidence emerging from longitudinal studies seems to confirm that young players who experience the greatest physical challenges, as long as they are feasible, become more resilient and demonstrate a superior ability to develop the technical and psychological attributes required for adult professional success (Ostojic et al., 2014). Specifically, girls showed divergent patterns of physical development and differences in physical performance are not as significant as in boys (Baxter-Jones et al., 2002; Sherar et al., 2010). Based on this rationale, the importance of future research when considering the effect of maturation on the development of youth players (e.g., basketball) in both genders can be derived.

Usually, the sports system includes chronological age (CA)-based training and competitions, using the "one-size-fits-all" approach, instead of considering the biological age (i.e., bio-banding), which could challenge the athlete in a unique way and create a learning environment that is more diversified and suited to the physical, technical, and tactical development of each player (Cumming et al., 2017; Arede et al., 2019). During the adolescence, there are inter-individual differences at biological level within each age category, which may lead to distinct performance in other domains (Coelho e Silva et al., 2010; Arede et al., 2019). Using the pubic hair status as a method to estimate biological maturation of youth basketball players, in under-13 (U-13) level most of the players were in puberty (46%), while in under-14 (U-14) level were in late puberty (56%) (Coelho e Silva et al., 2010). Additionally, in each age category, other maturity factors were identified. In particular, Arede et al. (2019) using the predicted MO approach (Mirwald et al., 2002) found distinct maturity status within the same age category in the under-15 (U-15) boys national team. The authors clustered players into pubertal (MO = 0.31 ± 0.41, n = 9), late pubertal (MO = 0.97 ± 0.21, n = 10), and in post pubertal (MO = 1.73 ± 0.21, n = 15) groups. These distinct maturity statuses (i.e., clusters) underpin between-group differences at physical and game performance levels. For example, pubertal players had higher aerobic fitness than late pubertal and post pubertal players, but late pubertal players outperformed their counterparts in upper body power (Arede et al., 2019). The game performance results showed that post-pubertal players outscored in blocks, but pubertal players were better in assists, assist/turnover ratio (Ast:TO), and steal/turnover ratio (Stl:TO) (Arede et al., 2019). However, biological maturation needs to be controlled for sex effect due to the fact that it has important differences between adolescent males and females (Drinkwater et al., 2008), and more research is required for a better understanding of maturation effect on each age category. Females tend to reach their PHV at approximately 12 years old, and have shorter growth period, whereas males reach their PHV at 14 years old, with greater velocity curves of peak height and body mass (Sherar et al., 2005). However, there is little research accounting for how biological age differs in each age category in youth basketball (particularly in females), but also how different domains are related, including game-related variables.

Specifically, relationships between different maturation parameters (biological maturation, physical, and game-related variables) were found at the U-14 boys national level basketball (Torres-Unda et al., 2013). The MO was positively correlated to point average and negatively correlated to 20-m sprint test (20-m sprint), and Abalakov jump (ABA). Moreover, 20-m sprint, and ABA were significantly negatively correlated to point average. The same authors also explored the interaction between domains, and they concluded that MO and stature in conjunction with ABA, as well as stature in conjunction with 20-m sprint were significantly positively correlated (Torres-Unda et al., 2013). In fact, more extensive analysis including canonical correlation analysis had been used to examine the relationships between multivariate domains, and measured the magnitude of the association between variables in youth players (Coelho e Silva et al., 2010; Matthys et al., 2012). In particular, significant relationships were identified between APHV, height, and weight; and between handgrip, 20-m sprint, and five-jump test (Matthys et al., 2012). Thus, more mature players were taller, heavier, and presented better performance in physical tests, but not on sport-specific skills (Matthys et al., 2012). In other study, in youth basketball, functional capacities and basketball skills showed substantial positive correlations with 20-m shuttle run, and sit-ups as primary contributors to performance in sport-specific skills (Coelho e Silva et al., 2010). However, there is need of bridging the gap between science and practice helping the practitioners to increase their effectiveness of their decisions during training and competitions, and then grouping players according to growth and maturation attributes (Cumming et al., 2017), particularly in the case of knowing the relationships of maturational and physical domains with game-related variables.

Therefore, considering the need to provide some recommendations to help coaches to improve the development of young basketball players, the aim of this study was to examine the influence of maturation in anthropometric, physical, and game-related variables in youth boys' and girls' basketball age groups of U-13 and U-15. The hypothesis of the study suggests that physical and game-related variables are different by sex and largely associated with biological maturation in both age groups.

MATERIALS AND METHODS

Subjects

One-hundred and eighty-five basketball players taking part in a U-13 boys' category (mean CA = 12.91 ± 0.56, n = 50), U-13 girls' category (mean CA = 12.75 ± 0.70, n = 29), U-15 boys' category (mean CA = 14.77 ± 0.54, n = 54), and U-15 girls' category (mean CA = 14.42 ± 0.78, n = 52) were considered for this study (**Table 1**). The U-13 age category included those players born before or within the year 2005, while U-15 age category included players born on the years 2004 and 2003. Most players were of Portuguese Ancestry, apart from few players of African (n = 3), Eastern Europe (n = 1), and South American Ancestry (n = 1). All participants were selected by sport clubs to play in a non-official youth basketball tournament, which included 10 boys' teams and nine girls'

TABLE 1 | Descriptive and inferential analysis of anthropometrical and maturational variables and blocks, according to the age groups and established clusters (Mean ± SD).

Blocks	Variables	BOYS U-13 Pre-PHV C1 (*n* = 29)	BOYS U-13 Mid-PHV C2 (*n* = 21)	BOYS U-15 Mid-PHV C3 (*n* = 27)	BOYS U-15 Post-PHV C4 (*n* = 27)	GIRLS U-13 Mid-PHV C1 (*n* = 7)	GIRLS U-13 Post-PHV C2 (*n* = 22)	GIRLS U-15 Post-PHV C3 (*n* = 17)	GIRLS U-15 Post-PHV C4 (*n* = 35)	Magnitude-based inferences U-13 Boys C1–C2	U-15 Boys C3–C4	U-13 Girls C1–C2	U-15 Girls C3–C4
Anthropometrical	CA (y)	12.7 ± 0.6	13.2 ± 0.4	14.7 ± 0.6	14.9 ± 0.5	12.1 ± 0.6	12.9 ± 0.6	13.9 ± 0.8	14.7 ± 0.6				
	Height (cm)	154.4 ± 4.7	166.7 ± 4.7	167.6 ± 8.5	178.7 ± 5.8	153.7 ± 5.9	162.8 ± 4.9	158.3 ± 2.4	166.7 ± 5.5				
	Body mass (kg)	42.8 ± 6.2	57.9 ± 8.9	54.4 ± 5.2	68.6 ± 5.0	38.1 ± 4.2	57.8 ± 9.9	52.3 ± 4.7	62.3 ± 6.7				
	%BF (%)	12.7 ± 4.7	15.2 ± 6.0	10.3 ± 2.7	13.2 ± 3.8	16.9 ± 4.3	26.9 ± 7.2	24.5 ± 4.4	27.0 ± 5.5				
Maturational	MO (y)	−2.2 ± 1.0	−0.5 ± 0.4	0.2 ± 1.0	1.2 ± 0.5	−0.2 ± 0.5	1.2 ± 0.4	1.4 ± 0.4	2.3 ± 0.4	−2.41** [−3.01;−1.81]	−0.72** [−1.41;−0.03]	−2.10** [−21.81; 17.61]	−2.11** [−2.90;−1.31]
	APHV (y)	14.9 ± 1.1	13.7 ± 0.5	14.4 ± 0.9	13.7 ± 0.4	12.3 ± 0.3	11.7 ± 0.4	12.5 ± 0.4	12.3 ± 0.4	1.60** [1.00; 2.21]	1.06 [0.44; 1.68]	1.58** [0.78; 2.39]	0.32 [−0.28; 0.92]
	PAH (cm)	183.7 ± 4.3	187.3 ± 3.2	180.4 ± 5.9	185.9 ± 4.9	169.1 ± 4.8	169.3 ± 4.9	162.9 ± 4.2	168.6 ± 5.4	−0.99 [−1.57; −0.41]	−1.00 [−1.54; −0.46]	−0.02 [−0.90; 0.86]	−1.14** [−1.71;−0.58]

*Note: **p < 0.01. Abbreviations: CA, chronological age; MO, maturity offset; APHV, age of peak height velocity; PAH, predicted adult height; %BF, body fat; C1, Cluster 1; C2, Cluster 2; C3, Cluster 3; C4, Cluster 4. Cohen's "d" units, and threshold values were: 0–0.2 trivial; >0.2–0.6 small; >0.6–1.2 moderate; >1.2–2.0 large; and >2.0.*

teams. During this 3-day event, every team played a minimum of six and a maximum of seven games.The eligibility criteria of the study were: (i) players who did not suffer any injury during the last 6 months (including tournament); (ii) players who took part in at least four matches during the tournament; and (iii) those players who completed the full test battery. From the original sample (n = 198), 14 participants were excluded because due to incomplete full test (U-13 boys, n = 6; U-13 girl, n = 2; U-15 boys, n = 3; U-15 girls, n = 2). Written informed consent was obtained from all participants and their parents before the investigation began. The present study was approved by the University of Trás-os-Montes and Alto Douro research ethics committee and conformed to the recommendations of the Declaration of Helsinki.

Procedures

All data were gathered during a 3-day non-official youth basketball tournament, using cross-sectional design. The data collection followed a fixed schedule and supervised by the same members of the research team ensuring the test accuracy and reliability. In the morning of day 1, anthropometrical data were collected. Then, in early afternoon of the same day, physical measurements were performed in indoor basketball court with verbal encouragement. Specific warm-up was performed prior to the physical tests (Taylor et al., 2013). The protocol included a cardiovascular phase (5 min of general jogging/run), followed by dynamic stretching and task-specific activity, which consisted of two 20-m slalom runs, two 40-m shuttle sprints at 50 and 75% of the subjects' perceived maximal effort, respectively, and one maximal 40-m sprint (Taylor et al., 2013). A practical demonstration and familiarization (minimum two trials) with testing procedures were held before the tests were conducted. Finally, game-related variables were collected during non-official youth basketball tournament games (late afternoon of day 1, day 2, and day 3).

Anthropometrical Data

Height and seated height were recorded for estimation of MO, using portable stadiometer (Tanita BF-522W, Japan, nearest 0.1 cm), and following specific guidelines (Taylor et al., 2013). Body mass was estimated using the body fat (BF) monitor (Tanita BF-522W, Japan, nearest 0.1 kg). All measurements were taken following the guidelines outlined by the International Society for the Advancement of Kinanthropometry (ISAK). In addition, the %BF was estimated using the same device, through the bioelectrical impedance analysis technique (intraclass correlation coefficient [ICC] = 0.87, [95% CI 0.47; 0.97]; typical error of measurement [TEM] = 0.44, [95% CI 0.29; 0.89]). According to the manufacturer instructions, the present BF monitor is suitable for adults and children (ages 7–17) with inactive to moderately active lifestyles and adults with athletic body types. Height and seated height were assessed while subjects were barefoot and gathered by the same researcher to ensure testing accuracy and reliability. The ICC for Height was 0.97 (95% CI 0.85; 0.99) and for TEM was 0.23 (95% CI 0.15; 0.46). The ICC for Seated

Height was 0.90 (95% CI 0.58; 0.98) and for TEM was 0.39 (95% CI 0.26; 0.79).

Somatic Maturation

Despite having some limitations and although new prediction equations are appearing in these last years, the assessment of the years from/to the peak height velocity (PHV) (i.e., predicted MO) is the most commonly used indicator of the somatic maturation in the sports field (Kozieł and Malina, 2018). The MO was estimated using a non-invasive method appropriated for age range of sample, considering anthropometric data (leg length and sitting height) and CA, which has shown to be accurate with a reported error of approximately 6 months (Mirwald et al., 2002). This method has previously been tested in longitudinal study among 8–18 years old boys and girls (Malina and Kozieł, 2014a,b). Leg length was estimated as the difference between height and sitting height (Mirwald et al., 2002). The APHV was calculated by subtracting the MO from the CA (Mirwald et al., 2002). Considering the MO, the subjects could be classified into three maturity status categories: pre-PHV (PHV $\leq$ −1.00 year), mid-PHV ($-1.00 < \text{PHV} < +1.00$ year), and post-PHV (PHV $\geq +1.00$) (Carvalho et al., 2017). Predicted adult height (PAH) resulted from the sum of the height at the time of the measurements and distance left to grow in height according to APHV and MO (Sherar et al., 2005). No published data exist on the validation of equation to predict adult height. Consequently, we used unpublished data from our laboratory using male basketball national team players (n = 19) recorded an underestimated adult height at 16 years old using non-invasive method (Sherar et al., 2005) comparing with real value at adult age [p = 0.007; mean difference (SD) between methods = -1.86 ± 0.63 cm, 95% CI = −3.19 to −0.69). However, the data recorded almost perfect relationship and substantial agreement between the values of PAH measured with both methods [r = 0.93, 95% CI = 0.88–0.98, standard error of measurement (SEE) = 0.03 cm, slope of the regression line = 0.86; $P < 0.001$, ICC = 0.93, 95% CI = 0.83–0.97, Cronbach's alpha (α) = 0.96]. Also, unpublished data from our laboratory (male population) shown that the Mirwald method (n = 15; CA range = 12.20–15.43 years) significantly overestimated adult height comparing with gold-standard Khamis and Roche method [p = 0.003; mean difference (SD) between methods = 3.77 ± 0.91 cm, 95% CI = 2.14–5.70]. However, the data recorded almost perfect relationship and substantial agreement between the values of PAH measured with both methods [r = 0.92, 95% CI = 0.74–0.97, SEE = −0.06 cm, slope of the regression line = 0.83; $P < 0.01$, ICC = 0.91, 95% CI = 0.76–0.97, Cronbach's alpha (α) = 0.96]. Based on clustering analysis (see section "Statistical Analysis"), participants were grouped considering MO for each age category as follows: U-13 boys more mature vs less mature players (clusters 1 [C1], and 2 [C2]), and the procedure was repeated for U-15 boys (clusters 3 [C3] and 4 [C4]), as well as to girls' age groups, U-13 more mature vs less mature players (clusters 1 [C1] and 2 [C2]), and U-15 (clusters 3 [C3] and 4 [C4]). Considering the difference to the mean APHV in reference population subjects could be classified into three maturity timing categories: early (APHV ≤ -1.00 years), average ($-1.00 < \text{APHV} < +1.00$ years), and late (APHV $\geq +1.00$ years) (Sherar et al., 2005). Most players were average maturing, apart from few players who were early maturing (C3 boys = 1; C4 boys = 2; C2 girls = 1) or late maturing (C1 boys = 8; C2 boys = 4; C3 boys = 5; C3 girls = 1; C4 girls = 1).

Testing

Jump ability was recorded using an infrared optical system (*OptoJump Next—Microgate, Bolzano, Italy*). Running and change-of-direction speed were recorded with 90-cm height photoelectric cells separated by 1.5 m (Witty; Microgate). Each participant performed two trials of jumping and running abilities with 2 min of rest between the trials. Players started each speed tests in standing position with their foot 0.5 m behind the first timing gate.

Jumping Ability

Vertical jumps [ABA and horizontal jump (HJ)] were performed according to the protocol described by Bosco et al. (1983). The ICC for ABA was 0.97 (95% CI 0.84; 0.99) and for TEM was 0.23 (95% CI 0.15; 0.51). The ICC for HJ was 0.89 (95% CI 0.49; 0.98) and for TEM was 0.42 (95% CI 0.27; 0.92).

Speed and Agility

Speed was evaluated by 20-m sprint (ICC = 0.96, [95% CI 0.83; 0.99]; TEM = 0.24, [95% CI 0.16; 0.49]) and the agility t-test determined speed with directional changes (forward sprinting, lateral shuffling, and backward running) (ICC = 0.82, [95% CI 0.33; 0.96]; TEM = 0.50, [95% CI 0.33; 1.01]) (Pauole et al., 2000).

Game-Related Statistics

Game-related variables (points, field-goals attempted, total rebounds, assists, steals, and turnovers) during the youth tournament were used to assess players' performances (see **Table 1**). All data were collected using the official FIBA box-scores recorded by experienced and qualified technicians. All calculations were performed as per National Basketball Association procedures. All game-related variables were presented as a percentage of the team total score (Arede et al., 2019). The Ast:TO and Stl:TO ratios were calculated by comparing the number of assists or steals to the number of turnovers committed (Arede et al., 2019).

Statistical Analyses

Data were presented as mean $\pm$ standard deviation. First, to analyze data normality assumptions, the Shapiro–Wilk test was used. Then, in cases of non-Gaussian distribution, non-parametric methods were used to evaluate differences between medians. Second, a two-step cluster analysis was performed using Ward's method—squared Euclidian distance as a distance measure—considering MO as the grouping variable (Everitt, 2011). Third, one-way ANOVA with Bonferroni *post hoc* analyses were conducted to make comparisons between clusters. Effect sizes (ES) of the difference were assessed using standardized Cohen's "d" units, and threshold values were: 0–0.2 trivial; >0.2–0.6 small; >0.6–1.2 moderate; >1.2–2.0 large; and >2.0

very large (Batterham and Hopkins, 2006). Lastly, to assess the relative contributions of maturational, physical, and game-related variables, the regularized generalized canonical correlation analysis (RGCCA) was used with scaled variables. In this study, RGCCA was used to extract the information shared by the blocks of variables, namely, maturational, physical, and game-related which were all linked through the reduction to a few meaningful canonical variables (CV), visualization of relevant variables, and interaction between these blocks. It was decided to extract and evaluate a pair of CV (CV_1 and CV_2), since we aim to extract the maximum information of the interrelations within and between the three blocks of variables. The statistical package IBM SPSS 24.0 (Armonk, NY, United States: IBM. Corp.) was used to perform the statistical tests and cluster analysis. RGCCA analysis was conducted using "RGCCA" package in R 3.4.2 (R Core Team, 2014) (Tenenhaus and Guillemot, 2017).

RESULTS

Tables 1, **2** display the descriptive analysis of anthropometrical, maturational, physical, and game-related variables for each age group according to the established clusters.

In both gender, the results show significant differences in the APHV and MO between C1 and C2 (U-13) and between C3 and C4 (U-15) (all $p < 0.01$). In both genders, subjects included in C1 and C4 presented a later APHV, comparing to their peers of same age category. The Post-PHV U-15 boys (C4) had higher values in speed, agility, and lower limb power tests. Within each age category, more mature subjects generally scored more points, attempted more field goals, and got more rebounds, but not significantly. The results of the correlation matrix among canonical variates are displayed in **Figure 1**. The U-13 boys showed the highest correlation between physical and game-related variables followed by maturational and game variables. The U-15 boys showed the highest correlation between physical and game-related variables, followed by physical and maturational variables. The U-13 girls showed the highest correlation between physical and game-related variables, followed maturational and game-related variables; in CV_2, the highest correlation was found between game-related statistics and physical. The U-15 females showed the highest correlation between maturational and physical variables, followed by physical and game-related variables.

Table 3 and **Figure 2** show correlations between original and CVs within age groups for boys and girls. In U-13 and U-15 boys, the results confirmed that players with higher MO, higher PAH, and lower APHV also had high scores in physical variables, and scored more points, field goals attempted, and rebounds. Moreover, the results of CV_2 in U-13 boys revealed that players with higher APHV presented lower performance in Ast:TO and Stl:TO ratios. Considering the U-13 girls, the results of CV_1 demonstrated that players with lower MO had low performance in sprinting and agility test, but also in all game-related statistics. The results of CV_1 for the U-15 girls showed that players with higher MO and APHV had better HJ, got more rebounds, and presented better game efficiency performance (i.e., Ast:TO and Stl:TO ratios). Moreover, the results of CV_2, demonstrated that players with higher PAH had better in ABA and HJ, attempted lower field goals, scored less points, got less rebounds, but had better Ast:TO ratio.

DISCUSSION

The main objective of this cross-sectional study was to examine the influence of the MO on the composition of U-13 and U-15 basketball age groups in both genders. As was argued, the age group, gender, and maturational factors may affect the performances displayed by players. The current findings support this hypothesis due to the fact that the MO allowed establishing two different cohorts within each age group. Globally, the results confirm the influence of MO in performance profiling of youth basketball players. Moreover, the correlation between maturational, physical, and game-related variables correlated differently according to age category, and gender. Evidence regarding the differences that usually characterize players of the same age group in terms of anthropometrical scores, body composition, and physical measurements from previous cross-sectional research in youth team ball sports was confirmed in this study (Malina et al., 2004; Malina et al., 2007). More mature players are typically characterized by higher performance in speed, agility, and lower limb power which are determinants of basketball and positively influence the probability of being selected to practice and play with the best players and coaches (Sherar et al., 2010). Although the results of this study indicate that more mature players possessed no significant physical or game advantages, the MO variation between clusters clearly indicates the existence of different maturational statuses within different age categories. Evidence from a recent study with young basketball players (Arede et al., 2019) are in accordance with our results, especially the non-significant differences between maturity status in points scored and game efficiency. However, it is important to note that data from the present study were obtained from a sample consisting of participants aged between 11 and 15 years old, contrary to what occurred in the previous studies (Lefevre et al., 1990; Malina et al., 2007; Arede et al., 2019), where the samples were less numerous and shorter regarding to the age ranges. Particularly important in the case of girls' subsets was that the results showed a more homogenous anthropometric and physical profile than in boys' sample. Maturity-related trends in anthropometric and physical performance of girls are consistent with those for boys, but differences in physical capacities are less apparent. Limited data suggest that less mature girls perform better than more maturing girls in some tasks, but overall maturity-associated variation is not consistent across tasks and ages (Myburgh et al., 2016).

A greater difference was identified when comparing game-related variables between U-13 clusters (C2–C1) than between U-15 clusters (C4–C3). Additionally, the differences between maturation-related clusters are different according to gender. In fact, between-gender differences in players' development in youth basketball were previously reported with girls revealing

TABLE 2 | Descriptive and inferential analysis of physical and game-related variables and blocks, according to the age groups and established clusters (Mean ± SD).

Blocks	Variables	BOYS				GIRLS				Magnitude-based inferences			
		U-13		U-15		U-13		U-15		U-13	U-15	U-13	U-15
		Pre-PHV C1 (*n* = 29)	**Mid-PHV C2 (*n* = 21)**	**Mid-PHV C3 (*n* = 27)**	**Post-PHV C4 (*n* = 27)**	**Mid-PHV C1 (*n* = 7)**	**Post-PHV C2 (*n* = 22)**	**Post-PHV C3 (*n* = 17)**	**Post-PHV C4 (*n* = 35)**	**Boys C1–C2**	**Boys C3–C4**	**Girls C1–C2**	**Girls C3–C4**
Physical	20m (s)	3.7 ± 0.2	3.6 ± 0.3	3.3 ± 0.2	3.2 ± 0.2	3.8 ± 0.1	3.8 ± 0.6	3.6 ± 0.1	3.7 ± 0.1	0.27 [−0.34; 0.88]	0.51 [−0.02; 1.05]	−0.02 [−1.00; 0.95]	−0.32 [−0.88; 0.25]
	T-test (s)	11.3 ± 0.6	11.4 ± 0.9	10.3 ± 0.6	9.9 ± 0.6	12.4 ± 0.5	11.8 ± 0.7	11.3 ± 0.5	11.6 ± 0.6	−0.16 [−0.78; 0.45]	0.50 [−0.03; 1.30]	0.89 [0.07; 1.70]	−0.48 [−1.05; 0.08]
	ABA (cm)	29.4 ± 6.2	30.0 ± 5.9	38.4 ± 5.8	39.9 ± 5.3	26.5 ± 2.4	26.2 ± 4.0	27.8 ± 3.1	26.5 ± 4.5	−0.11 [−0.67; 0.44]	−0.27 [−0.81; 0.27]	0.17 [−0.63; 0.96]	0.41 [−0.16; 0.98]
	HJ (cm)	162.8 ± 21.6	162.1 ± 21.4	198.7 ± 21.7	211.2 ± 23.1	150.7 ± 12.1	148.6 ± 18.2	152.7 ± 10.0	154.6 ± 16.2	0.02 [−0.53; 0.58]	−0.52 [−1.05; 0.01]	0.17 [−0.63; 0.96]	−0.10 [−0.68; 0.47]
Game-related statistics	Points (n)	7.8 ± 7.2	12.2 ± 11.8	6.8 ± 7.8	11.2 ± 11.0	9.6 ± 11.7	14.4 ± 12.9	9.8 ± 10.4	8.7 ± 7.4	0.01 [−0.68; 0.69]	−0.39 [−0.97; 0.19]	−0.27 [−1.36; 0.82]	−0.05 [−0.69; 0.80]
	Field goals (n)	3.3 ± 2.0	4.0 ± 3.1	3.0 ± 2.2	3.8 ± 2.8	3.4 ± 2.2	3.4 ± 2.2	3.6 ± 1.9	3.1 ± 1.8	−0.06 [−0.64; 0.52]	−0.22 [−0.76; 0.32]	−0.68 [−1.92; 0.56]	0.44 [−0.14; 1.02]
	Rebounds (n)	7.2 ± 6.3	9.9 ± 8.3	6.7 ± 5.6	9.9 ± 6.1	9.1 ± 4.7	13.4 ± 9.4	8.1 ± 6.5	9.9 ± 6.7	−0.51 [−1.10; 0.08]	−0.73 [−1.30; −0.16]	−0.30 [−1.15; 0.55]	−0.23 [−0.84; 0.38]
	Ast:TO (a.u.)	0.2 ± 0.3	0.1 ± 0.2	0.2 ± 0.3	0.4 ± 1.1	0.1 ± 0.1	0.2 ± 0.4	0.2 ± 0.3	0.2 ± 0.5	−1.32 [0.39; 2.26]	0.12 [−0.81; 1.04]	−0.85 [−1.96; 0.25]	−0.10 [−0.97; 0.77]
	Stl:TO (a.u.)	0.8 ± 1.5	0.5 ± 0.7	0.5 ± 0.5	1.0 ± 1.5	0.3 ± 0.3	0.9 ± 0.8	0.9 ± 1.0	0.9 ± 1.3	0.13 [−0.56; 0.82]	−0.62 [−1.22; −0.02]	−0.81 [−1.80; 0.18]	0.03 [−0.60; 0.66]

Abbreviations: 20m, 20 meters' sprint time; T-test, agility t-test; ABA, Abalakov vertical jump; HJ, horizontal jump; Ast:TO, assist per turnover ratio; Stl:TO, steal per turnover ratio; C1, Cluster 1; C2, Cluster 2; C3, Cluster 3; C4, Cluster 4. Cohen's "d" units, and threshold values were: 0–0.2 trivial; >0.2–0.6 small; >0.6–1.2 moderate; >1.2–2.0 large; and >2.0.

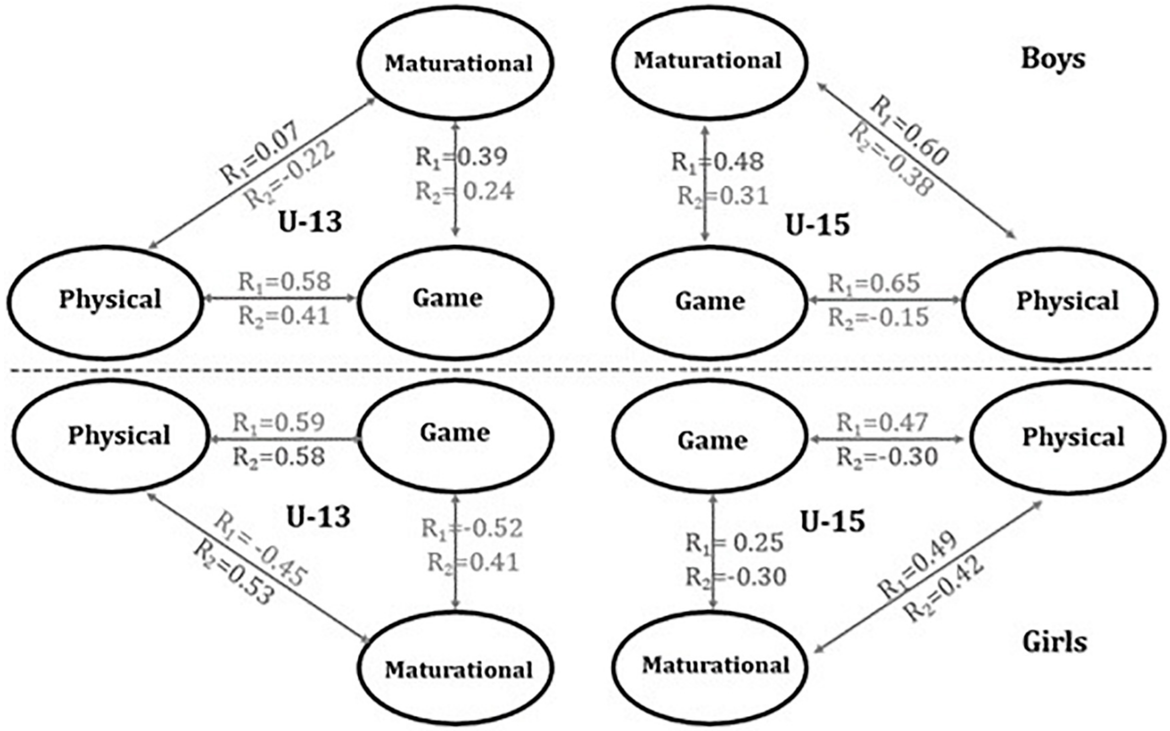

FIGURE 1 | Canonical variables correlations between maturational, physical, and game-related statistics blocks (R_{cv1} and R_{cv2}). Abbreviations: U-13, under-13; U-15, under-15.

TABLE 3 | Correlations between original and canonical variables within groups for boys' and girls' age groups.

Original variables	BOYS				GIRLS			
	U-13		U-15		U-13		U-15	
	CV_1	CV_2	CV_1	CV_2	CV_1	CV_2	CV_1	CV_2
MO	0.753	0.156	0.970	−0.243	−0.957	0.191	0.877	0.173
APHV	−0.713	0.396	−0.850	−0.109	0.238	0.064	0.512	0.137
PAH	0.763	0.125	0.494	0.821	0.292	0.674	0.185	−0.665
20m	−0.893	0.192	−0.876	−0.240	−0.495	0.128	−0.034	0.640
T-test	−0.902	0.331	−0.853	−0.450	−0.810	−0.482	−0.085	0.289
ABA	0.637	−0.585	0.899	−0.053	−0.012	0.871	−0.046	−0.956
HJ	0.786	0.231	0.942	−0.259	0.135	0.944	0.806	−0.506
Points	0.916	−0.130	0.924	−0.185	0.751	0.344	−0.074	0.394
Field goals	0.901	−0.206	0.915	−0.305	0.810	−0.102	0.237	0.647
Rebounds	0.911	−0.046	0.808	0.466	0.692	0.682	0.409	0.552
Ast:TO ratio	−0.082	−0.801	0.010	−0.578	0.419	0.041	0.843	−0.381
Stl:TO ratio	0.146	−0.946	0.120	−0.551	0.667	−0.440	0.822	0.032

MO, maturity offset; APHV, age of peak height velocity; PAH, predicted adult height; Abbreviations: 20m, 20 meters' sprint time; T-test, agility t-test; ABA, Abalakov vertical jump; HJ, horizontal jump; Ast:TO, assist per turnover ratio; Stl:TO, steal per turnover ratio; CV1, canonical variable 1; CV2, canonical variable 2.

lesser commitment to sport (lower average minutes per week and per season) (Leite and Sampaio, 2012). Thus, the development of motor abilities, as well as technical–tactical performances may deteriorate, contributing to different between maturity status group discrepancies than in boys. In both age categories, boys in advanced maturity status scored more points and got more rebounds. Although non-significant, the comparison of game-related variables revealed interesting trends: on the one hand, the analysis of the variation between clusters of the same age group (i.e., C1–C2 and C3–C4) and on the other hand, the between-gender variation. Globally, more mature players were characterized by a higher contribution to team's performance in terms of points scored, rebounds, and field-goals attempted. These game actions are highly dependent on

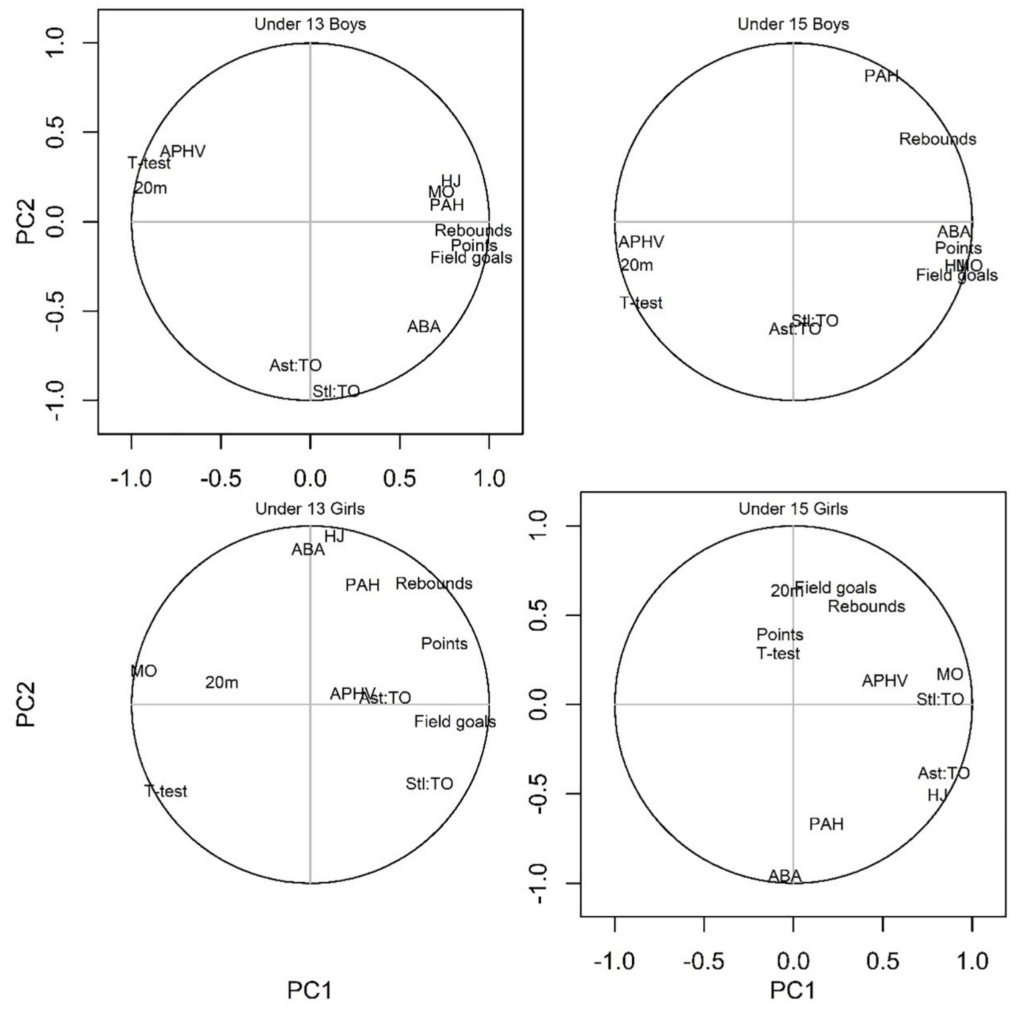

FIGURE 2 | Graphical representation for correlations between original and canonical variables within groups. Legend: MO, maturity offset; APHV, age of peak height velocity; PAH, predicted adult height; %BF, body fat; 20m, 20 meters' sprint time; T-test, agility *t*-test; ABA, Abalakov vertical jump; HJ, horizontal jump; Ast:TO, assist per turnover ratio; Stl:TO, steal per turnover ratio; PC1, principal component 1; PC2, principal component 2.

conditional motor skills, such as strength, speed, or power, which aid more mature players in obtaining better scores (Torres-Unda et al., 2013). However, they also depend on the game knowledge, i.e., perceptual-cognitive skills. Along these lines, the results are contradictory to previous findings (Arede et al., 2019), since ratio scores were not significantly different across maturity status. Improved ball-handling and passing (i.e., assists) and gain possession (i.e., steals) skills are strongly associated with the speed in which multiple objects may be visually tracked, namely, visual tracking speed (Mangine et al., 2014). Thus, the visual-motor capability, which elicits better game-related performance, may be associated with better pattern recognition skills due to a higher number of hours dedicated to sport-specific practice and competition (Arede et al., 2019). Besides, assists and steals are strongly associated with agility skills (McGill et al., 2012). In the present study, the more mature players obtained better records in agility than those who were less mature. Higher body control in different planes may not only contribute to increasing the level of defensive pressure but also promote high-quality distribution skills. Thus, due to the biological advantage, the more mature may benefit from both training experience in affordable situations to correctly respond to the recognized game patterns and easily transfer to game situations.

The results of the present study confirm the existence of different maturity status among U-13 and U-15 boys and girls. From a methodological point of view, the maturity status assessment can be supported in isolated or combined criteria (Lloyd et al., 2014), but it is more important to create the proper competitive environment to foster talent in sport. Coaches recognize the importance of grouping athletes relative to attributes associated with the processes of maturation in youth sport and because they are forced to reflect on other players, provides them the opportunity to evaluate skills and attributes in a more balanced environment (Sherar et al., 2005; Cumming et al., 2017; Malina et al., 2019). Considering the variation in the MO that characterized participants in the youth basketball tournament, the results should be cautiously used when applying a competitive model, since it is clear that players had distinct body composition and physical scores may be competing for the same sport in a team. A high responder for one form of training response (e.g., speed) may not necessarily be a high responder for a different form of training or competition demand (e.g., drive the ball successfully to the basket). Researcher approaches accounting for multivariate, holistic, and flexible factors and variables need to be developed rather than isolated analysis of individual's performances (e.g., anthropometry). Furthermore, a better understanding of how anthropometrical, maturational, physical, or game-related variables correlate across different age groups would be particularly beneficial given that these factors could be managed to improve the training optimal effects.

Globally, the results of this study confirm a greater importance of the maturational aspects during initial and intermediate stages of boys' development and performance. Considering the fact that boys in advanced maturity status (both in U-13 and U-15) outscored their counterparts in body height and mass, this may possibly result in a game dominance. Conversely, girls' clusters showed a lower individual's variation among them, which apparently suggests somehow a detraction from the importance of maturational aspects in performance evolution. Interestingly, in some cases, best performances were obtained by the players grouped in C3, what could suggest that approximately 1.5 years after the PHV, advantages resulted from maturational bias seem to attenuate. This fact may suggest that the transition between these age groups is less detrimental in performance. Biological maturation can play a large influence on sports selection and talent development (Arede et al., 2019a,b). Within each age category and gender, there is a significant individual variability in terms of growth and maturation, which interacts differently with human performance (e.g., physical and game skills). Thus, if practitioners consider training and competition with respect to the maturational status, it could increase the effectiveness of their decisions, providing more appropriate and individualized stimuli (Cumming et al., 2017; Malina et al., 2019). This approach may include long-term benefits providing the same opportunity and quality of training and competition, irrespectively of current global performance, and suitability to obtain short-term objectives. The present study has some limitations that must be acknowledged. It could be possible that the small size of certain groups may have affected the between-group differences. Moreover, the spectrum of contributing variables is broader; then future studies can include perceptual-cognitive and psychological variables in experimental designs, but also training experience as confound variable. Nevertheless, the findings of the present study do provide new insights in the development of young basketball players. Future research should include a comparison of game performance profiles under different conditions: when playing traditional (i.e., CA-based) and bio-banding (i.e., biological age-based) competitions.

CONCLUSION

The results of this study improve our understanding how biological maturation influences both physical and game-related variables in each age category among youth basketball players. Present findings demonstrated the existence of different maturity status within each age category, and greater differences in terms of MO in younger age categories. Moreover, the results of this study have not confirmed a significant difference between maturity status in physical and game-related variables, but they cannot be overlooked. In fact, RGCCA revealed different relative contributions of maturational aspects according to each age category and gender. That said, CA-based training and competition systems may be not enough to provide an individualized stimulus considering growth and maturation. Thus, the strategy of grouping athletes relative to attributes associated with the processes of maturation can be an alternative or complementary approach to provide optimal training/competitive situations, matching individual needs, and consequently encourage long-term development. Practitioners in youth basketball (e.g. coaches, strength and conditioning coaches/athletic trainers, managers, etc.) can use present findings for better matching athletes based on maturity status, according context (e.g., training, competition or strength, and conditioning), and purpose (i.e., talent identification or development).

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of Trás-os-Montes and Alto Douro research ethics committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

JA and NL contributed to conceptualization, investigation, methodology, and writing—original draft. JA, IO, and NL contributed to data curation, formal analysis, and software. JA, M-AÁ, and NL contributed to writing—review and editing. All authors contributed to the article and approved the submitted version.

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CONCEPTUAL ANALYSIS
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The Role of Siblings in Talent Development: Implications for Sport Psychologists and Coaches

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Developing talent requires consideration of social networks that can facilitate or inhibit progression. Of fundamental influence in this regard is the family, with recent investigation extending its focus from parents to the role of siblings. As such, the purpose of this *Conceptual Analysis* article is to, firstly, review the characteristics of the sibling relationship that may support or inhibit talent development. Secondly, the analysis then provides empirically derived practical examples to emphasize the holistic and complex role that siblings can play in talent development. Thirdly, strategies are proposed to support practitioners identify specific sibling characteristics, alongside recommendations for how the relationship can be utilized within both the formal and informal environments by coaches and psychologists. Finally, and crucially, important implications of these characteristics are considered to support effective coach and sport psychologist decision making.

Keywords: coaching, family, professional practice, biopsychosocial development, psychology, talent development environments, sibling characteristics

INTRODUCTION

Talent development (TD) refers to "a multi-faceted process of optimally nurturing athletes over time within a sport-system" (Cobley et al., 2021, p. 8). As such, and in recognizing that TD is usually a long-term process, TD environments (TDEs) are recommended to focus on introducing and building pertinent skill-sets. Indeed, these skills should enable adaptability across the talent pathway with the aim of achieving high performance outcomes (Martindale and Mortimer, 2011). Specifically, optimizing the impact of formal experiences, such as adult-led coaching sessions, and working through informal environments, such as child-led activity in gardens, should be considered by practitioners to appropriately assist athletes toward reaching their potential in what is typically a non-linear and challenging pathway (Collins and MacNamara, 2018). Reflecting the emphasis of this paper, siblings can be important and unique developmental agents within these contexts when compared to coaches, parents, psychologists, and peers (Collins et al., 2016; Blazo and Smith, 2018). However, there is also the potential for siblings to have no impact, or a negative impact, on development (Weissensteiner et al., 2009; Warmenhoven et al., 2020). Undoubtedly, one argument which is often applied to siblings is the nature vs. nurture debate. This is, of course, of academic interest, although examining intact families with siblings is clearly not informative. The situations encountered are clearly an indivisible combination of nature *and* nurture (cf. Mark et al., 2017). For research purposes, psychologists have focused on a particular type of sibling, namely twins (e.g., Segal, 2012) and ideally, twins separated in early life (Segal et al., 2015). This is not a concern of this paper however, rather its aim is to highlight issues and methods which might be useful for coaches and psychologists when working with sporting siblings.

Surprisingly, despite widespread and longstanding observance of sibling involvement within cases of elite sporting success, how these relationships may best support TD has only recently formed an explicit focus within the coaching literature. Therefore, this paper aims to focus on the sibling relationship by reviewing empirically derived characteristics, its impact on holistic development, and its complexity. Finally, the paper will conclude by discussing how sport psychologists and coaches can identify and positively utilize a sibling relationship for TD across formal and informal environments.

REVIEWING CHARACTERISTICS OF THE SIBLING RELATIONSHIP

Several studies have considered the role of siblings across sport participation (i.e., participation, development, and performance), suggesting that siblings can have a meaningful influence on an athlete in both a positive and negative way (Côté, 1999; Davis and Meyer, 2008; Blazo et al., 2014; Trussell, 2014; Hopwood et al., 2015; Allbaugh et al., 2016; Nelson and Strachan, 2017; Osai and Whiteman, 2017; Taylor et al., 2017, 2018, 2021). Reflecting this polar influence, an initial retrospective study by Côté (1999) investigated the historical family dynamics of four 18-year old elite junior level athletes throughout their developmental years. Results revealed positive role modeling behaviors between siblings, that included an influence on the elite-level athlete's decision to specialize within a sport. Significantly, there were also negative emotions reported, such as bitterness and jealousy, from other siblings due to the family shifting attention more toward the talented athlete. Expanding on this, Davis and Meyer (2008) qualitatively examined current adult experiences of 10 elite level sibling-athletes (aged 18–27 years old) through a psychological lens during competition against one another. They identified sibling competitiveness as being different from other opponents. Specifically, this was characterized by previously unidentified processes, again interpreted by the authors as positive (i.e., rivalry, closeness, and respect) by providing emotional support and motivation, as well as negative in the form of gloating.

In broader sport participation studies, Fraser-Thomas et al. (2008) examined the outcomes of dropout vs. prolonged engagement in adolescent competitive sport. These authors identified a differential role of siblings when comparing these outcomes. Those dropping out highlighted high levels of competition, rivalry, and jealousy, while those that maintained engagement experienced generally positive role modeling from their sibling. Furthermore, Weissensteiner et al. (2009) made the case for acknowledging the socio-developmental environment as part of a conceptual model of expertise in cricket. Within this model they highlighted the role of siblings through competition, thereby supporting the development of psychological attributes such as competitiveness, strategizing, coping, and mental toughness. At this point in the literature the sibling relationship in sport can now be seen to be complex in nature.

Next, Blazo et al. (2014) investigated 10 participants (aged 18–32 years old) who had at least one older sibling on an athletic scholarship. Participants themselves either played the same sport as their older sibling, played a different sport, or did not play sport beyond youth recreational leagues. They highlighted the positive impact siblings might have on achievement in sport, suggesting that the relationship had a broader positive family and social influence; as well as helping to develop fondness of another sibling and the development of an identity, whether shared or individual. Similar to previous studies, Blazo et al. (2014) also identified negative connotations such as abandonment and jealousy, which further established the sibling influence as both broad and diverse.

The first quantitative exploration of siblings in sport, conducted by Hopwood et al. (2015), concluded that siblings may play an important role in the development of sporting expertise. Two hundred and twenty-nine athletes (aged 15–35 years old), classified as elite, pre-elite, or non-elite, identified associations between sport expertise, sibling characteristics, and sibling participation in sport and physical activity. Findings suggested that elite athletes were less likely to be first born children, while siblings of elite athletes were more likely to have participated in sport at the pre-elite and elite levels. Similarly to previous qualitative studies, this research revealed the positive older sibling influence on psychological and social factors. Subsequent qualitative studies by Osai and Whiteman (2017) and Nelson and Strachan (2017) explored the potential impact of siblings on TD. Both studies attributed siblings' active engagement to the enhancement of skills and abilities. Nelson and Strachan added that athletes participating in the same sport as their siblings developed a much deeper understanding of each other and their experiences within sport, with the sibling role being potentially both positive (relationship growth and understanding) and negative (sibling competition and emotional response).

Recently, Taylor et al. (2017, 2018, 2021) advanced the study of siblings and TD by tracking athletes across meaningful timeframes and at relevant ages. Initial investigation retrospectively explored the impact of siblings from retired athletes who had competed at the Olympic Games, World Championships or professionally. Data highlighted the perceived importance, and holistic role of siblings during development (Taylor et al., 2017). Consequently, further qualitative study tracked junior athletes (aged 8–16 years) longitudinally during the TD process, combining data from the siblings with parent perceptions to encapsulate the wider family interpretation of the process (Taylor et al., 2018, 2021). All three studies by Taylor and colleagues outlined a number of characteristics perceived to be positive mechanisms for TD, which supported and expanded on the findings from previous studies (see **Table 1**). Importantly, analysis of the findings illuminated the presence of biopsychosocial interactions resulting from important contextual information when interpreting these data across time and sibling dyads.

Finally, a quantitative questionnaire study conducted by Warmenhoven et al. (2020) explored the different types of

TABLE 1 | Empirically derived characteristics of the sibling relationship.

Characteristics	Components	Examples in action
Interactional context	Competition	Competing at same level
	Practice	Skill training
	Play	Sport-focused play at home
	Recreation	Involved in different sports
Emotional interpersonal skills	Closeness	Spending time together
	Comfort	First person they go to for help
	Empathy	Understanding if something goes wrong
	Support	Encourage each other
Rivalry	Competitiveness	Do as well as each other
	Motivation	Learning driven by each other
	Success	Frustrated if sibling won
	Performance	Want to do better than the other
	Affective response	Lose temper in defeat
Skill development	Mentoring	Help each other improve through guidance
	Co-operation	Bounce ideas off each other
	Observation	Watch sibling do a skill
	Challenge	Skill challenges against each other
Communication	Instruction	Tell sibling how to get better
	Discussion	What they are doing, what they need to do
	Feedback	Evaluate skills/progress
Conflict	Arguments	Disagreement about performance
	Frustration	Annoyed they do not agree
	Criticism	Tell sibling what they did not do well
Resilience	Ambition	Sibling at the level the other wants to be
	Development	Harder on each other to
	Test	help improvement
	Behavior	Dealing with failure/loss against sibling
		Learn to take criticism or let it affect them
	Mental process	Develop mental toughness
Identity	Shared	Embrace being compared as siblings
	Self	Develop individual niches in sport
Separation	General	Have different social groups
	Sport-specific	Avoid training together
	Self-initiated	Choosing not to talk about the match
	Distance	Going to different competitions

support and support providers utilized during the development of male cricket players across different levels of skill expertise. Data highlighted that 77% of siblings were important fellow participants in sport. Furthermore, siblings of elite when compared to community cricketers, were more likely to provide access to coaching and technical advice, while also identifying appropriate drills for skill development and supporting the setup of such environments (Warmenhoven et al., 2020). Therefore, based on these latter studies, utilizing, or even developing, characteristics that are positive for TD through the sibling relationship, might be considered as beneficial both within and away from the formal coaching environment (cf. Casey and Goodyear, 2015; Taylor et al., 2018).

To summarize, the literature focusing on siblings and TD is in its infancy, yet some clear considerations are emerging. Specifically, this relationship seems consistently complex and diverse. Research highlights that no individual relationship looks or works in the same manner, nor that this will remain constant across all ages. Furthermore, there is important evidence suggesting that the sibling relationship can support a range of skills to underpin TD. Evidence has predominantly addressed psychological and social influences a sibling can have on TD through formal and informal settings, although with much less attention has been directed toward biological or motoric development. For psychologists and coaches to best contextualize, rationalize, and utilize the relationships in practice, a stronger appreciation of how the psychological, social, and biological disciplines interact, is needed (Bailey et al., 2010).

RECOGNIZING THE HOLISTIC NATURE OF SIBLING RELATIONSHIPS: OPTIMAL INTERPRETATIONS THROUGH AN INTERDISCIPLINARY PERSPECTIVE

As identified, the relationship characteristics (see **Table 1**) are expressed as a result of interactions from different disciplines that underpin TD; namely, biological, psychological, and social. Indeed, Abbott et al. (2005) identify environments that do not acknowledge or encourage such a multifaceted developmental approach, as risking the quality of an appropriate environments to compliment the complex, dynamic, and non-linear reality of professional sport. Consequently, a deep and broad understanding of these interactions will afford more effective interventions across formal and informal TDEs; as opposed to only focusing on physical or social development in isolation. For example, in the context of a performance review, which is a process most coaches and psychologists will be familiar with, consideration of biopsychosocial interactions might demonstrate: *Reflective discussion between siblings about what happened, why, and how it could be improved (psychological), re-enacting the skill as it would be intended to in the future (biological), followed by reinforcement and support from the sibling to ensure that it takes place (social).* Accordingly, the review process is not simply a desk-based activity, but a process of thinking, doing, and sharing, which can then be continued post-session between coach/psychologist-athlete and athlete-sibling through monitoring procedures.

Such an example acknowledges how siblings can create contexts that support the biopsychosocial development of an athlete. Empirically, Taylor et al. (2017, 2018, 2021) identified relationship characteristics that exemplify how holistic development can take place. In addition to the work of Taylor and colleagues, Davis and Meyer (2008) suggested that the motivations some siblings gain from being compared can fuel an increase in both physical and mental training workload. Similarly, Weissensteiner et al. (2009) highlighted the relationships impact on the psychological skills of strategizing, coping, and mental toughness. Furthermore, Allbaugh et al. (2016) suggested positive social relationships between siblings are more likely to influence positive behaviors. Finally, Nelson and Strachan (2017) identified that the psychological impact of a competitive relationship can create an emotional response, developing a more meaningful social bond.

These studies have consistently recognized and explained interactions between disciplines, with arguably Taylor et al. providing the only purposeful biopsychosocial lens through which to frame these interactions. Notably, there is increasing recognition within TD of the important development of skills within these disciplines alongside, and underpinning, sport-specific technical and tactical development (Bailey et al., 2010). As such, for research and practice to continue to expand within TD, exploring the impact of significant others (e.g., siblings, psychologists, coaches) on the biopsychosocial athlete development athlete, is crucial.

TREADING CAREFULLY: THE COMPLEXITY OF THE SIBLING RELATIONSHIP

As Taylor et al. (2018, 2021) highlight, it is important to be cautious when considering the role of siblings in supporting TD. As such, there is increasing evidence showing the difference in the nature, and importance, of specific characteristics both within, and across, sibling dyads (Fraser-Thomas et al., 2008; Taylor et al., 2018; Warmenhoven et al., 2020). With such variety reinforcing the notion that this relationship requires careful consideration over time (Blazo et al., 2014; Allbaugh et al., 2016; Nelson and Strachan, 2017; Taylor et al., 2017). This view reflects Cruickshank and Collins's (2016) appeal for practitioners to take an "it depends" approach when intervening (e.g., sibling competition or collaboration) in the pursuit of a relevant biopsychosocial development outcome, within a specified context. Within the context of the sibling relationship during TD, it is important to affirm the meaning of such a phrase; with "it" being the impact a sibling can have on TD, and, "depends" representing the need to understand the differences in what characterizes a specific relationship and a consideration intervention timing (e.g., pre-season or mid-season).

For example, when considering the role and impact of rivalry within a sibling relationship, several studies have identified paradoxical considerations. Davis and Meyer (2008) suggested that sibling competition may only benefit some athletes' performances. Taylor et al. (2018) further demonstrated that levels of reported rivalry differed across sibling dyads (e.g., brother-sister dyad reported less rivalry than brother-brother dyad) and temporally within a sibling dyad (e.g., more during- than post-season). Furthermore, Davis and Meyer (2008) highlighted that older siblings might be motivated to maintain superior athletic status in the family, while younger siblings might be motivated to move out of the shadow of their sibling. Their findings also suggested a greater rivalry existed between siblings who were born closer together. In contrast, Blazo et al. (2014) and Côté (1999) both suggested such a closeness in age might result in bitterness, jealousy, or envy. More specifically, Côté highlighted that this took place during the investment years of development (16+ years; Côté, 1999). Crucially, such a relationship, and the emotional potency it can conjure, has the potential to result in dropout or burnout, as well as negatively impact on the wider family dynamic if not managed effectively (Fraser-Thomas et al., 2008).

Of course, there is a need to recognize that the influence, or even the very existance, of such abritary stages of development seems to be a psychosocial phenomenon. For example, Bridge and Toms (2013) found that the stages suggested by Côté were not as prevalent in a large sample of UK-based athletes, with specific socio-political influences (such as educational transitions) modifying the sampling, specializing, and investment stages within the Developmental Model of Sports Participation (DMSP: Côté, 1999). In short, coaches and psychologists must carefully consider the psychosocial milieu within which they are operating, especially when trying to import guidlines developed in other national setups.

In summary, the use and impact of rivalry between siblings on TD requires an "it depends" approach, primarily toward; birth order, gender, positive, and negative interpretations by each sibling, and the social milieu within which development has taken place. In short, siblings can matter, but exactly how is less straightforward.

SUPPORTING PRACTITIONERS: BUILDING A TOOLBOX TO NAVIGATE THE COMPLEXITY

Having highlighted the unique, broad, and complex contribution the sibling relationship can play in TD, it is important that practitioners are supported with tools that can help them to understand and utilize the relationship. As such, effective decision making by considering the TDE context and available options for action must be paramount. A good starting point for practitioners is to engage in critical reflection, asking; when should this be used (and when not)? with whom (and whom not)? where (and where not)? and crucially, why (and why not) (Cruickshank and Collins, 2016)? To illustrate, assuming that all siblings are competitive, and therefore should always play against each other, will not enhance development opportunities for all siblings in TD all of the time. For example, a large age-gap between same-sex siblings may lead to constant failure for one. Indeed, research demonstrates that excessive or ill-targeted sibling rivalry can be a major source of subsequent challenge to mental health (Tucker and Finkelhor, 2017).

Of course, there are genuine advantages to be gained, as can be seen from established research within more objectified environments, such as academic development. Described as "sibling spillover," Nicoletti and Rabe (2014) suggest that small but significant positive impacts on academic attainment can cascade from older to younger siblings. Importantly, however, these are seen as related to specific behaviors, including older siblings helping the younger with homework or acting as an effective role model for positive behaviors. The point here is clear. Positive benefits can accrue if appropriate behavioral relationships exist. Whilst the extent to which coaches or psychologists (or perhaps even parents) can influence this is unclear, one key message is that such benefits require active encouragement and facilitation rather than being left to emerge spontaneously (Collins and MacNamara, 2018).

Expanding upon this mechanistic approach (i.e., exactly how and on what may sibling influence be positive), is the role of older siblings as agents of socialization (Kramer and Conger, 2009; Kramer, 2010). In simple terms, whilst first born children tend to be parent-focused in learning about the appropriateness of behaviors, those who follow tend to acquire more from their older siblings. As one of several results, younger siblings may acquire better insights into peer interactions, simply because their role model (their older brother or sister) is closer to the environment (Kramer and Conger, 2009). This can be particularly useful when the older sibling is in the same, or a parallel, sporting environment, as shown perhaps by the positive sibling examples highlighted earlier.

In order to support practitioners in navigating the complexity of this relationship by adopting an expertise approach, several hypothetical evidence-based examples are provided of sibling relationships to acknowledge both supportive and disruptive relations (see **Table 2**). Finally, the following section unpacks such considerations from the perspective of a sport psychologist and a coach, by providing implications for how to identify the characteristics of an individual relationship and possible options for action.

SO HOW MIGHT YOU DO IT? CONSIDERATIONS FOR COACHES AND SPORT PSYCHOLOGISTS

As highlighted by Cruickshank and Collins (2016), in order to make optimal decisions about the potential role of siblings in their TDE, it is important that practitioners take time to consider, and reflect on, a number of factors through the lens of their specific context. Firstly, the age and stage of an athlete's development will impact on the type of action a coach may take. For example, when the athlete concerned is 12-years old and the relationship is characterized by high levels of play (Interactional Context) and co-operation (Skill Development), siblings may be encouraged to create and play games that develop broader movement skills. From a biopsychosocial perspective, this might help an athlete develop muscular endurance (biological), planning, and evaluation (psychological), and communication and collaboration (social) skills. In comparison, a 16-year old athlete may be encouraged to practice (Interactional Context) a specific movement skill within the sport they participate in and seek feedback (Communication) from their sibling. Thus, developing the athlete biologically (e.g., agility), psychologically (e.g., focus), and socially (e.g., understanding) all within the same decision.

Furthermore, practitioners may consider how they can utilize the sibling relationship at different levels of planning. Consider **Figure 1**, a nested plan focusing on TD. Grounded in the coaching literature that underpins the Professional Judgement and Decision Making (PJDM) of practitioners, nested planning encourages coaches to engage in thinking at multiple levels of practice (Martindale and Collins, 2012). With greater coherence, this serves to maximize the potential to fulfill their intention

TABLE 2 | Sibling relationship examples.

Type of relationship	Biopsychosocial characteristics	Components	Context	Opportunities to accentuate	Opportunities to counter
Harmonious	Interactional Context Emotional Interpersonal Skills Skill Development Communication Separation	*Practice* *Play* *Closeness* *Support* *Empathy* *Mentoring* *Co-operation* *Discussion* *Feedback* *Sport-specific*	**Same sport**	Encourage technical skill development through practice in informal environments, with support, mentoring, co-operation and feedback and/or discussion	Encourage points of separation (time/distance) as athletes develop to allow individualized interpretation of sporting experiences with coaches and/or peers
			Different sport	Older sibling can provide mentor support through a desire to watch their sibling compete, providing both support and feedback, that can be discussed later and worked on through play or practice	To develop skills such as realistic performance evaluation siblings may provide a good source of criticism at the right times, using their empathetic relationship to deliver this in a constructive manner
Non-Harmonious	Interactional Context Rivalry Skill Development Conflict Resilience Identity Separation	*Competition* *Motivation* *Success* *Challenge* *Arguments* *Frustration* *Criticism* *Test* *Self* *Self-initiated*	**Same sport**	Use the desire for sibling to create their own identity as an opportunity to grow self-regulatory skills on an individual basis. Potential to tap into level of rivalry to support and grow these skills	If rivalry becomes too intense it may lead to burnout or dropout. As such, trying to develop skills such as empathy through an external perspective (i.e., the coach or parent)
			Different sport	Encourage physical challenges to take place using motivation to win as a resource for developing key skills such as focus and coping with pressure	Encouraging siblings to spend more time together discussing how their specific skillset might benefit the other in their own sport

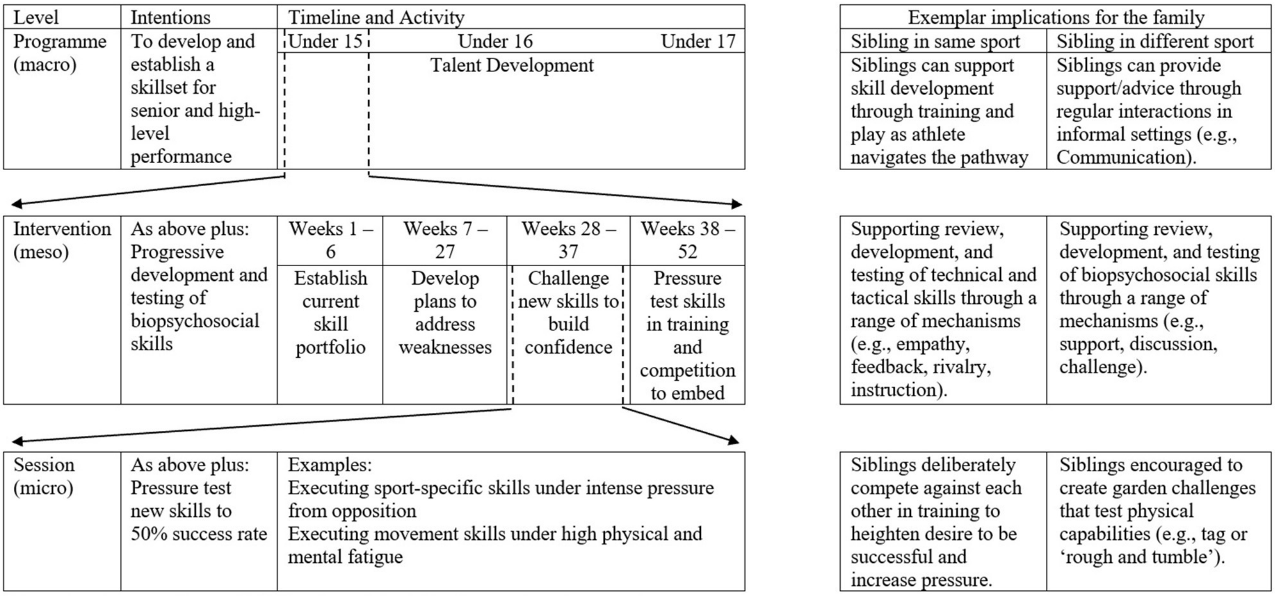

FIGURE 1 | An exemplar nested plan for a talent development environment.

for impact (Abraham and Collins, 2011; Martindale and Collins, 2012). Such an approach also facilitates the practitioner to frame the situation and conceptualize the issues involved (Martindale and Collins, 2012). Practitioners should consider where short-term goals (session) should be nested within medium (intervention) and then long-term (program) goals. In essence, a single intervention, should always have a purpose toward the longer-term objectives of the environment (Abraham et al., 2014). Indeed, such an approach fosters an improved understanding of important contextual demands, and therefore promote more efficient and accurate decisions for action that are aligned to the aims and objectives of any given phase of the TDE (Abraham and Collins, 2011). For example, consideration at a program level may see siblings utilized pre-season to increase motivation for the upcoming season. Following, they may be included at an intervention phase to support athletes interpret and respond to challenging experiences. Whilst at a session level, siblings playing the same sport may be used to create such challenge, by competing against each other. In short, a nested plan can provide a useful framework for planning and implementing effective strategies to engage sibling development (Abraham et al., 2014). Importantly though, as Collins L. et al. (2016) suggest, operationalizing decision making through biases based on generalizable competencies (e.g., all siblings are competitive), as opposed to more complex metacognitive skills (e.g., I have identified that sibling set A are highly competitive, but sibling set B are co-operative), will not allow us to optimally understand, explain, and support effective TD.

In summary, but also in keeping with good practice for all athletes, case conceptualization and subsequent PJDM (Martindale and Collins, 2005, 2007) are absolutely essential considerations when working with siblings. As such, this paper has highlighted many considerations which need to be addressed in developing an optimum plan for each individual. Of course, more research is needed to further understand such a complex relationship and its interaction with the talent environment. For example, a deeper exploration into individual mechanisms identified across the literature, and coaches' perceptions while coaching siblings or twins would represent a potentially beneficial next step. As our final point, and the essential take home from this paper, we refer to the website for educators, "we are teachers." In 2018, they offered five rules for effective teaching of siblings. Notably, whilst the first four were two pairs of complete contradictions, the final was "There are absolutely *zero* rules when it comes to teaching siblings. So just sit back and enjoy the ride" (WeAreTeachers, 2018). We hope coaches and psychologists will do so too!

AUTHOR CONTRIBUTIONS

RT applied findings from his PhD thesis to the manuscript, writing the first manuscript draft. DC applied his expertise in psychology across the manuscript with a focus on the application to talent development. HC developed the final manuscript draft and reviewed and edited the final manuscript. All authors contributed to the manuscript revision and approved the definitive manuscript.

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ORIGINAL RESEARCH
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An Examination of Training Load, Match Activities, and Health Problems in Norwegian Youth Elite Handball Players Over One Competitive Season

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Talent development is integral to the policy and organizational practice of competitive sport, but has also been associated with excessive amounts of training and competition, and athlete injuries and illnesses. The lack of available prospective data on the training and match activities of youth athletes and their health problems is therefore of concern. The aim of this study was two-fold: (a) to examine the amount and frequency of training load, match activities, injury and illness incidence, and prevalence among Norwegian youth elite handball players over the course of the 2018–2019 competitive season; and (b) to explore whether the injury rates are related to the sex or competition level of players, or their membership of the youth international team. We recruited 205 handball players (64% female, 36% male), aged 15–18 years (17.2 years ± 0.9) from five different sport school programs in southeast Norway. Data were collected daily from September 2018 to May 2019, during the competitive handball season. The variables included types of athlete activities, the number of activities, the rating of perceived exertion (RPE), and the duration of training and matches. Injury and illness data were collected weekly using the Oslo Sports Trauma Research Center (OSTRC) questionnaire. The mean number of matches per week per player was 0.9 ± 1.29; the number of weekly training events was 6.1 ± 4.4; and the mean weekly session RPE was 986 ± 1 412 arbitrary units. The players reported a total of 472 injuries, and the mean number of injuries per player was 2.3 ± 2.9. The results demonstrated a 53% weekly injury prevalence, of which 38% were categorized as substantial injuries. Male players and players who participated at the highest level of senior competition and/or the youth international team reported significantly lower weekly incidences of health problems, compared to other players. Our findings showed that players enrolled in sport school programs are exposed to high training and competition loads, and that both general and substantial health problems are common. The potential implications for talent development and future research are discussed.

Keywords: talent development, sport schools, youth sport, sports medicine, athlete development, injuries, illness, rating of perceived exertion of session (session RPE)

INTRODUCTION

Talent identification and development are integral to the policy and organizational practice of competitive sport (Johnston et al., 2018). Typically, they are pyramidal in structure: at each successive stage, the number of available places for athletes decreases, and the amount of available support increases (Till and Baker, 2020). This "pyramid model," associated with early and single sport specialization, can have negative consequences for athletes (Bailey and Collins, 2013). Medical practitioners have expressed concern that premature and excessive amounts of intense training and competition can, for instance, lead to higher injury rates, athlete burnout, or drop-out from sport at an early age (Bergeron et al., 2015). A few studies, however, have prospectively reported the training and match activities that characterize the pathways in systems of athlete development.

In Norway, researchers have begun to explore how athlete development systems and specialization pathways in sports such as handball affect the prevalence of injuries, and how overuse impacts youth athletes (Åsheim et al., 2018; Moseid et al., 2018). Athlete development in Norwegian handball emerges from an interplay between club-based practice and competition, sport academy secondary school programs, and the regional and national athlete development initiatives provided by the Norwegian Handball Federation. The model is loosely connected and decentralized, and is one in which emphasis is placed on providing practice opportunities for as many children and youth as possible. Regulations prohibit sport-specific specialization toward elite-oriented development before the age of 13, and financial sanctions can be imposed at the individual and club-level if the regulations are violated. The athlete development model is therefore structured in a way that facilitates later-age engagement without specialization (Bjørndal and Ronglan, 2020).

In Norwegian handball, challenges and opportunities arise in athlete development because players move regularly between practice and competitions in club, school, and federation-based settings (Bjørndal et al., 2015). When multiple actors—coaches and players, for example, are involved in both training and competitions at the same time, the complexity and intensity of practice activities increases (Bjørndal and Ronglan, 2018). As in other multi-centric models, this creates coordination challenges that need to be addressed in ways that ensure that athlete development is purposeful and negative impacts are minimized (Bjørndal and Ronglan, 2021). Research has shown that when the handball athlete development model is implemented successfully, complementary influences—such as being exposed to different coaches, players, competitive experiences, and training methodologies—can help to create diverse pathways to the elite level (Bjørndal et al., 2016).

Efforts to promote athlete and talent development in Norway have focused mostly on increasing opportunities for play and practice, often by adding more activities across the spectrum of activities offered by clubs, schools, and associations. These include, but are not limited to, the introduction of sport school programs at the lower secondary school level, as well as activities at the youth international team level, and age-based national club championship level (Bjørndal and Ronglan, 2020). Sport school programs can provide important opportunities for individually-focused and complementary training (Bjørndal and Ronglan, 2018; Bjørndal and Gjesdal, 2020). However, young athletes attending sport school programs may also experience many stressors, such as less sleep time, and significant increases in training volumes which may result in severe and long-lasting injuries (Kristiansen and Stensrud, 2016). Too much training and competition across clubs, schools, and federation settings can lead to injuries and burnout, and compromise the success of an athlete's transition to the adult elite level (Bjørndal et al., 2017; Kristiansen and Stensrud, 2020).

While the number of studies examining associations between training load and injuries in adult elite sport has increased in recent years (Griffin et al., 2020), no studies, to date, have simultaneously and prospectively reported on both injuries and training load, and match exposure among youth handball players, either in Norway or elsewhere. This is surprising given that training load and match exposure have been shown to be associated with overuse injuries (Soligard et al., 2016) and can impact adversely on athlete development in general (Myer et al., 2015). In the current research literature on training load quantification in handball, most studies have focused on load variables in match play or specific training drills (Buchheit et al., 2009; Michalsik and Aagaard, 2015; Luteberget and Spencer, 2017; Luteberget et al., 2018), and there is still little research on longitudinal training and competition load (Bresciani et al., 2010; Clemente et al., 2019). As such, the present findings present novel data on the training load of young handball players throughout a competitive season.

The aim of this study was therefore to explore the training load, number and frequency of match activities of athletes, and the incidence and prevalence of health problems (injury and illness) in Norwegian youth elite handball players over the course of a competitive season. Further, the study examines athlete health problems related to sex, competition level, and international team membership.

METHODS

Design

The study was designed as a prospective exploratory study of training load, match activities, and injuries in Norwegian youth elite handball players over a competitive season. Athletes from five different sport school programs in southeastern Norway were invited, from the counties of Oslo, Viken, and Innlandet. A total of 231 players were asked to participate: 228 accepted the invitation, and 205 players consented and responded to the survey at baseline. The participating athletes were between 15 and 18 years old (17.2 years $\pm$ 0.9), 64% were female and 36% male.

Ethical Statements

The study was approved by the Norwegian Centre for Research Data (reference number 407930) and the Ethics Review Board of the Norwegian School of Sport Sciences. The study followed ethical principles in accordance with the Declaration of Helsinki (Malik and Foster, 2016). All participants were provided both verbal and written information about the study, and informed consent was submitted electronically. Ethics approval did not require parental consent because all the players were above the age of 15 years. Participants were assured that their responses would be available only to the research team, that their responses would not be given to their coaches or respective sport schools, that their participation was voluntary, and that their consent could be withdrawn at any time.

Data Collection

The data were collected longitudinally over 237 days in Norway during the competitive handball season, from September 2018 to May 2019. Data were collected via the Briteback AB online survey platform (https://lynes.io/).

Data related to player characteristics, their sport backgrounds, and their past experiences with practice and competition were collected at baseline. Players reported daily how many training sessions and matches they had attended, and the duration of these sessions in minutes. Each athlete reported his or her Rating of Perceived Exertion (RPE) using a modified Borg CR-10 scale (Borg et al., 1987; Foster et al., 2001) with integers and verbal anchors. Session RPE (sRPE) was calculated by multiplying the RPE of the players by the duration (in minutes) of the matches/training sessions (Foster et al., 2001). In instances in which players reported multiple trainings and/or matches on the same day, the sRPE was calculated for each session separately.

During the study, each of the 205 participating players was asked to provide a report on his or her training activity, on each of the 237 study days. The maximum potential number of replies was therefore 205 × 237 = 48,585 replies, and 17,268 replies (36%) were received (see **Supplementary Table 1** for a discussion of the missing data). The replies (53%) were submitted on the same day when the players received the reminders (**Supplementary Table 1**).

The players also submitted daily reports on whether they had experienced an injury or illness since their previous response. Players were asked to record their health status by selecting one of three options: (1) no health problem, (2) new health problem, (3) worsening of an existing health problem. Players who selected either (2) or (3) were asked whether their health problem was an injury or an illness; if they reported an injury, players were asked to indicate whether it was an acute or overuse injury. Players were asked to report all health complaints, regardless of whether or not these impacted on their sport participation or whether they needed to seek medical attention.

Overuse injuries are difficult to capture via daily responses. For this reason, the OSTRC questionnaire was also used for the weekly self-reporting of health problems (Clarsen et al., 2013, 2014). The questionnaire was sent to every participant each Sunday morning, and a reminder was sent twice the following day if a response had not yet been received. A total of 1,479 OSTRC questionnaires were sent, and 97% were answered.

Statistical Analysis

To examine the general load level of the study population, the weekly mean, standard deviation (SD), median, and maximum values of the following load characteristics were calculated:

- Number of matches
- Number of training sessions
- Number of free days (days without matches or training)
- Sum of minutes in activity
- Sum of the sRPE.

To visualize the group sizes, the percentage of players participating at each level of competition was plotted in a bar graph. The category levels were Premier League, Division 1, Division 2, Division 3, Division 4 or lower, Under-18, Under-16, and None. Similarly, player development levels were also plotted (Youth International Team, Regional Team, Player Development, and None).

Days on which players were unable to train due to injury (determined by their responses to the weekly OSTRC questionnaire) were excluded from these analyses. Vacation weeks and other weeks in which players did not have training or matches were considered to be part of the total load exposure for the players and, therefore, included. When calculating the weekly sum of minutes and the sum of the sRPE of player activity, only weeks missing two or fewer days were included per player. If a player's response indicated that he or she had no training or match on a given day, the sRPE and minutes were set to 0 for that day.

Daily injury incidence was calculated as the number of health problem incidents divided by the number of replies submitted and reported as a percentage. More detailed insights were possible by stratifying the analysis by illness and injury (both acute and overuse).

The response rate to the weekly OSTRC questionnaire was high (97%): we therefore used these to calculate weekly injury incidence, in addition to our original aim of calculating weekly prevalence. Only responses to the first OSTRC question ("Have you had any difficulties participating in normal training and competition due to injury, illness, or other health problems during the past week?") that were *not* "Full participation without health problems" were considered to be indicative of a health problem and included in our calculation. For injury incidences, only players who did *not* respond that they had had an injury the week before were included in the numerator. When calculating injury prevalence, all injury replies were included. The denominator included all replies received. Weekly incidence and prevalence were stratified using the same subgroups as the daily incidence.

Substantial health problems were defined as injury or illness that reduced training volumes or performance to a moderate extent or worse, or to a complete absence from sport. This categorization was identical to the methodology used in Moseid et al.'s (2018) cohort study of the prevalence and severity of health problems in Norwegian youth elite athletes.

All numeric analyses were stratified by sex, player competition level (Level 1 = Premier League + Division 1; Level 2 = Division 2 + Division 3; Level 3 = Other Levels) and whether the player was a member of the Norwegian Youth International Team or not. The highest level of play included players who participated in multiple levels of competition play.

Temporal changes in training and competition load were visualized using the mean of the weekly sRPE sum plotted over time. Similarly, when comparing the injury rate with the measurement of exposure, the weekly match percent (the number of matches divided by the number of non-missing activity responses) was plotted against the weekly injury incidence (for comparability, daily data were used).

The data quality of the daily training load responses was deemed too poor to test for group differences. Group differences in injury frequency could, however, be tested using the responses to the weekly OSTRC questionnaire. To investigate whether the injury frequency was different between players who participated at different levels of competition play, traditional Chi-squared tests could not be used because it was not possible to assume that players could participate at one level of play only. In this instance, a Poisson regression was applied instead, and the response variable was the weekly health problem incidence. Two models were considered to assess if group differences were altered by injury definition: one using all health problems, the other using substantial health problems only.

Instead of choosing the highest participation level per player, as we did in the descriptive analyses, three logical variables were used. These were the number of players participating at: (a) Level 1, Premier League, or Division 1 (yes/no); (b) Level 2, Division 2, or Division 3 (yes/no); and (c) Level 3, Other Divisions and Levels (yes/no). By including all three variables in the model, we were able to adjust for instances in which players had participated at more than one level. Similarly, two variables were created for players who participated in: (a) an international team (yes/no), and/or (b) a regional team or no team (yes/no). In all the variable categories listed above, the "no" answers were included in the reference group.

The three levels of competition play (Level 1, Level 2, and Level 3) and the three team levels (International Team, Other Teams, or No Team) captured the same dimension, namely the level of play, and the risk of multicolinearity was therefore high. We thus modeled these two measures independently. When combined with the two injury definitions, this resulted in a total of four models.

The variable which described whether a player participated in a regional team or no team (yes/no) had a high multicolinearity with the variable describing participation in the international team. We therefore removed the regional or no team variable from the model and included only the variable for international team participation.

The following variables were included to adjust for potential confounding factors in the models: sex (male reference vs. female), age ($\leq$16 reference vs. 17 and vs. $\geq$18 years), and time (study week). Coefficient estimates were transformed to Incidence Rate Ratios (IRR). We presumed it to be unlikely that there would be a linear relationship between time and injury frequency, and modeled this using Restricted Cubic Splines with three knots (Durrleman and Simon, 1989). The levels of overdispersion were checked, and robust standard errors calculated. The alpha level was set to 0.05. R scripts and data are available for reproducibility.

All analyses were performed using the software R version 4.0.2 with RStudio. version 1.3.1056.

TABLE 1 | Player characteristics.

Characteristic	*N* (%)
Number of players	205
Sex	
Female	131 (64%)
Male	74 (36%)
Participate in additional sports	182 (88%)
Participate in multiple competition levels	153 (73%)
Participate in multiple teams	92 (44%)
	Mean (SD)
Age (years)	17.2 (0.9)
Age when starting handball (years)	7.0 (2.1)
Handball experience (years)	9.8 (2.6)
Number of other sports	2.0 (1.6)
Number of other levels	2.0 (1.0)
Number of other teams	1.7 (0.8)

RESULTS

The characteristics of the players are reported in **Table 1**. Most players participated at the Under-18 competition level (76%), and at the Player Development level without being a member of the international team or a regional team (72%), and most players participated at multiple levels concurrently (73%, **Figure 1**). Both the number of matches, the number of trainings per week, the number of minutes in activity, and sRPE levels were highly variable in all groups (**Table 2**). The weekly training load remained high throughout the season, with the exception of the end-of-year holiday period and declined rapidly toward the end of the study (coincident with the end of the competitive handball season).

The players reported 472 injuries, with a mean of 2.3 $\pm$ 2.9 injuries per player during the study period. Daily injury incidence was 3% of the 17,379 player days (**Supplementary Table 2**). The weekly incidence of health problems was 12%, and players reported fewer illnesses than injuries, with no apparent differences between levels of acute and overuse injuries (**Table 3**). The weekly injury prevalence was 53% (**Table 4**). Males reported a lower weekly prevalence of health problems compared to females, consistent across all types of health problems ($\approx$5–10% difference). The weekly injury percentage compared to the match percentage across the season is shown in **Figure 2**.

The results from the Poisson regression models are presented in **Table 5**. In contrast to the unadjusted results shown in **Table 3**, players participating at the Level 1 competition level, Premier League, or Division 1, reported significantly fewer health problems than players who did not participate at Level

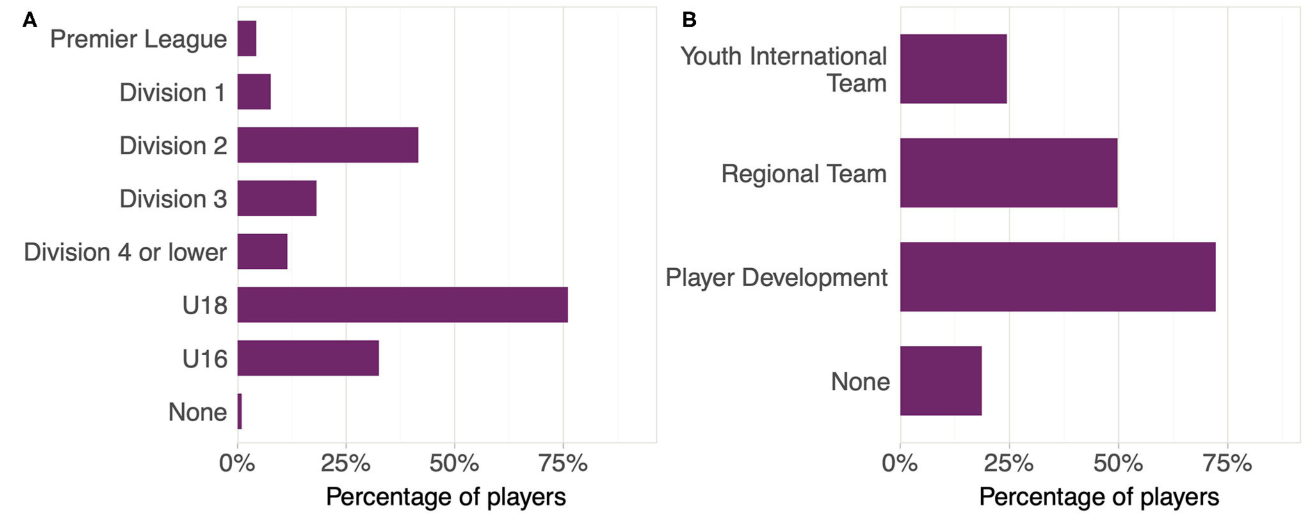

FIGURE 1 | The percentage of the 205 handball players participating in different levels of **(A)** competition and practice play, and (**B**) experience from association-level player development activities. Players participating in more than one level could be counted in multiple categories (a player, for example, could be a member of both the Youth International Team and a Regional Team at the same time).

TABLE 2 | Weekly mean and median load parameters for handball players based on 21,737 trainings and matches.

		Sex*		Team*		Competition Level*		
	Total (205)	**M (74)**	**F (131)**	**Int. Team (50)**	**Other (155)**	**Level 1 (32)**	**Level 2 (89)**	**Level 3 (84)**
Number of matches								
Mean (SD)	0.9 (1.3)	1.1 (1.4)	1.0 (1.2)	1.2 (1.5)	1.0 (1.3)	1.2 (1.5)	1.0 (1.3)	0.9 (1.1)
Median (Max)	1 (14)	1 (14)	1 (10)	1 (14)	1 (13)	1 (14)	1 (13)	1 (7)
Number of trainings								
Mean (SD)	6.1 (4.5)	6.3 (4.5)	6.0 (4.5)	6.4 (4.7)	6.0 (4.4)	6.9 (5.0)	6.0 (4.1)	5.8 (4.6)
Median (Max)	6.1 (36)	6 (36)	5 (34)	6 (36)	5 (34)	7 (36)	6 (23)	5 (34)
Number of free days								
Mean (SD)	0.75 (1.3)	0.6 (1.2)	0.8 (1.3)	0.5 (1.2)	0.8 (1.4)	0.7 (1.4)	0.8 (1.3)	0.7 (1.3)
Median (Max)	0 (7)	0 (7)	0 (7)	0 (7)	0 (7)	0 (7)	0 (7)	0 (7)
Minutes in activity								
Mean (SD)	468 (207)	485 (206)	460 (207)	497 (206)	462 (207)	527 (197)	485 (194)	455 (191)
Median (Max)	480 (1,125)	510 (1,066)	465 (1,125)	518 (1,125)	480 (1,066)	555 (1,125)	495 (1,066)	450 (1,006)
Sum sRPE (AU)								
Mean (SD)	2,568 (1,229)	2,781 (1,338)	2,470 (1,163)	2,714 (1,270)	2,537 (1,219)	2,688 (1,163)	2,574 (1,204)	2,507 (1,251)
Median (Max)	2,565 (8,460)	2,730 (8,460)	2,505 (7,215)	2,730 (7,815)	2,535 (8,460)	2,730 (7,815)	2,565 (6,743)	2,520 (8,460)

*Stratified by sex, team (International Team, Other = Regional Team, Other, or No Team), and competition level (Level 1 = Premier League + Division 1; Level 2 = Division 2 + Division 3; Level 3 = Other Levels), with number of participants reported in parentheses. *M, males; F, females; Int. Team, International Team.*

1 (IRR = 0.21, $p < 0.001$); these results were consistent for substantial health problems (IRR = 0.21, $p < 0.001$). Players who participated in the international team had significantly fewer health problems than players who did not participate in the international team (IRR = 0.15, $p < 0.001$), a finding also consistent for substantial injuries (IRR = 0.15, $p < 0.001$, **Table 5**). In addition, male players reported having significantly fewer health problems than female players (IRR = 0.47, $p < 0.001$) and this result was consistent for the reporting of substantial health problems among men and women (IRR = 0.34, $p < 0.001$). The covariates of sex, age, and time measured in weeks, demonstrated consistent results throughout all the models (**Table 5**).

DISCUSSION

The aim of this study was to examine the amount and frequency of training load, match activities, and injury and illness incidence, and prevalence among Norwegian youth elite handball players over the course of the competitive season in 2018–2019. The

TABLE 3 | Weekly incidence of health problems pertaining to the last 7 days for the whole study period.

	Total (205)	Sex*		Team*		Competition level*		
		M (74)	F (131)	Int. T (50)	Other (155)	Level 1 (32)	Level 2 (89)	Level 3 (84)
All								
Reponses**	1,447	446	1,001	263	1,184	219	684	544
Health Problems	176 (12%)	52 (12%)	124 (12%)	30 (11%)	146 (12%)	33 (15%)	82 (12%)	61 (11%)
Illnesses	49 (4%)	11 (2%)	38 (4%)	5 (2%)	44 (4%)	7 (3%)	25 (4%)	17 (3%)
Injuries	120 (8%)	38 (9%)	82 (8%)	25 (10%)	95 (8%)	26 (12%)	55 (8%)	39 (7%)
Acute	59 (4%)	21 (5%)	38 (4%)	14 (5%)	45 (4%)	18 (8%)	22 (3%)	19 (3%)
Overuse	61 (4%)	17 (4%)	44 (4%)	11 (4%)	40 (3%)	8 (4%)	33 (5%)	20 (4%)
Substantial								
Responses	1 446	446	1 000	263	1 183	219	684	543
Health Problems	119 (8%)	28 (6%)	91 (9%)	20 (8%)	99 (8%)	24 (11%)	52 (8%)	43 (8%)
Illnesses	38 (3%)	6 (1%)	32 (3%)	3 (0.2%)	35 (2%)	6 (0.4%)	18 (1%)	14 (1%)
Injuries	79 (5%)	21 (5%)	58 (6%)	17 (6%)	62 (5%)	18 (8%)	33 (5%)	28 (5%)
Acute	39 (3%)	11 (2%)	28 (3%)	11 (4%)	28 (2%)	13 (6%)	15 (2%)	11 (2%)
Overuse	40 (3%)	10 (2%)	30 (3%)	6 (2%)	34 (3%)	5 (0.3%)	18 (1%)	17 (1%)

*Stratified by sex, team (International team, Other = Regional Team, Other, or No Team), and competition level (Level 1 = Premier League + Division 1; Level 2 = Division 2 + Division 3; Level 3 = Other Levels). *M, males; F, females; Int. T, International Team. **Seven responses indicated a health problem, but the type was missing.*

TABLE 4 | Average weekly prevalence of health problems during the competitive season of all health problems and substantial problems, as well as subcategories of illness and injuries stratified by sex, team (International team, Other = Regional Team, Other or No Team), and competition level (Level 1 = premier league + Division 1; Level 2 = Division 2 + Division 3; Level 3 = Other levels).

	Total (205)	Sex		Team		Competition level		
		M (74)	F (131)	Int. T (50)	Other (155)	Level 1 (32)	Level 2 (89)	Level 3 (84)
Reponses	1,447	446	1,001	263	1,184	219	684	544
All Health Problems	760 (53%)	191 (43%)	569 (57%)	153 (58%)	607 (51%)	106 (48%)	351 (51%)	303 (56%)
Illnesses	134 (9%)	26 (6%)	108 (11%)	39 (15%)	95 (8%)	21 (10%)	65 (10%)	48 (9%)
Injuries	604 (42%)	155 (35%)	449 (45%)	110 (42%)	494 (42%)	78 (36%)	282 (41%)	244 (45%)
Acute	271 (19%)	60 (14%)	211 (21%)	58 (22%)	213 (18%)	60 (27%)	112 (16%)	99 (18%)
Overuse	333 (23%)	95 (21%)	238 (24%)	52 (20%)	281 (24%)	18 (8%)	170 (25%)	145 (27%)
Responses	1446	446	1000	263	1183	219	684	543
All Substantial Health Problems	546 (38%)	139 (31%)	407 (41%)	114 (43%)	432 (37%)	79 (36%)	268 (39%)	199 (37%)
Illnesses	102 (7%)	20 (5%)	82 (8%)	21 (8%)	81 (7%)	15 (7%)	50 (7%)	37 (7%)
Injuries	428 (29%)	115 (26%)	313 (31%)	87 (33%)	341 (29%)	58 (27%)	213 (31%)	157 (29%)
Acute	171 (12%)	31 (7%)	140 (14%)	42 (16%)	129 (11%)	42 (19%)	73 (11%)	56 (10%)
Overuse	257 (18%)	84 (19%)	173 (17%)	45 (17%)	212 (18%)	16 (7%)	140 (21%)	101 (19%)

M, males; F, females; Int. T, International Team.

study analyzed whether the rate of player injuries was related to the sex of the athletes, their competition level, or membership of the youth international team.

Our findings show that the study population experienced highly variable amounts of training and match activities across the competitive season, and that the incidence and prevalence of injuries and illnesses were high. The combination of higher exposure and the prevalence of injuries and illnesses could possibly compromise athlete development. Large inter-individual variations were also noted: training loads were highly variable between individuals, and female athletes experienced significantly more injuries compared to their male counterparts.

The sports histories of our study population were similar to those previously reported in studies of Norwegian players who have been active in youth international teams. Our study further indicates that athlete development pathways in Norwegian handball are characterized by diversification: a large number of the participants were involved in other sports in addition to handball. Furthermore, our results demonstrated that most of the players in our study (73%) participated at multiple competition levels and teams (44%). Similarly, Åsheim et al. (2018), noted that 72% of players aged 17–18 years participated in more than one handball team.

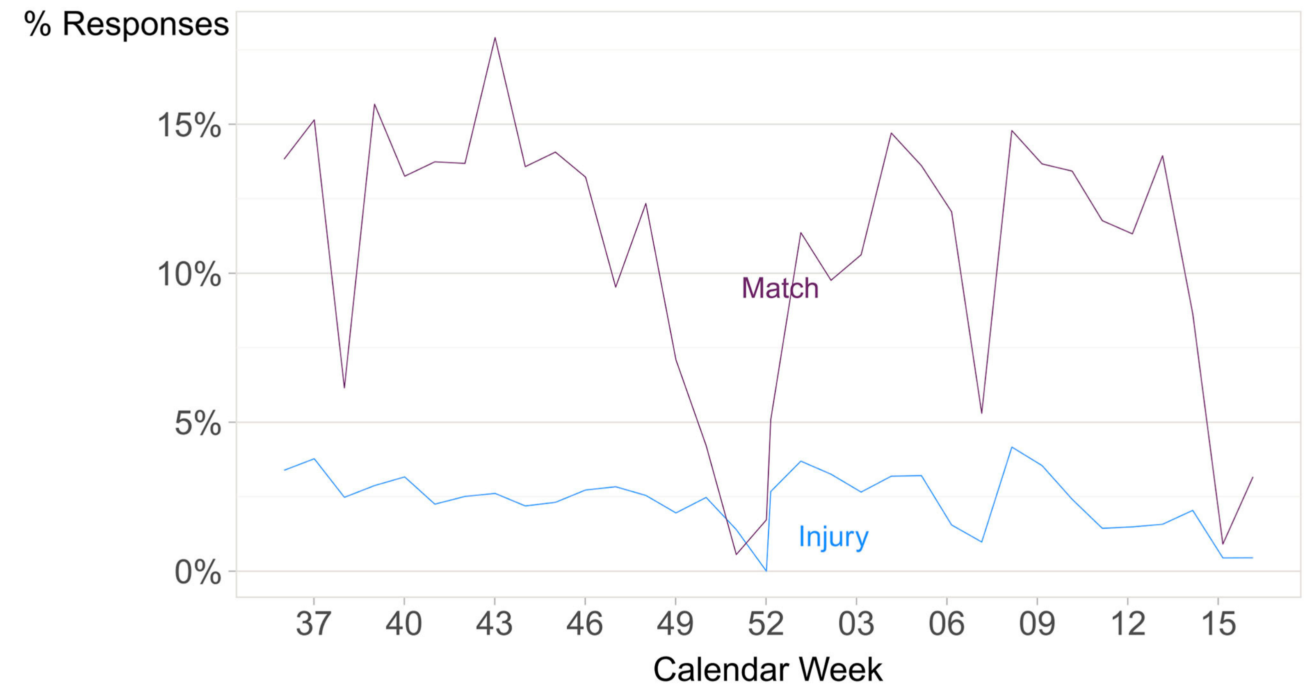

FIGURE 2 | The weekly injury percentage compared to the match percentage across the season from week 37 in 2018 to week 17 in 2019. Based on 17 293 responses about player activity, and 17 379 responses about player injury from 205 handball players.

Other studies of youth athletes have reported higher volumes of training than those noted in ours: 9.3 (3.5) h per week of cross-country skiing (Landgraff and Hallén, 2020), for example, and 11.5 (4.2) weekly training hours in handball (Kristiansen and Stensrud, 2020). However, differences between the types of sports and in the methodologies used to analyze them (retrospective rather than prospective) could potentially explain such variations and highlight the potential importance of examining each sport separately and in consistent, comparative ways. In Spain, the number of training sessions per week during the competitive season in handball has previously been reported as between 4.0 and 5.3 for male handball players (Bresciani et al., 2010). One reason for the higher reported number of sessions in our study may have been due to the participants being enrolled in sport school programs. In contrast, the participants in the study by Bresciani et al. (2010) were above school age (20.1 [2.5] years) and therefore probably only training in club and/or association settings.

Previous reports of sRPE in handball have reported sRPE values of 338–693 AU in training sessions in professional male handball players (Clemente et al., 2019), while female handball players have reported sRPE values of 443–630 AU in matches (Kniubaite et al., 2019). To our knowledge, only one previous study has reported weekly sRPE values in handball (Bresciani et al., 2010), ranging from 1,911 (200) to 2,712 (292) during the competitive season. Similar average values to ours were noted in the study, ranging from 1,500–3,000 AU (**Figure 3**). In basketball, differences in weekly sRPE load between playing levels have also been reported, with higher loadings reported among professional players compared to semi-professionals (Ferioli et al., 2018). In contrast, our data from Norway indicated that the sRPE loads were similar both at the team level (international vs. other) and the competition level—a reflection, possibly, of the unique and more democratic talent development pathways in the Norwegian sporting system which offers a broader base of players multiple opportunities and pathways within and outside the formal talent development pipeline (Bjørndal et al., 2015).

However, sport school participation cannot be disregarded as a key factor affecting the weekly load of youth handball players. As Bjørndal and Gjesdal (2020) have observed, sport school programs can help to bridge gaps in the training load between adult elite level players and/or youth international team players and others. In their study of the developmental paths of Norwegian female handball players, Bjørndal et al. (2016) found that the differences in the number of weekly training hours reported by athletes could be explained by whether the athletes were enrolled in a sport school program or not.

The *range* of training load noted in this current study is also of importance because such variability highlights the potential need for the individualization of processes to monitor training loads and training planning (Kiely, 2018). The maximum training load values (see **Table 2**) indicated that some of the players were exposed to very high weekly training loads, and a very high numbers of training sessions and matches. Training loads seemed to vary by setting: players reported higher sRPE scores when practicing in club settings compared to school or federation settings (see **Supplementary Table 3**), due possibly to the competitiveness of these club settings and the uniqueness

TABLE 5 | Incidence Rate Ratio (IRR), 95% Confidence Intervals, Robust Standard Error and *P*-value from four Poisson regression models to ascertain the association between different levels of play (Level 1 = Premier League + Division 1; Level 2 = Division 2 + Division 3; Level 3 = Other Levels) and weekly health problem frequency, and participating in the international team and weekly health problem frequency.

Model	Parameter*	IRR	CI (lower to upper)	Robust SE	*P*-value
All Health Problems, Level	Intercept	2.63	0.9–7.5	1.41	0.071
	Level 1	0.21	0.1–0.3	0.05	<0.001
	Level 2	1.30	0.9–1.9	0.25	0.161
	Level 3	1.64	0.7–3.6	0.67	0.223
	Sex, Male	0.47	0.3–0.7	0.05	<0.001
	Sex, Female (Ref)	-	-	-	-
	Age ≥ 18	0.54	0.4–0.8	0.11	0.003
	Age 17	0.95	0.6–1.5	0.20	0.828
	Age ≤ 16 (Ref)	-	-	-	-
	Time (Week)	0.79	0.7–0.9	0.06	0.002
	Time (Week')	1.14	0.9–1.4	0.12	0.204
Substantial Health Problems, Level	Intercept	3.19	1.0–10.2	1.89	0.050
	Level 1	0.21	0.1–0.4	0.06	<0.001
	Level 2	1.28	0.8–2.0	0.28	0.267
	Level 3	1.04	0.4–2.4	0.45	0.926
	Sex, Male	0.34	0.2–0.6	0.08	<0.001
	Sex, Female (Ref)	-	-	-	-
	Age, ≥ 18	0.54	0.2–0.5	0.13	0.013
	Age, 17	0.80	0.5–1.3	0.20	0.380
	Age, ≤ 16 (Ref)	-	-	-	-
	Time (Week)	0.79	0.7–0.9	0.07	0.005
	Time (Week')	1.16	0.9–1.5	0.14	0.199
All Health Problems, Team	Intercept	9.78	6.3–15.0	2.12	<0.001
	Int. Team	0.15	0.1–0.2	0.03	<0.001
	Sex, Male	0.43	0.3–0.6	0.08	<0.001
	Sex, Female (Ref)	-	-	-	-
	Age ≥ 18	0.53	0.4–0.8	0.10	0.001
	Age 17	0.92	0.6–1.3	0.16	0.658
	Age ≤ 16 (Ref)	-	-	-	-
	Time (Week)	0.79	0.7–0.9	0.05	<0.001
	Time (Week')	1.15	0.9–1.4	0.11	0.156
Substantial Health Problems, Team	Intercept	7.54	4.8–11.8	1.72	<0.001
	Int. Team	0.15	0.1–0.2	0.04	<0.001
	Sex, Male	0.31	0.2–0.5	0.07	<0.001
	Sex, Female (Ref)	-	-	-	-
	Age ≥ 18	0.57	0.4–0.8	0.11	0.004
	Age 17	0.78	0.5–1.2	0.16	0.235
	Age ≤ 16 (Ref)	-	-	-	-
	Time (Week)	0.79	0.7–0.9	0.05	<0.001
	Time (Week')	1.17	1.0–1.4	0.12	0.130

*Time was modeled by Restricted Cubic Splines, and the IRR is therefore uninterpretable. Based on 176 health problems and 119 substantial health problems. *Reference groups are as follows: Level 1 No Participation, Level 2 No Participation, Level 3 No Participation, Sex Female, Age ≤ 16 years, International Team No Participation.*

of the sport school system in Norway, in which players do not compete for one particular school team (Bjørndal and Gjesdal, 2020). It could also be speculated that participation in multiple arenas could increase the risk of high training loads: as more coaches are involved, the demand for communication and coordination of training schedules will necessarily increase, potentially leaving only the individual players themselves with complete oversight over their total training load (Bjørndal and Ronglan, 2018). Further investigation is therefore needed into how training and competition load levels may vary depending on combinations of involvement in club, school and federation practice, and competition settings.

Our findings also indicated a high prevalence of injury and illness in the study population. These findings were similar to

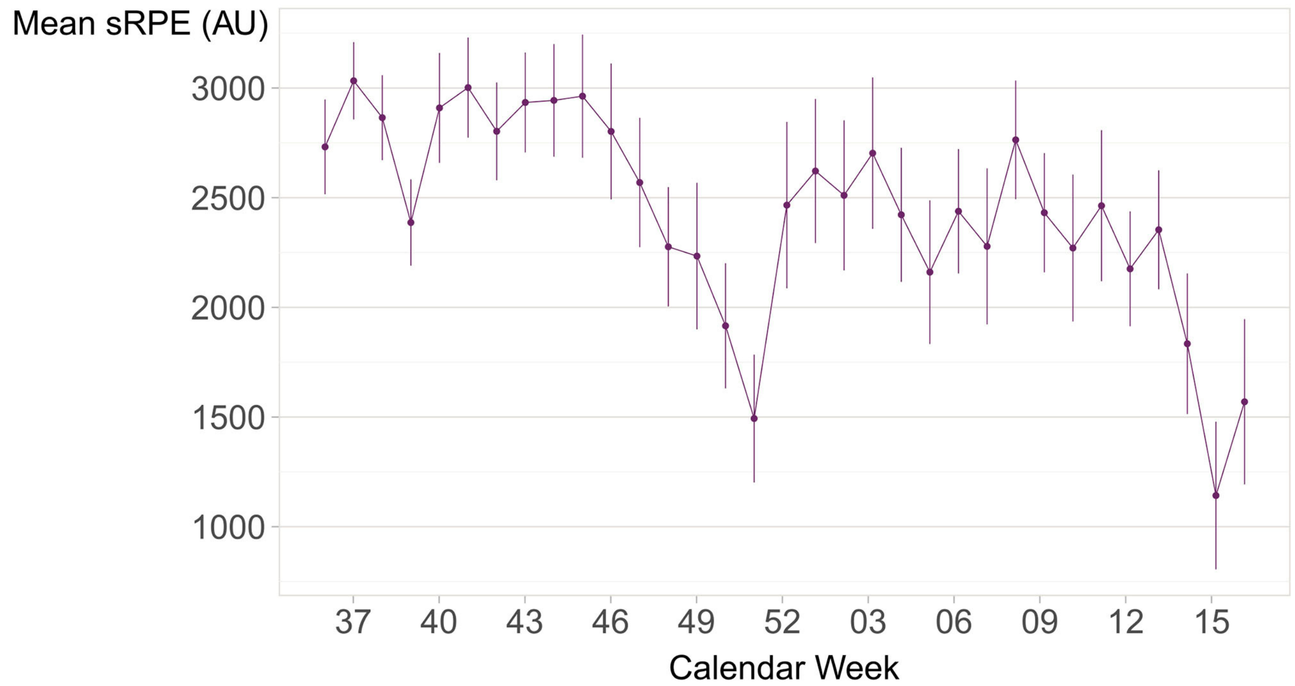

FIGURE 3 | The mean of the sum session rating of perceived exertion (sRPE) value per player per week, with 95% confidence intervals, showing the change in the sRPE values across the season from week 37 in 2018 to week 17 in 2019. A total of 14,704 activity responses from 176 handball players were included.

those reported in previous studies of Norwegian youth athletes: in specialized sport academy high schools, for example, the weekly prevalence of health problems was found to be 43% at any given time, and even higher among team sport athletes (Moseid et al., 2018, 2019a,b). Data from Swedish sport academy high schools (Von Rosen et al., 2018) and female youth elite athletes in team sport and gymnastics (Richardson et al., 2017) indicated similarly high levels of injury.

Female players were found to have significantly more injuries and substantial health problems. Sickness levels among female players, too, were higher compared to male players (11 vs. 6%). Previous research on youth elite athletes across different sports also reported that girls were at a higher risk of injury (Myklebust et al., 1997; Moseid et al., 2018). However, these variations may be due to differences in the way male and female players interpret symptoms, and may not necessarily indicate more serious underlying problems specific to female athletes in handball. It would be appropriate, therefore, to investigate how sport development programs should be structured to protect female athletes during their developmental years.

Surprisingly, the players who participated at the highest level of senior competition and/or the youth international team reported significantly fewer health problems (weekly incidence), compared to the others (IRR $= 0.21$, $p < 0.001$). One potential explanation for this may be that high-performing players represent the "survivors" of the athlete development system: being healthy is a prerequisite for transitioning successfully to the elite level (Bjørndal et al., 2017). Another plausible explanation may be that the best players are more valued and taken better care of by clubs and coaches (Bjørndal and Ronglan, 2018). Clubs may, for example, be incentivized to provide injury prevention programs at the highest level that are robust and well-implemented to protect players during the regular team practices.

Our study design did not allow us to test for causal relationships between the incidence of injuries and training, and competition loads. Instead, we aimed to establish an association between participation at particular levels of handball competition and health problems. We did not adjust for any measure of load levels (training load, match frequency, etc.). This would have been more appropriate if we had attempted to explain *why* players at certain levels of play had, or did not have, a higher frequency of health problems. Further, identifying a causal relationship would have been difficult due to apparent gaps in the load-related data we collected. However, when represented graphically, the incidence of match and health problems appeared to follow similar patterns: decreases/increases in the number of matches co-varied with decreases/increases in injuries, and appear to indicate that match exposure may be closely associated with incidences of injury. This suggests that an understanding of the association between training load and levels of injury is important to ensure that future talent development programs are developed and applied in sustainable ways. However, there is little consensus yet on how data on the frequency and volume of training and competition and injuries should be collected and analyzed (Bourdon et al., 2017; Bahr et al., 2020; West et al.,

2020) and future research should focus on developing a deeper understanding of this apparent relationship.

Strength and Weaknesses

Our study has methodological limitations. First, the amount of missing data may have led to selection bias in the data related to training load and daily incidence measures. Second, as the 2018–2019 handball season progressed, gaps in data reporting were observed. We used daily reporting in our longitudinal research to improve the quality of the data. However, the participants may have suffered from response fatigue and this could have potentially impacted on the quality of the data. However, the response rates to the weekly reporting of injury and illness were high and this suggests that the data are robust.

Despite these apparent limitations, the study also has several strengths. Our research is the first to provide a focused exploration of training and competition characteristics, in combination with an incidence and prevalence recording of health problems in youth handball players enrolled in school-based athlete development programs. Second, the prospective design of the study, which included a daily measurement of training load, provided a valuable starting point for quantifying and presenting a more detailed and nuanced picture of the daily activities of youth athletes, and how athletes develop over time. Third, the study provides insights into sub-group differences (related to sex, competition-level and youth national team membership).

Practical Implications and Future Directions

The results of the current study indicate that handball players are subject to substantial training and competition loads and that levels of injury and health problems are high. This suggests that current training loads may not promote talent development or athlete well-being in sustainable ways. Our findings indicate that the key stakeholders involved must provide better ways of organizing the everyday activities of athletes, and of sustaining the quantity and quality of the training and competition needed. This may require a shift from the normative benchmarks used for young athletes at different ages and stages of sport development. The current monitoring of player activities and training loads may also be inadequate to the needs of athletes, given that athlete development is individually specific and can be non-linear.

More research is needed to provide insights into talent development programs, how to optimize training and competition loads, and reduce the injuries and illnesses associated with the training of elite youth athletes. It is likely that moving beyond singular perspectives, such as those rooted in physiology only, may aid in this process (Denison and Mills, 2014, p. 14). Examples include athlete-centered approaches to development and performance preparation in team sports (Woods et al., 2020). Intervention-based and more practitioner-driven research methods such as action research may be especially useful ways to combine inter-disciplinary, contextual, and practical perspectives.

CONCLUSION

Our findings show that players enrolled in sport school programs are exposed to high training and competition loads, and that both general and substantial health problems are common. In our opinion, these forms of talent development are unsustainable. Efforts to strengthen athlete development should be based on a detailed knowledge of the impacts of training and competition loads and the injury risks within specific contexts. Our study represents a new step in the process of knowledge development.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Norwegian Centre for Research Data Ethical Review Board of the Norwegian School of Sport Sciences. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

CB and LL conceived and designed the analysis, collected the data, contributed to data analysis, and wrote the paper. LB-M performed the analysis and wrote the paper. SG conceived and designed the analysis, contributed to data analysis, and wrote the paper. CM and GM contributed to data analysis and wrote the paper. All authors contributed to the article and approved the submitted version.

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The Poor "Wealth" of Brazilian Football: How Poverty May Shape Skill and Expertise of Players

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Worldwide, 1.3 billion people live in *Poverty*, a socio-economic status that has been identified as a key determinant of a lack of sports participation. Still, numerous athletes around the world have grown up in underprivileged socio-economic conditions. This is the case in Brazil, a country with around 13.5 million impoverished citizens, yet, over decades, many of its best professional footballers have emerged from its favelas. In this article, we explore the role of the socio-cultural-economic constraints in shaping the development of skill and expertise of Brazilian professional football players. The methodological and epistemological assumptions of the "*Contextualized Skill Acquisition Research*" (CSAR) approach are used as an underpinning framework for organizing and analyzing data. Results suggested that, at the exosystemic level of Brazilian society, *Poverty* emerges as an influential constraint that can potentially enrich football development experiences of Brazilian players. *Poverty*, however, is not the *direct* causation of outstanding football skill development. Rather, from the perspective of ecological dynamics, *Poverty* creates specific contexts that can lead to the emergence of physical as well as socio-cultural environment constraints (e.g., *Pelada*, *Malandragem*) that can shape affordances (opportunities) for skill acquisition. These ideas suggest the need to ensure that environmental constraints can support people to amuse themselves cheaply, gain access to employment opportunities and maintain health and well-being through (unstructured and more structured) sport and physical activities in dense urban environments such as favelas, inner city areas, and banlieues. For this purpose, design of open play areas and even parkour installations can provide affordances landscapes for physical activity and sports participation in urban settings.

Keywords: ecological dynamics, skill acquisition, football, poverty, affordances landscapes

INTRODUCTION

Brazil is a country perhaps best known for its Amazon rainforest, Carnival, but in particular, football (see Lever, 1995; Goldblatt, 2006). As Freire (2011) pointed out, Brazilians and football have enjoyed a perfect marriage with successful outcomes such as winning five World Cups and several other triumphs; and for producing many exceptional footballers (see Bellos, 2002; Ankersen, 2013).

Unfortunately, Brazil is also known for its challenging social issues such as corruption, inequality, and *Poverty*. Such socio-economic issues have been endemic in Brazil, with data showing that in 1960, the rich, who represented 5% of the population, received 27.7% of national income, rising to 35.8% in 1990. In contrast, the poorest representing 20% of the population received 3.5% of income in 1960, a declining to 2.3% in 1990 (see Eakin, 1998). Today, the number of Brazilians living in extreme poverty is estimated at 13.5 million (IBGE, 2019). Hence, such underprivileged socio-economic conditions (continue to) touch the lives of millions of Brazilian children, including those who later go on to perform at professional level in football.

According to the United Nations (2020a), "Poverty entails more than the lack of income and productive resources to ensure sustainable livelihoods." Specifically, it is multi-faceted in that "Its manifestations include hunger and malnutrition, limited access to education and other basic services, social discrimination and exclusion, as well as the lack of participation in decision-making." Thus, *Poverty* is more than solely economic in nature. However, little has been addressed in relation to questions pertinent to the relationship between development of skills and expertise and *Poverty*. This is particularly evident when addressing related questions through the theory of ecological dynamics, which explains the emergence of skills and expertise in sport through the interaction of task, individual, and environmental constraints (Button et al., 2020). At the socio-economic level, *Poverty* may be an influential environmental constraint.

Thus far, broader questions of *Poverty* and sports participation opportunities have largely been approached sociologically, utilizing concepts of social class in Western contexts. This research, whilst understood through multiple theoretical lenses (for a review see Newman and Falcous, 2013), has focussed upon social power relations and inequality. In western nations, relationships have been found between social status and sports participation, identifying higher social class status as offering more opportunities, access and particular attitudes toward physical activity and sport.

In this regard, organized sport is widely understood as a cultural site that is marked by stratified opportunities and widely varying access. The concept of socio-economic status (SES) has privileged understanding of such issues in economic terms. The term "social class," however, has also been conceptualized in broader terms. For instance, writers have emphasized economic capital (financial assets, wealth) but also identify cultural (qualifications, acquired knowledge, cultural codes, ways of speaking), social (relationships, networks of relationships), and symbolic (honor, status) forms of capital as significant in determining and reproducing social positions and hence in sharpening sports participation. Numerous writers have drawn on the work of French sociologist Bourdieu (1978, 1984) for whom sporting practices are entangled in a continual striving for capital and as sites that reinforce social class boundaries and identities. Thus, he understood sport as a site of "distinction"—with social class significant in shaping opportunities, access, and attitudes toward physical activity and sport. Bourdieu's concept of habitus, which captures those aspects of class-based culture that are anchored in the body or daily practices of individuals, groups, societies, and nations has been influential. More specifically, habitus captures a set of acquired/socially learned habits, bodily skills, styles, sensibilities, dispositions and tastes that can be understood as taken for granted for a specific social class grouping. In Bourdieu's analysis class-based habitus is the result of strivings for class "distinction," not simply individual preferences. Social class groupings then form themselves by cultivating distinguishing features and signs of "distinction."

For Bourdieu habitus consists of both the hexis (the tendency to hold and use one's body in a certain way, such as posture and accent) and mindsets, expressed in judgments, appreciation/tastes, and feelings, for example. The concept of bodily hexis may provide a useful conceptual scheme to understand the linkage between the bio-physical body and the socially constituted body. That is, hexis is about more than individual "habits" expressed at the bodily level, instead capturing how the individual body is also collectively and socially shaped. From an ecological dynamics perspective, the concept of hexis can be seen as the symmetric interactive dimension between organismic (body) and environmental (physical and socio-cultural) constraints. In this sense, the sociological notion of hexis can open up questions in skill acquisition terms, especially in relation to linkages between socio-economic-cultural constraints and skill development that may be predisposed by particular social contexts and dispositions. *Poverty* is one such social context.

One reason why the relationship between development of skill and expertise in sport and *Poverty* has not been widely addressed, may be explained in paradigmatic terms. Traditionally, skill acquisition research has often been undertaken from a positivistic, hypothetic-deductive, laboratory-based approach (Uehara et al., 2016). This state of affairs has been called a "significant limitation," leading to criticisms that skill acquisition theory may be too task-driven, rather than seeking explanations that are based on a broader range of constraints (Newell, 1989). In other words, theoretical understanding needs to be predicated on a wider range of variables related to unique personal constraints of learners interacting with task- and environmental-related factors in the skill acquisition process (e.g., kinematic analysis of hip, knee, and ankle of the kicking leg when chipping a football ball; see Araújo and Davids, 2011; Button et al., 2020 for a review). Such inquiry relies on research tools that are effective when investigating tangible variables that can be measured in a quantitative manner. However, for the study of socio-cultural constraints which are clearly complex, numerous and irreducible, other methods of inquiry are required.

In this sense, Larsen et al. (2013) highlighted the importance of considering the overall environment (i.e., holistic ecological approach) when investigating talent development in sport. They argued that the holistic ecological approach provides methodological tools capable of analyzing not only individual constraints but also environmental constraints such as organizations' settings and strategies.

To shed light on this issue of investigating a broader range of constraints, the Contextualized Skill Acquisition Research

(CSAR) framework has been proposed for collecting, analyzing, and discussing data of socio-cultural nature; and in turn for bridging the gap between sociology and sport science (Uehara et al., 2016). Briefly, the CSAR framework is underpinned by the philosophical assumption of the interpretive paradigm, the theoretical principles of Bronfenbrenner's bioecological model of human development, Willis's (2000) ethnographic strategy of inquiry, and the correspondence theory of truth (Dunwoody and College, 2009). It should be noted that, the theory of the ecological dynamics forms the overarching foundation for the implementation of this framework (see Methodology section for further details; see also Uehara et al., 2016 for a review). Ecological dynamics provides movement scientists with a powerful platform to help explain human movement behavior through principles such as self-organization under constraint and perception-action coupling (Button et al., 2020).

Derived from the CSAR, a series of studies has been conducted by Uehara et al. (2018, 2019, 2020) which highlight the relevance of considering complex, interacting socio-cultural constraints upon the formation of football expertise of Brazilian players. Brazilian football is the chosen research vehicle due to its historical tradition of developing high standard football players who seem to emerge from informal, unconventional, and even aversive environmental constraints.

To this end, the present research complements Uehara and colleagues' attempts to answer the following central question: What are the unique socio-cultural environment constraints that influence the development of a distinctive and high caliber of perceptual-motor skills in Brazilian football players? To answer this question, this paper specifically addresses the intersection of skill acquisition in Brazilian football and *Poverty*. In other words, this study aims to investigate the influence of *Poverty* as one of the socio-cultural constraints affecting the development of skill and expertise of Brazilian football players.

METHODOLOGY

This paper builds on a multi-methodological approach underlined by the interpretive paradigm. Through the process proposed by the CSAR framework, Bronfenbrenner's bioecological model was used to organize our data, which were generated via an ethnographic strategy comprising three data collection techniques: contextual analysis, participant observation, and unstructured interviews. Guided by the qualitative analytical steps proposed by Creswell (2009), saturated data were codified and analyzed. The credibility of our findings and analyses have been based on the tenets of the correspondence theory of truth in which the truth is based on a thick description of the variables analyzed through a thorough process of contextualization and reflexivity (Dowling, 2008). Subsequently the discussion and interpretation of the findings are related to key concepts from the ecological dynamics theoretical perspective. Overall, this study was conducted with scientific rigor as well as with interpretive originality supported by the notion of bricolage of the qualitative methods of inquiry. As such, whilst this paper has been structured in the traditional way with abstract, introduction, methods, results and discussion sections, readers are invited to immerse themselves in a dialogical and dialectical process of reading throughout the entire paper so that the key points of articulations that intersect *Poverty* and skill-acquisition can be insightfully interpreted. All procedures were conducted according to the ethical guidelines of the University of Otago Ethics Committee (ref: 10/158) and all participants provided written consent before taking part in the study.

Contextualized Skill Acquisition Research (CSAR): An Ecological Dynamics Conceptualization

As highlighted previously, the central pillar of the CSAR is underlined by the concepts of the ecological dynamics approach which describes the emergence of expertise in developing athletes as a function of interacting task, individual and environmental constraints (Button et al., 2020). When analyzing intangible variables such as socio-cultural, environmental constraints on sport expertise, Bronfenbrenner's bioecological model of human development (Bronfenbrenner, 2005) offers the scaffolding to help identify and understand emerging data themes. In this sense, the bioecological model is useful in considering human development as a function of the interaction between nature and nurture (Krebs, 2009), that is, between individual and environmental constraints.

Based on a nested scheme, the environmental contexts of the bioecological model are composed of four different, but interconnected, systems including the microsystem, the mesosystem, the exosystem, and the macrosystem (Araújo et al., 2010; Uehara et al., 2016). In relation to each environmental context, only microsystems are physically located (e.g., *Pelada*, i.e., pickup games). The others are "events or forces" that influence the person and the particular microsystem under analysis. The mesosystem encompass other microsystems frequented by the person (e.g., family support, and training system). The exosystem comprises the microsystems that indirectly influence the person and the microsystem under analysis (e.g., a nation economic situation). The macrosystem embraces the overarching patterns of the micro, meso, and exosystems contexts of a given culture (e.g., *Samba, Capoeira, Ginga,* and *Malandragem*). Further than the person and the context, the bioecological model comprises time and process. Process expresses the characteristics of person-context interactions over time. Additionally, person and context change over time (Araújo et al., 2010).

Relevant to our research aim is the exosystem, which refers to one or more settings or contexts that do not involve the developing person as an active participant, but which influence a person's behavior and development. In other words, a child in development is not responsible for the financial situation of his family as neither he/she directly participate in the type of job his/her parents have. However, this financial situation indirectly influences process with the immediate settings for that individual. As an example in football, a lower income family may not be able to provide access to appropriate facilities nor provide adequate shoes for their child. As a consequence, the child has to learn their skill in bare feet in unconventional facilities such as the ones provided in *Pelada* (i.e., pickup games).

However, the bioecological nested system does not operate with clear-cut boundary definitions to classify variables in context (Bronfenbrenner, 2005). It depends on how the context is situated and theorized. In the case of *Poverty*, for example, it could have been classified differently. However, as per this paper, it is categorized under the exosystem context when most likely a family is only poor due to the unequal and corrupted socio-economic system of the country in question, for example, Brazil (see further information in the Results section).

Nonetheless, these interconnected systems inform how the relationship between the person and context are organized under what Bronfenbrenner called "proximal processes," which change over time (19). The mechanisms underlying the proximal processes "encompass particular forms of interaction between organism [person] and environment…, that operate over time and are posited as the primary mechanism producing human development" (Bronfenbrenner and Morris, 2006, p. 795). However, it is important to emphasize here that, while Bronfenbrenner's bioecological model offers an effective "socio-cultural" framework for the analysis of human development, it does not provide analytical tools required to investigate and interpret processes of skill acquisition (Araújo et al., 2010). For that, related studies rely on the tenets of the ecological dynamics framework to explain socio-cultural constraints on skill acquisition, as explained earlier.

Ethnographic Strategy of the Inquiry

The ethnographic approach adopted in this study was based on the notion of "*the ethnographic imagination*," proposed by Willis (2000), who advocated that "… [the] ethnographic imagination is relevant to the production of all kinds of intellectual work. Non-field-based writing and intellectual work [e.g., contextual analysis] can certainly inform the crafts and methods of ethnography" (p. 113). The essence of this inquiry involves practical criticism, rather than mere description; the analysis of lived everyday culture from different sources; and the unique perspective of the researcher.

Three ethnographic methods were employed in this study: contextual analysis (conducted prior to and after fieldwork in Brazil); participant-observation, and unstructured interviews (both during fieldwork in Brazil). These methods are interrelated and complementary in a non-linear, non-sequential research analytical process based on the notion of *reflexivity* described by Dowling (2008).

Contextual Analysis

The contextual analysis in this paper involves explication of the socio-cultural-economic context in which football in Brazil has been historically constructed (Patton, 2002; Silverman, 2006). In doing so, a number of socio-cultural and political-economic sites of articulation within Brazilian football were elucidated. In particular, these sites of articulation involve the ethos of the white as well as the black and mulatto people in the early years of football in Brazil. Predominantly informed by written texts from sources such as newspapers, articles, books, films, and the internet regarding the history of Brazilian football as well as the broader history of the country, the historical, economic, political, socio-cultural contexts in which acquisition of Brazilian football expertise occurs was significant for this investigation. To facilitate data collection of texts, the first author used a notebook to write notes about the key ideas in the text and the credibility of the data source. His reflections about the document were also recorded.

Participant Observation

To investigate the topic and generate rich and apt evidence, the first author was prepared to collect data from whatever and whomever provided an opportunity (Patton, 2002; Silverman, 2006), be that from professional or non-professional people related to football, structured or non-structured football settings.

The chosen locations for data collection were based on the parameters of contemporary commentaries regarding the history of Brazilian football, which shows that many successful players emerged from underprivileged suburbs around Brazil (Bellos, 2002). The field research started in Jundiaí—the hometown of the first author—province of São Paulo in two moments in time: first in 2010–2011 and once more in 2017. This location was chosen because of the privileged access that first author had to the place and people from his childhood connections and through his contacts as a former player in this region. Subsequently, four contrasting environments were purposefully identified for the participation and/or observation of football activities. The identified settings were Paulista Football Club, São Paulo Football Club, a football *Pelada* (i.e., pickup game) instigated by a former professional player, and a favela called Vila Ana (see **Table 1** for further details).

Overall, through observation and informal conversations the first author took notes on the behavior and activities of participants. He focused on the experiences and events that happened during the football training and the meaning of the experiences according to the participant's point of view. The first author also participated in the training in all possible ways, for example, setting up the equipment, carrying water for the players, participating as a player if necessary. He recorded descriptive notes in a field log divided into sections such as physical setting, aim of the training, training activities, instructions from the coach, portraits of the participants, reconstruction of dialogues, accounts of particular events, and informal chats. Demographic information about the date, time, and place were also noted.

Open-Ended Unstructured Interview

Thirteen Brazilian adults with differing football-related backgrounds (i.e., developing players, ex-professional players, coaches, educators, football administrators, and writers) voluntarily participated in this study. Regarding the developing and ex-professional players, whilst not purposefully sampled *per se*, they all grew up under humble economic living conditions. Some were extremely poor. Due to ethical reasons, especially in relation to the principles of protection and confidentiality, the identity of the participants has not been revealed. Participants are referred to by their initials.

TABLE 1 | Fieldwork settings for the participant-observation method of inquiry.

Settings	Level	Numbers of subjects	Age range	Achievement
Paulista FC	Professional	40	17–32	Titles: Copa do Brasil, 2005
São Paulo FC	Youth	25	U18	One of the most successful football clubs in Brazil at professional and youth levels. Their youth training center is amongst the top 10 in the world. See https://goo.gl/maps/PJgVDVJQD3qU5fkDA
Pelada	Friends	20	15–55	With few exceptions, the majority of the subjects in this setting were former professional football players
Favela Vila Ana	Children	20	7–15	Children of all levels of skills and gender joined together to play the typical Brazilian football Pelada

In this sense, rather than be limited by interviewing only one specific group (e.g., professional players), many different actor, specifically related to football (e.g., professional and amateur players, coaches, agents, and writers) were interviewed so that the exploration of the topic could be enhanced (see Patton, 2002). According to the literature, a well-performed unstructured open-ended interview enables such an exploration (Denzin and Lincoln, 2005). As such, the first author asked unstructured and open-ended questions, eliciting the views, and opinions of participants. Because of the open-ended nature of this research, the amount of data collection required to make this study coherent was based on the parameters of "*point of saturation*" or the point where new information no longer emerges (Lincoln and Guba, 1985). This is vital because, if the amount of data is insufficient, then important information may be missed, providing an incomplete exploration of the topic. On the other hand, if data were oversaturated, then redundant information would be displayed (Patton, 2002).

Analytical Procedures

The contextual analysis of this paper aimed to find key points of articulation that link Brazilian football experiences and its socio-economic-cultural formation. Through a point of saturation process (Lincoln and Guba, 1985), it was found that one of the key sites of articulation entangles the ethos of the white as well as the black and mulatto people in the early years of football in Brazil. This broad historical contextual sensitivity was the starting point of the investigation and analyses of other data generated by the two other adopted methods.

In a non-linear fashion, the analysis of the interview and fieldwork methods were guided by the qualitative analytical steps proposed by Creswell (2009). Interviews were transcribed and field notes were typed. Both sources of material were then translated from Portuguese to English. Although the first author was mainly responsible for the translation, a Brazilian academic teacher also helped with the translation. The first author then read all of the transcripts in order to have a general sense of the information and to reflect upon its overall meaning. Next, the process of coding began by organizing the raw material into chunks of text and then separating paragraphs and sentences into categories (e.g., family, training, dance, street-smart, class, economy, "race") before bringing meaning to the information.

These categories were further explored with additional analysis identifying emergent themes such as *Pelada, Poverty, Ginga,* and *Malandragem*. These themes were then classified according to the nested systems of the bioecological model (noted above), which encompasses four levels: microsystem, mesosystem, exosystem, and macrosystem. In other words, further analysis revealed the emergence of many different interacting constraints (i.e., themes) such as *Pelada* (Uehara et al., 2018) at the micro-level, *Ginga* and *Malandragem* at the macro-level, and *Poverty* at the exosystemic level of the bioecological model. To finalize the analytical process proposed by Creswell (2009), these themes were then described, interpreted, interconnected, and discussed.

It is important to note here that, due to the complexity of each constraint (theme) involved in the analysis, we were only able to primarily analyse *Poverty* in this paper and briefly discussed it in relation to other variables such as *Pelada*, *Ginga*, and *Malandragem*. There are other interrelated findings at the macro-level, which have been presented in other publications (e.g., see Uehara et al., 2020). As such, we would like to emphasize here that *Poverty* is not the only explanatory factor, but rather one among several, interlinked socio-cultural-economic constraints that influence expertise development in Brazilian footballers (see Uehara et al., 2016, 2018, 2019).

Evaluation in the Form of the Correspondence Theory of Truth

The credibility of the research study can be enhanced by a thorough contextualization of a phenomenon, in this case expertise and skill in Brazilian football. Subsequently, agreements about how sources of data corresponded to the development of expertise of Brazilian football players were informed by theory and rely on how coherently and consistently we can interpret the findings (see Dunwoody and College, 2009). However, none of the interpretations were assumed to be value-free or un-influenced by the writer and reader's assumptions and background. Moreover, considering the local people's perspective of the phenomenon in question also enhance the credibility (a plural link to reality) of the research. Such a negotiation is what Saukko (2005) calls dialogic validity.

Furthermore, this research has ensured credibility by drawing from the notion of reflexivity. According to Dowling (2008), reflexivity can be described as "…qualitative researchers' engagement of continuous examination and explanation of how they have influenced a research project" (p. 747). With reflexivity in mind, throughout the development of this project we continuously questioned the methodological decisions undertaken so that, if necessary, we could adjust the research focus without detriment to purpose. Under this parameter, the proposed multi-methodological *contextualized skill acquisition research approach* emerged.

Summary: Researcher Bricolage

Essentially, in order to achieve the aim of this research, the first author acted as a *bricoleur*. In qualitative research terms, a bricoleur draws from multi-disciplinary perspectives, distinct theoretical and philosophical orientations, and various methods of inquiry (e.g., contextual analysis, participant observation, interviews) in order to interpret social phenomenon generated by complex variables, such as those evidenced in socio-cultural studies (Sparkes, 1992).

In effect, this form of analysis requires a multi-qualitative approach that presents suitable methodological and theoretical insights to investigate linkages between socio-cultural environmental forces and cultural and corporeal practices of Brazilian footballers (Uehara et al., 2016). Further, interpretive analyses have to be historically contextualized so that meaningful interpretations of the acquisition of expertise in football in Brazil can be made. To make sense of participants' understanding of how football players in Brazil develop relevant perceptual-motor skills, the first author inductively explored their perceived experiences, views and subsequently attempted to develop a coherent pattern of meanings from their insights.

To summarize, therefore, the multi-methodological approach underlined by the contextualized skill acquisition research framework required a bricolage that intertwined epistemological and methodological concepts from the Bronfenbrenner's bioecological model of human development, ethnography, the correspondence theory of truth (Uehara et al., 2016), and the ecological dynamics perspective.

RESULTS

Describing and Contextualizing Poverty as a Socio-Economic Constraint in Brazilian Football

While football has been a symbol of Brazilian success and a source of pride for the people, the same cannot be said about the socio-economic situation of the country, of which a large gap separates the rich from the poor. According to Suneson and Stebbins (2019), Brazil seats in 5th place in a list of the top fifteen countries with the widest gaps between the rich and the poor, and within that, it ranks among the most corrupt countries in the list. One of the major problems caused by such an inegalitarian society is the lack of opportunity for those living in *Poverty*.

Arguably, access to an adequate and effective education system is the best opportunity that a government can provide to its children. In fact, this is one of the UN's 17 sustainable development goals (United Nations, 2020b). However, Brazil's educational system has historically grossly underserved the poor—to the extent that half of the Brazilian population could not read when Brazil hosted the FIFA World Cup in 1950 (the national literacy rate was 44% in 1940, and 49% in 1950; Souza, 1999). Since then, the rate of illiteracy decreased, but today it is still very high with 11.3 million people at the age of fifteen and above who are classed as illiterate (Oglobo, 2019). This shows that the socio-educational system in Brazil has yet to succeed as many children still do not attend school regularly. In fact, education has never been a priority in their lives and this may be explained by McLoyd (1998) who reported that persistent *Poverty* has detrimental effects on socio-emotional functioning, and school achievement.

Public schools in Brazil struggle with the lack of government support and hence poorly qualified teachers, and substandard facilities, equipment, and security. They are only slightly better because of the voluntary help of community and non-governmental organizations. In contrast, the quality of private schools is far superior. However, with a cost that is almost the monthly salary of a working class person, attendance in private schools is only accessible for the middle and upper classes (Redação, 2020). Consequently, these upper-class students are the ones who tend to go to the best universities in the country and subsequently get the best jobs. And so, the *Poverty* cycle continues with the working poor struggling throughout their entire lives without realistic opportunities for improvement.

With this in mind, football in Brazil emerged out of irreconcilable differences between the rich and the poor. The early clubs were founded within the elite social groups of Rio de Janeiro and São Paulo and played under the English imported ethos of "amateur spirit" where values of chivalry and fair play were paramount to their existence (Guterman, 2009). Hence, football games were almost outdoor parties played for the pleasure of camaraderie, a spectacle of colonial class, status, and racial whiteness. As such, football participation was restricted to people of a similar social and racial background (see Franco, 2007; Priore and Melo, 2009). In this sense, the elite were more than just proclaiming moral values as if it was part of their status, but they could also distinguish themselves from what they saw as the customs of the uneducated immigrants and former slaves (Guterman, 2009).

Despite the initial resistance of the elite strata of society in Brazil, football was soon diffused amongst the masses (Guterman, 2009). However, while the higher social class players had financial power to play under the best facilities such as on grass fields and with specialized coaching, the lower socio-economic classes had to play with bare feet on streets full of stones and mud, and were forced to make their own football materials like goal posts made of bamboo sticks, balls made of socks, and their own rules (Filho, 2003). More than 100 years later, many Brazilian children are still playing under similar penury conditions.

In the fieldwork at favela Vila Ana[1], the first author had the opportunity to observe and play football/futsal with local youth

[1]The favela Vila Ana no longer exists as the area has been urbanized since conducting our fieldwork in this location (see Samora and Jimenez, 2019). For a brief overview of the ex-favela Vila Ana, see YouTube:

and teenager players. The venue was a deteriorated futsal court partially built up with money from the "lords" (a term used by the children to refer to the drug dealers). The indigent characteristics described above were present at all levels, including for instance, playing with bare feet, mixed age and gender, using an old, tattered ball, and players self-organizing into teams. However, a characteristic enthusiasm to play, the happiness and celebration of scoring goals, the determination to win, the teasing, and the arguments between players were also evident. In essence, they were playing under the typical spirit of *Pelada* (i.e., pickup games; see Uehara et al., 2018) or in the word of Freire (2011), street football, as further delineated below.

There, the first author informally asked some of the children about their professional football aspirations and frequently their answer was about playing football for the love of the game, but also to improve their socio-economic status. Understandably, by seeing those Brazilian football superstars who made it to the top these children want similar lives too. As two children explained:

> Child A: I would like to be a professional football player to make enough money so I don't need to get involved in this kind of life style of using or selling drugs. My whole family played football, including my father. I love it.
> Child B: I love football. I would like to be like Ronaldinho. He is my hero!

Under this context, it could therefore be argued that football in Brazil offers opportunities that underprivileged children do not usually have through other means. It is an opportunity for economic independence and social recognition as exemplified by many of the Brazilian football icons such as Pelé, amongst others. They become the heroes of a nation "who represent the triumph of men from a poor background over the wealthy and powerful" (Miller and Crolley, 2007, p. 20). They are the heroes who represent nationally and internationally the history, the values, and the identity of Brazil.

On a parallel but relevant note, the opportunity for economic independence for underprivileged children through football is not only the privilege of Brazilians. Numerous football heroes from other nations have also emerged from *Poverty*, such as the case of Diego Maradona from Argentina. Without getting into the traps of futile comparisons between Maradona and Pelé, *Poverty* was a significant part of their childhoods. Certainly, they both played a lot of street football, and they both achieved incredibly high standards of perceptual-motor skills (see Nascimento, 2006; Maradona, 2007). However, whilst Pelé managed his career off-field as good as on-field, the same cannot be said about Maradona. According to Enkvist (2010), the key point of difference in this respect is, arguably, related to values learned through education. In one hand, there is Pelé, an individual who completed a tertiary degree in physical education and surrounded himself with responsible people. On the other hand, there is Maradona, a person who barely finished the first year of secondary school and many of his support clan were not necessarily people with the best interests (Enkvist, 2010). For instance, when Maradona was transferred to Barcelona in 1982, he brought with him from Argentina a whole group of people, made up of family and friends, who lived with him. They were his personal assistants. Commentators alike use words like "parasites" or "pirates" to qualify them. In order to continue living off the footballer, they flattered him. So much so that Maradona lived immersed in what has come to be called "*sidieguismo*," meaning: "Yes, Diego" (Enkvist, 2010).

From a skill acquisition point of view, it can be said that Maradona, Pelé, and of course, many other former and current players, were highly influenced by what Freire (2011) refers to as the pedagogy of "street football." According to Freire (2011), street football offers opportunities to learn and enhance skills in an informal and natural way, emphasizing many important pedagogical principles (e.g., co-teaching, collaborative-learning, modeling, fun and enjoyment, freedom, creativity, improvisation, skill adaptation, challenges; for an overview see Renshaw et al., 2019) that positively shape their experiences. In a similar line of focus, Machado et al. (2019) also highlighted the importance of street football to players' skills development. However, from a socio-educational point of view, as explained by Freire (2011), street football can also be cruel and susceptible to undesirable and detrimental experience and influences, such as lack of inclusiveness, empathy and compassion (e.g., the best players are selected first and the less or non-skillful ones are only chosen to complete the teams). Very often, these non-skillful players are stigmatized and humiliated, and a popular name for them in Brazil is *Perna de Pau* (i.e., wooden leg). In addition, without formal rules or officials to enforce them, street football does not necessarily encompass principles of moral and educational values (Freire, 2011).

To this end, these accounts lead us back to the notion that *Poverty* can *directly* affect in a negative way other socio-cultural constraints such as education. Yet, *indirectly*, it potentially positively influences individual constraints at perceptual-motor skills and expertise levels.

Poverty as an Exosystem That Can Enrich Football Expertise

An exosystem is an environmental influence which affects a developing person but they are not directly responsible for it. A typical example of an exosystem is the family economic situation in which a child relies on the parents for their upbringing. The economic status of a family may impact the child in either negative or positive ways (see Bronfenbrenner, 1979; Krebs, 2009).

In the case of Brazil, *Poverty* has negatively impacted developing children in a multitude of ways. Besides the schooling issues, as explained above, many children have to get into the informal and very often underpaid working force at an early age to help with the household expenses. Unfortunately, many of these children are easily seduced by the life of crime and illegal drugs. An example is RD an interviewee who explained how he went through this pathway:

https://www.youtube.com/watch?v=Y5h03ZQloSw. The futsal court, however, remained (see the Google maps link: https://goo.gl/maps/AuiX8N3EdQ6fSG6r9).

> Yes, I was poor living in a shanty town and drugs were 'in my face' all the time. I tried to avoid it but due to the frustration of living in such conditions plus the pressure from peers, illegal drugs such as crack became part of my life. But there is always a way to overcome it and move towards a healthy lifestyle regardless of socio-economic status. I found my way. I got a degree in physical education and now I coach underprivileged kids from shanty towns in an attempt to guide them for better choices in life. As a physical educator, I am amazed by the level of skills of some of these kids. Everything seems to be natural for them. They never had a formal type of coaching but when they play football, their talent flourishes in the field (Interview, January 13, 2011).

However, not many citizens possess the will power demonstrated by RD to overcome such aversive living conditions. Now he serves as a role model in his community for those underprivileged children to follow suit and at the same time, he can identify and support those with the potential to pursue a football career. As RD pointed out, football skills seem to be common among many of the children from his shantytown. In this regards, JPM—a former Brazilian football national team fitness coach who also dedicates part of his time to voluntarily work with underprivileged children—highlighted this issue as follows:

> I think the poorer the child the richer he/she will be in terms of body coordination movement. I don't want to close this information or generalise it, but from my experience as a physical educator and as a coach, I have observed it. In contrast, children from families with financial stability tend to be less physically coordinated, especially in the last fifteen or so years due to the advance of technology, computers, television, and electronic games. They play fewer of those kinds of games the poor children play in a natural learning environment. They tend to spend more time at home. In contrast, children of lower socio-economic status tend to be less educated compared to the middle/rich class children. They tend to focus less on education and like being outside playing. For that reason they are better physically coordinated children. As such, for those poor children who play football they tend to be more skillful players too, comparatively speaking (Interview, February 10, 2011).

As this quotation suggests poor children may be more skillful because they focus more on playing football compared with rich children who tend to have other duties and hobbies. However, other influences have to be taken into consideration when investigating Brazilian football skills as a product of *Poverty*. For instance, it is often the case that children from *Poverty* stricken favelas do not have enough food on a daily basis. Many have parents who are unemployed and possibly are themselves drug users. Thus, inspired by their football heroes, as explained above, many of these children are motivated and determined to get out of these miserable conditions through football.

These ambitions are not new. Since football turned professional in the 1930s and became a national sport, these lower social economic status players have seen football as an achievable way of escaping *Poverty*. As Didi, a Brazilian football superstar in the 50s, argued, "the boy who has an easy life doesn't have a chance in football because he doesn't know the value of a plate of food" (Pelé, 2008, p. 47). This assertion is reinforced in the words of VL:

> "When I went to SPFC at the age of fifteen I was feeling like I was walking on a cloud. However, I must say that it was difficult to be on my own. I missed my family and friends a lot. On the other hand, I knew that it was the opportunity of my life. My mom was deeply sad when I left but I tried to cheer her up by promising this: "Soon I will be able to buy you a house". Years later when I got the money from my first contract, the first thing I did was to keep my promise to her. Subsequently, along the years I bought a house for each of my brothers and sisters. But you see, I had determination and motivation to overcome any obstacles because I knew how hard the dark side of life is when you don't have enough food on your plate. It is quite rare to see middle class players achieving what I have achieved in football. For instance, my son was quite a good footballer, so he was accepted to be part of the SPFC youth academy. Like in my youth days, he had to live in the dormitory of the club which wasn't as near as flash as it is now. Today the training centre in Cotia where the youth players stay is a world class place. But do you think he managed to stay there? No, he couldn't stay there for more than two months. He had to come back to the comfort of his home, even though he knew that by doing so the dream of following the footsteps of his dad was over" (Interview, February 16, 2011).

This quote helps to explain why many football players in Brazil come from lower socio-economic status (see Dana, 2013). Players like VL's son have more options to successfully do well in life than merely by the means of football. As a result, they do not have the motivation and determination for what it takes to become football professionals. In this sense, this quote highlights how resilience is a key psychological virtue, which may be promoted through under-privileged living conditions.

In further discussing this issue of *Poverty* with OA, he offered a controversial point of view that is worth highlighting. In his view:

> Now, the better players are those from financially poor families. They are much more skillful and bold too in football. But I ask myself why? This is because they don't have rules at home. They go to other people's house and don't have manners. They act as they were at their own houses. They are not educated to be politically correct. So, as football players, when they go to play away, they do the same, that is, they play as they are playing at home. In my view, they are much more mentally stronger. The thing is, the poor children have so many other difficulties in life that when they play football they don't choke, they play like they are playing football for fun, regardless of the pressure. I say this based on my experience that I have acquired along my career as a player as well as a coach (Interview, February 9, 2011).

As it can be seen, OA was quite radical in his thoughts about the reasons for poor children being resilient. He associated the idea that *Poverty* is synonymous with bad manners and, in turn, with being mentally stronger. Regarding the former (i.e., the relationship between idiosyncratic mannerism and poverty), it is beyond the scope of this article to elaborate further. However, regarding the relationship between *Poverty* and mental strength, further discussion is warranted as it may add important value.

For instance, Emerson, also popularly known in Brazil by the nickname Sheik, was born and raised in a slum in Rio de Janeiro. As a (former) professional footballer, he reached his "glory" by winning, as a decisive player, three consecutive Brazilian Championship titles followed by three different teams: Flamengo, Fluminense, and Corinthians, respectively. For the latter, at a press conference after the final match of Libertadores Championship 2012 against Boca Juniors FC, he explained how life in the favela helped him not to feel the pressure of decisive games. He said:

> "I was born and raised in a very simple place, and I saw things that maybe many of you [journalists] will never see. Previously, I was asked if there was pressure to play at the Bombonera stadium in Argentina [first leg game]. Dude, pressure is lying in bed being afraid that stray bullets may hit your face, your chest, yes this is pressure. Playing in a packed stadium with new balls, perfect grass, etc, there is no room to feel pressure, it is all about enjoyment" (Laurentiis, 2012).

Here Emerson explains the relativity of pressure on a football field compared to the violent environments he had faced. Indeed, Emerson did not choke in any of these decisive games. At the Libertadores Championship, he was one of the key players in the first leg game played in Argentina, including setting up the goal Corinthians scored to secure a 1–1 draw. Further, in the second leg game in Brazil, he scored the two goals that made Corinthians the champions of South America. Later in the same year (2012), Corinthians defeated Chelsea 1–0 to win their second FIFA Club World Cup.

The first author's fieldwork at favela Vila Ana can also provide relevant insights on this issue. For instance, he noticed a much younger and smaller boy facing up to the bigger one in an argument. This shows that children learn quickly to stand up for themselves to be able to survive in this kind of environment. From a sociological point of view, this issue may be explained by the notion that *Poverty* intersects with gender, and gender with sports. In this sense, masculinity equates with being strong and fearless which seemingly gives it greater credence and which in turn elevates masculinity to a hierarchical status in football (see MacLean, 1999). From a psychological point of view, it can be argued that being fearless is about developing resilience and a certain mental toughness (see Rachman, 1984).

TABLE 2 | Quotes from the interviewees* highlighting their experience on playing in a natural learning environment.

OA	I lived in a small town so we had a lot of space to play and at that time it was safe to play around my neighborhood. We swam in the rivers, climbed trees to get fruit, played hide and seek, etc. Football of-course was my favorite. It was normal for us to play football bare foot with homemade balls.
CL	In think we Brazilians learnt skills in a natural way or at least used to. This helps in the acquisition of skills rather than in just learning tactical movements. Therefore, the fact that I played a lot in a natural environment under all sorts of fun tasks, all of that have positively affected my motor-perceptual skills.
VL	I played football everyday on the street, but I also did what other kids in my time used to do. We trespassed into some farms to get fruit from trees, such as avocado and orange. We learned how to swim in the lakes around. We had to be smart to not come home with wet pants, as if so our mums would smack our bums.
DB	Given that I lived in Rio de Janeiro which is surrounded by hills and mountains, we had a lot of natural environment to play all kind of games, but ultimately we all ended up playing football more than anything else every day on the street.
MS	No doubt that I played more football than anything else. It was and still is my passion. But as a kid I lived in a suburb surrounded by nature and there we were able to play all kind of other games too.
JS	Swimming in the rivers, stealing fruit, running here and there, running after balloons, my childhood was like that. Today that does not exist anymore, well at least in São Paulo city where urbanization has dramatically increased.

These interviewees have been directly involved with professional football.

Poverty and Unconventional Football Practice Environment: Multi-Interactive Constraints

As highlighted so far, many Brazilian children live in *Poverty* and/or in rural areas and therefore have to draw upon whatever possible physical means to be able to play. On this note, successful Brazilian football players are often associated with the notion of developing their skills in natural learning environments under multiple tasks and environmental conditions (Araújo et al., 2010; Uehara et al., 2018, 2019). Not all Brazilian children who have learned football in an informal natural learning environment were poor. However, the children from poorer families tend to be more exposed as they often live in underdeveloped areas such as favelas or in rural areas that lack structure, infrastructure and adequate educational system. By being exposed to informal learning conditions, many children in Brazil tend to explore more than football itself with other activities such as climbing trees, swimming in lakes, and other physical activities that tend to be challenging yet fun (see **Table 2**), although with certain restrictions today due to increasing urbanization. Such activities encourage creativity, improvisation, adaptive skills, and ultimately the overall development of perceptual-cognitive-motor skills (see Louv, 2005). Exposure to a range of outdoor environments and opportunities to adapt to dynamic constraints has been recently recognized within the ecological dynamics framework as an important means to promote lifespan skill development (e.g., Rudd et al., 2020).

Underpinning these quotes in **Table 2**, our interviewees commonly reported that they used to explore different forms of physical activities for fun and enjoyment, which in effect, resemble the practice of *parkour* in a sense of activating all sorts of perceptual-motor and cognitive skills at gross and fine neuro-muscular levels. Briefly, parkour is a sport where practitioners (i.e., traceurs) transverse man-made or natural obstacles with the use of simple and complex actions such as running, climbing, vaulting, jumping, landing, rolling and other movements in order to achieve a talk goal of traveling from one point to another in an innovative and efficient manner (Aggerholm and Højbjerre, 2017).

Still, underpinning the quotes in **Table 2**, in spite of the other physical engagements, football seems to be the preferable activity for the interviewees. On this note, it has been reported that more than the 11-a-side regulation form of the sport, various other configurations of the game such as *Bobinho* (i.e., rondo), *Rebote* (i.e., rebound), and *Artilheiro* (i.e., striker, top scorer) have composed the traditional culture of playing ball games with the feet (Scaglia et al., 2021). In addition, street football, beach soccer, and futsal have been traditionally played within the Brazilian society (Uehara et al., 2019). In effect, playing under such informal conditions can be linked to other socio-cultural constraints at the micro and macro levels of the Brazilian football such as *Pelada* (i.e., pickup games) and *Malandragem* (i.e., street smart, cunning, trickery, creativity), respectively (Uehara et al., 2018, 2020).

According to Uehara et al. (2018), *Pelada* is a type of spontaneous and unsupervised "pick-up" football that can be played in different physical environment constraints such as the waste grounds and landscapes, streets, schools, beaches, and backyards. Importantly, *Pelada* can be played with very few resources or supervision (i.e., referees, coaches) which removes barriers that other forms of football may present to those living in *Poverty*. Playing in such informal contexts provides the opportunity for the development of high caliber of perceptual-motor skills, including the *Malandragem* skills for deceptive and creative actions so that the game can flow with a *Joga Bonito* (play beautiful) style. That is, the Brazilian *Ginga* (i.e., body sway) style (see Uehara et al., 2020).

In this regard, Mr. VL provides an enlightening comment in which he intersects key points of articulation at different systemic levels such as *Pelada* for microsystem, *Poverty* for exosystem, and *Malandragem* for macrosystem. He says:

> I lived in a very rough neighbourhood full of crime. We played *Pelada* every day on the streets. We had players at various levels of skills and age. I was about 6 years old. So everybody knows that football has 17 rules, but in our street there is only one rule: if no blood no foul. Under this context you create certain *Malandragem* [trickery] for the rest of your life. For example, I knew that if I bumped into a 15 year old boy I would break myself up, so I had to look over my shoulders all the time and anticipate the moves to avoid physical contact. In doing so, you develop quick thinking and the notion of searching for space and time to play (Interview, February 16, 2011).

In this sense, Mr. VL shows how the task of playing *Pelada* in an aversive environment constraint shaped his *Malandragem* skills for the purpose of self-preservation. In other words, VL connects the notion of *Malandragem* with key elements of skill acquisition such as anticipation, rapid thinking, perceptual information, decision-making, problem solving, and exploration of space and time.

Furthermore, under the scope of *Malandragem* skills the text below provides another point of articulation in which the mischief/trickery of others creates an opportunity for VL to develop perception and attentiveness skills in relation to other parameters in the playing field:

> I was the youngest, my father was killed when I was a baby and my mother was a cook at the neighbourhood school. She worked 14-16 hours a day. So we were very poor. My mom used to make our shorts out of those big cloth bags of sugar. It was the biggest reason for mockery. Sometimes when we were playing football on the street my mates tried to lower my shorts down because I was not wearing underwear. So I had to stay alert all the time looking around (Interview, February 16, 2011).

Here it is interesting to note that *Poverty* and *Malandragem* represented by the notion of perceptual skills are all entangled in a "non-linear fashion." That is, whilst VL's friends were *Malandro* (i.e., streetwise person, naughty) by being cheeky in trying to lower his unconventional home-made shorts and make fun of him, VL used his *Malandragem* skills to constantly scan his environment and thereby improving his perceptual awareness.

An additional point of articulation provided by VL during the interview is worth highlighting. For him, *Malandragem* is about using *Ginga* (i.e., body sway) to deceive the opposition with body movement that sways from one side to the other. Hence, VL articulates *Ginga* and *Malandragem* all together under the notion of body movement associated with perception, decision-making and ultimately improvisation:

> In my view, *Ginga* is synonymous with improvisation. I don't know if you think like me, but when you see someone playing we can say he plays with *Ginga* or not. But *Ginga* is not only about the way that one executes movement, it is also about astutely perceiving what is going on around. It is about being smart and cunning enough to anticipate what is going to happen and make decisions accordingly [Malandragem]. Therefore, based on these parameters I can say that *Ginga* is synonymous with improvisation (Interview, February 16, 2011).

From a socio-cultural point of view, it can be argued that VL's statement represents the typical "malandro" who is "smart and cunning enough" to find rapid solutions in different game situations. Essentially, for the Brazilian, *Ginga-Malandragem* is the utmost skill of perceiving, acting, creating and improvising in sport (for further clarification on this issue, see Uehara et al., 2020; and/or the movie entitled "Pelé: Birth of a Legend" directed and written by Zimbalist and Zimbalist, 2016). Arguably, the iconic Pelé best represents and endorses the Brazilian football *Ginga* style.

To this end, from a skill acquisition point of view, whereas some might have previously perceived the blend of constraints identified in this article as negative or aversive to overall learning and development, in fact much of the data have suggested otherwise. However, it is noteworthy that the pathways to reach success is extremely competitive and many children are left behind. Hence, from a sociological perspective, we can never ignore the fact that *Poverty* is one of the major constraints that negatively affect the development of many children in Brazil and around the world due to the lack of opportunity and economic means to participate in sport (see Newman and Falcous, 2013). In fact, it is common to hear stories in Brazil of talented young players who gave up pursuing a football career due to financial difficulties in their family—e.g., to pay bus tickets to attend training sessions; not having enough food to eat or because of an injury which demands surgery but there are no adequate resources for it (Simas, 2004). These effects of *Poverty* are still around in this millennium and not only in Brazil. Manchester

United striker Marcus Rashford reported the same problems in having the money for bus rides and food to eat. Luckily, a coach used to pick him up and drop him home because he was such a talented child (BBC, 2020). However, not all talented children have the same fate.

Therefore, be it for health and/or for performance purposes, it is essential that Government and institutions alike, at all levels, provide means for *all* to participate in sport and physical activities, as further discussed below.

DISCUSSION

Traditional sociology of sport, whilst not addressing the development of expertise or skill, is of contextual relevance in capturing the constraints associated with social class status. This sizeable body of research literature largely approaches the key environmental influence of low social class status (as an indicator of [relative] *Poverty*) as a *constraint* on sports' participation and access, and hence opportunities for skill acquisition/expertise development. From an ecological dynamics perspective, through the multiple lenses of the CSAR approach, in this article we have examined *Poverty* as one of the socio-economic constraints that *indirectly* influence the development of perceptual-motor skills of Brazilian football players. More specifically, we have provided interpretative analyses of the contextualized sites of articulation to explain the points in which experience of *Poverty* intersects with processes of skill acquisition.

Many children in Brazil live in rural areas and/or in *Poverty*, and therefore, have to draw upon whatever physical environment resources they have to play. However, from a skill acquisition point of view this is not necessarily a degrading constraint as these conditions actually favor the development of their perceptual-motor skills in different sports, like football. In other words, lack of resources can make you resourceful as an individual to explore what, how, when, and the locale for opportunities to play. This is because children' fledgling skills may be shaped in a positive way when playing freely under different environment and task constraints (e.g., climbing trees, swimming in the lakes, and playing hide in seek in the bushes; Uehara et al., 2018). Having had fewer opportunities for education and coaching and more emphasis on playing *Pelada*, these children need to be skillful and creative to succeed in football. As Uehara et al. (2018) pointed out, this informal way of playing football in Brazil often self-organizes on irregular surfaces, played with bare feet, and on small and deteriorating playing spaces and surfaces. However, such aversive task and environmental constraints can actually be beneficial for exploration, discovery and effective learning, and in turn for the development of a high level of perceptual-motor skills (Uehara et al., 2018). Such practice conditions are also known to promote degeneracy in skilled athletes which force them to adapt and recruit multiple movement patterns to satisfy the same task goal (see Seifert et al., 2013). This general argument is also in line with the notion that talented athletes' need challenges to overcome in order to develop characteristics to reach and stay at the top of their sport (Collins and MacNamara, 2012; Collins et al., 2016).

Further enhancement of Brazilian players' perceptual-motor skills can be influenced by other related socio-cultural constraints encountered in the Brazilian society such as *Malandragem* and *Ginga* (Uehara et al., 2020). Ultimately, the entanglement of physical, as well as socio-cultural, constraints such as *Pelada*, *Poverty*, *Ginga,* and *Malandragem* serves as a framework that supports the development of skills that go beyond motor and perceptual attributes. In other words, shaped by different environment and task constraints, Brazilian footballers, arguably, develop self-regulatory skills such as emotional control, skill adaptation, resilience and mental toughness to play well anywhere and under any circumstances (Araújo et al., 2010). In addition, the underprivileged living conditions may develop psychological fortitude and motivation to improve their socio-economic status. However, we acknowledge that this aversive constraint shall not be considered the only contributing factor toward talent development because a blend of aversive and coercive constraints is necessary to develop world-class players (see Collins and MacNamara, 2012). In Brazil, for instance, talented players are usually selected to join a federated club by the age of 14 years old, and once there—subject to the level of the club—they receive the professional support and structure to fine-tune their development. Without the input of trainers, specialist coaches, nutritionists, and doctors at some point it is unlikely they would make it to the very top (see Bettega, 2019; Thiengo, 2019).

Using the CSAR rationale, it is important to re-iterate here, therefore, that football expertise development is not directly caused by *Poverty*. Rather, *Poverty* produces specific contexts that, in turn, generate physical as well as socio-cultural environment constraints (e.g., *Pelada, Malandragem*) that can sculpt affordances (opportunities or invitations) for skill acquisition. In this regard, the perspective of ecological dynamics creates a powerful theoretical lens through which one can interpret these empirical observations. Somewhat counterintuitively, the lack of resources that may be denied for children living in poverty (e.g., ball, clothing, pitch, coaching, etc.) may help promote a resourcefulness in their character to overcome this inequity in status. Many of the interviewees we spoke to, confirmed their belief that opportunities to play informally in outdoor settings had been a significant contributing factor in their skill development. As evidenced by a vast number of empirical research studies, the development of expertise in sport, including football, emerges from the interaction of key constraints (Button et al., 2020). In the case of Brazilian football, these constraints can be exemplified as the task (e.g., *Pelada*), organismic (e.g., football players), and environment (e.g., socio-cultural ones such as *Ginga-Malandragem*) constraints (Uehara et al., 2018, 2019, 2020).

Limitations and Research Recommendations

It is worth noting that not all Brazilian players play with *Ginga*, neither all come from socio-economically underprivileged backgrounds. Kaká for instance, a former football player who won the Fifa player of the year in 2007, comes from a middle-class family and, arguably, his style was closer to the pragmatic European football style rather than Brazilian. On the other hand, Sócrates, a former Brazilian national team player, epitomized the *Ginga* style, yet, he also had a middle-class background. An interviewee (DB) who also grew up in a middle social class family can further add light to this issue. He said:

> Growing up in Rio de Janeiro, I used to play with my mates of the same social class, but the boys from the favelas used to come down from the hills and play with us. There was a visible difference in their skills compared to ours. They were much, very much more skillful than us. They had what we say is the essence of Brazilian football and played with trickery, flamboyance and style. Everything that I learnt in terms of football was not from my mates but from those boys some of whom didn't even have enough food on a daily basis. But they were good at football (Interview, December 12, 2010).

Here, DB reveals the difference in skills between poor and rich children and how the former influenced his football skills development. Under this context, a plausible reason for rich Brazilian children developing their *Ginga* style can be explained by what is known in motor learning literature as observation and transfer skills. This is because *Ginga* football style has been so deep rooted as a popular culture that regardless of socio-economic status, children learn from each other by playing with each other, by observing each other carrying therefore the legacy of *Ginga* across generations. However, to further elucidate and contemporize this issue, future research may consider investigating Brazilian football players who were not poor in the first instance. It is possible that future Brazilian footballers will come from a broader spectrum of backgrounds that they have in the past due to the widening gap between the rich and poor.

We acknowledge that funding resources were limited and as a result, fieldwork data were mainly collected in the region of São Paulo city where the first author grew up playing football. However, as per the contextual analysis, the development of Brazilian football players is not limited to one region, but extends to Brazil as a whole. In addition, we are mindful that the skills and expertise of Brazilian footballers are not solely due to an informal play (e.g., *Pelada*), neither are they just a function of aversive environmental constraint such as *Poverty*. Supportive and coercive environmental constraints, such as the ones encountered in family settings and federated clubs play an important role on the development of skill and expertise of Brazilian footballers. Thus, this issue also warrants future research (see Salmela and Moraes, 2003; Bettega, 2019; Thiengo, 2019).

Implications and Policy Recommendations

In highlighting the issue of *Poverty*, the point of interest is not about being poor to be able to play with *Ginga*. Regardless of social class, the focus should be on the development of a national football training programme with methodology that preserves the essence of Brazilian football style and at the same time makes it better by adding educational values to it. This issue has been addressed by our interviewee JPM:

> The number of soccer schools in São Paulo has increased dramatically in the last 20 years. This is due to urbanisation, which is taking away children's natural space for playing. As such, business minded-like people saw the opportunity to open soccer schools so children can continue to play football. However, the problem is twofold: the first is that not all children can afford to pay soccer school fees; the second is that the majority of these soccer schools are not methodologically prepared to coach children, and thus rather than developing them these soccer schools are in fact inhibiting children's football development skills (Interview, February 10, 2011).

In a similar line of focus, ACS said "these emergent soccer schools are inhibitors rather promoters of skill development. That is, they do not have the right methodology to train our children to become good footballers in the future" (Interview, February 8, 2011).

Indeed, this is an important argument to be considered as, arguably, it is notable that there are fewer current exceptional Brazilian football players than there were in previous national teams. Just as an example, in 2002, the last time Brazil won the World Cup, the squad was composed of players such as Ronaldo, Rivaldo, Ronaldinho, and Kaká (all FIFA World Player of the Year award winners), as well as other talented football players such as Cafu and Roberto Carlos (CBF, 2020). Further, most recently the *Seleção* (i.e., the Brazilian national team) performed below the huge expectations of the fans in the 2014 World Cup in Brazil, and 2018 in Russia. In previewing this issue, Rivelino raised concerns about the future of *Seleção* as he claimed that the problem was due to the lack of practicing street-football (i.e., *Pelada*; BBC, 2006).

Despite of all that, paradoxically, Brazil continues being one of the biggest exporters of professional football players worldwide (GloboEsporte, 2020). However, this does not suffice for a country with a strong historical tradition in football. Therefore, to effectively address this issue, it is crucial that Brazilian football organizations understand the importance of the socio-cultural contexts in which football has successfully evolved throughout the history of Brazil. In doing so, the problem of urbanization that has occupied the free spaces for *Pelada*, for example, can be overcome by setting up training centers with qualified coaches that understand the effect of physical as well as socio-cultural constraints influencing the development of perceptual-motor skills of Brazilian players. As JPM pointed out, the key for the success of Brazilian football in the future is to bring back the essence of street soccer (e.g., *Pelada*) to football training programmes and in fact, making the training curriculum even better by applying educational values to it.

Another contemporary trend of interest here is in relation to the practice of parkour, also known as free running, which involves the skillful negotiation of affordances of objects, surfaces, obstacles, gaps, ledges and inclines in the environment. As mentioned earlier, practice of parkour aligns well with the natural Brazilian way of playing. In a position paper, Strafford et al. (2018) provided insights on how parkour can act as a donor sport (i.e., various physical activities) for athletic development in youth team sports. They argue that "Integrating parkour-style activities into practice could develop/maintain athleticism and promote skill transfer in an enjoyable environment in team sport athletes due to utilization of performance-enhancing affordances and adaptive, functional, goal-directed movements" (p. 1). Moreover, Strafford et al. (2020) explored the views, experiences and insights of expert parkour-traceurs in relation to the enhancement of physical, cognitive, and perceptual skills through the practice of parkour. In line with their position paper, these expert participants concluded that parkour-style training environments indeed offer affordances (opportunity for actions) that enhance dynamic athletic performance in different sports, especially team sports like football (Strafford et al., 2020).

Therefore, the idea of parkour as a donor sport can be aligned with the unconventional learning environment to which many Brazilian children are exposed when engaged in all sorts of physical activities. This experience, in turn, can result in the enhancement of perceptual-motor skills of Brazilian football players as a function of playing under different environmental and task constraints. For this reason, design of parkour installations and open play areas can contribute to landscapes of varied affordances for physical activity and sports participation in urban settings such as favelas, inner city areas, and banlieues. These environmental constraints would provide means for people to entertain themselves inexpensively, gain access to employment opportunities and maintain health and well-being through (unstructured and more structured) sport and physical activities in dense urban environments.

Final Remarks

From a sociological point of view, it has been argued that sport participation is highly dependent on the social class in which a child belongs. The poorer the child, the less likely she/he will have the means and the opportunity to participate in organized sport. Beyond sport participation, the problem of *Poverty* is further aggravated when it comes to health and educational related issues. Research has shown that *Poverty* in childhood may lead to higher risk of depression, substance abuse and other diseases in adulthood (see Costello et al., 2003). In addition, evidence suggests that growing up poor has long been associated with decreased educational accomplishment and lower earnings in lifetime. However, for those who receive some form of assistance, they are prone to overcome behavioral and emotional problems and in turn may have a better quality of life in the future (see Velasques-Manoff, 2014).

In contrast, as we have articulated in this article, from a skill acquisition point of view *Poverty* creates different contextual sensitivities that can positively influence the development of perceptual-motor skills in many children. These suggestions were supported by data from interviews, reports, and observations of the experiences of many successful Brazilian football players. However, being raised under precarious socio-economic conditions does not mean that every child will grow up strong, since each individual can respond in a different way to these conditions. Moreover, environmental constraints are very dynamic and change constantly as the norms and behavioral patterns in different societies are in constant transformation. Unfortunately, many of these alterations may negatively affect a society such as the case of misgoverned increase of urbanization without any sustainable and eco-friendly plans.

For these reasons, at the exosystemic level of a society, governors, and sport managers/administrators in contemporary societies should carefully consider the values and benefits of sport, play, recreation, and exercise participation. It is important to create means and opportunities for all citizens to engage with these activities, to promote physical and mental health and well-being as well as for the development of perceptual-motor skills for competitive sport performance. One way of accomplishing this important goal is through the means of designing and providing adequate *Pelada* and *Parkour* parks around dense urban environments such as inner-city areas, favelas, and banlieues. For example, in urbanized inner city London this aim has been documented in the creation of cage areas for football participation (see Smith, 2017; Kershaw, 2020).

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of Otago, NZ. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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From Talent Identification to *Novo Basquete Brasil* (NBB): Multifactorial Analysis of the Career Progression in Youth Brazilian Elite Basketball

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This study examined individual, task, and environmental constraints that influence the career progression of youth Brazilian elite basketball players and the probability of reaching *Novo Basquete Brasil* (NBB) and to determine if the association of the relative age effect (RAE) is a key factor in the career progression. The sample consisted of 4,692 male players who were registered to participate in at least one U15, U17, or U22 youth Brazilian basketball championship between 2004 and 2018. Athletes who reached a high-performance level were coded like NBB players (9.6%). The birthdates, height, body mass, playing position, geographic region, club, competition category, and team performance were retrieved from the official data archive of the Brazilian Basketball Confederation and the National Basketball League. The maturity status was estimated using the predicted age at peak height velocity. A binary logistic regression examined the influence of each characteristic on the probability of a youth Brazilian basketball player to reach the NBB. The receiver operating characteristic (ROC) curves and the associated area under the curve (AUC) were used to assess the discriminant ability of the model. The taller and younger players not selected early into national teams, without specialization by playing position, who participated in U22 national championship, migrated to the southeast region, and remained in the formation process over time have a greater chance to reach the NBB. The ROC curve demonstrated an AUC of 93%. A combination of individual, task, and environmental characteristics influences the sport career of a young Brazilian basketball player in reaching the NBB. Further, early-maturing athletes have a greater chance to reach higher performances. RAE influences lower-level categories, but not a "NBB player's" career progression. The coaches, stakeholders, and practitioners should perform a holistic evaluation of sport talent in terms of a constraint-based theoretical model with the aim of avoiding bias produced by the maturational status and RAE in the youth Brazilian elite basketball.

Keywords: relative age effect, career progression, sports talent, basketball, talent identification, talent development

INTRODUCTION

The talent identification and development in sport is a dynamic process where individual, task, and environmental constraints interact in predicting long-term success (Phillips et al., 2010; Rees et al., 2016). Coaches and researchers are interested in identifying talented players (the most promising young athletes with the greatest sport potential) and how to optimize the long-term nurture in talent development programs in order for an athlete to become an expert—senior elite performance (Gulbin et al., 2013; Fransen and Gullich, 2019). The talent pathway is a key concern for sporting organizations and funding agencies due to considerable time and resource investments (Punkhurst and Collins, 2013). To date, there has been scientific evidence highlighting the necessity of longitudinal studies with multidisciplinary approaches for better understanding of how a career progression can be influenced from talent to expert, especially in team sports (Fransen and Gullich, 2019).

In basketball, performance and success are multifactorial; and many aspects, such as anthropometric, physiological, technical, tactical, psychological, and environmental, are required to become an elite athlete (Sáenz-López et al., 2005). In cross-sectional and short-term longitudinal studies, stature (Zarić et al., 2020), birthdate (Torres-Unda et al., 2013; Rubajczyk et al., 2017), maturation (Arede et al., 2019), physical fitness (Hoffman et al., 1996; Hoare, 2000), and skills (Arede et al., 2019) can be useful to predict individual performance and the selection of young basketball athletes. Thus, a more holistic and ecological analysis is considered an advance in the talent identification and development process to provide additional insight in the sport potential of the players (Moxley and Towne, 2015; Ribeiro Júnior et al., 2019). Hence, young athletes who present the right combination of characteristics required for good performance in basketball will probably have a greater chance of success. However, selecting athletes in the initial stage of talent development only from the physical performance perspective typically favors older members within a cohort, especially when in combination with early maturation and the influence of relative age effect (RAE) phenomenon (Pearson et al., 2006; Cobley et al., 2009; Rubajczyk et al., 2017).

The RAE is an immediate and long-term consequence of differences in chronological age between athletes who compete in the same age category. This phenomenon can be observed by an overrepresentation of players who are born closest to the cutoff date of the selection year (Cobley et al., 2009). The advantage in body size and physical performance of older and early-maturing players may confound the potential assessment of the player and could result in potential talent loss (Cripps et al., 2016). The coaches must to be aware that selection in the youth team sports tends to have a RAE impact (especially a maturational gradient), favoring those who have temporary advantages in relation to the others. In general, athletes who do not present outstanding performance in early phases of talent development are not recognized as a talent and do not receive the necessary support in order to develop their full potential (Votteler and Höner, 2014). However, maturation is not the only RAE explanation. The constraint-based theoretical model has been proposed to explain causes and consequences of the RAE considering the interaction between the aspects related to individual, task, and environment factors (Wattie et al., 2015).

Moreover, studies based on career progression have investigated if RAE is a factor that may influence the achievement of sport career success (de la Rubia et al., 2020). According to the highlighted results presented in de la Rubia et al. (2020) study, there is a RAE impact in short-term individual and team performances; however, in spite of RAE, the reverse was observed in the long-term competition performance. The RAE presence in basketball was confirmed in youth athletes (Torres-Unda et al., 2013, 2016; Arrieta et al., 2016; Rubajczyk et al., 2017) associated with performance (Ibáñez et al., 2018). In professional players, this phenomenon is less consistent (Werneck et al., 2016; Subijana and Lorenzo-Calvo, 2018; Lupo et al., 2019; Oliveira et al., 2019).

In Brazilian basketball, there is a player selection bias with respect to chronological age in the early stages. The RAE has been found from U12 to U22, in different geographic regions, playing position, and it is associated with team performance and stature (Oliveira et al., 2017; Ribeiro Júnior, 2020; Ribeiro Júnior et al., 2020). In addition, RAE is evident in the early senior career of players who reached the *Novo Basquete Brasil* (NBB); nevertheless, it disappears and even reverts (RAE reversal) in high performance (Oliveira et al., 2019), although there is no evidence of the RAE impact in the Brazilian basketball players related to the career progression (from talent, sport potential, to the expert, high level).

Furthermore, contextual factors such RAE (Cobley et al., 2009; de la Rubia et al., 2020), birthplace (Côté et al., 2006; Baker et al., 2009) and qualitative and quantitative practice (Ford et al., 2009; Moesch et al., 2011; Rees et al., 2016) must be considered in the expertise development. Some studies have demonstrated that birthplace is more important than birthdate effects on the achievement of sporting expertise (Côté et al., 2006; Baker et al., 2009). In basketball, high levels of proficiency and selection are correlated with an earlier start in sport and a later specialization (Leite and Sampaio, 2012; Arede et al., 2019). Retrospectively, research with the Chinese (Bonal et al., 2020) and the Brazilian elite basketball players (Cunha et al., 2017; Beneli, 2018) found relevant contextual factors to talent development pathway.

Recent research in basketball has attempted to track the development of young talented athletes into adulthood. Youth success, specialization, and birthdate, for example, do not appear to predict late success at the elite level (Barreiros et al., 2014; Güllich and Emrich, 2014). Professional players emerged from repeated procedures of selection and deselection (Güllich, 2014). However, a small percentage of athletes recognized as talented from the Spain national basketball youth teams reached senior performance (Sáenz-López et al., 2006; Ibáñez et al., 2010) improving from junior national teams to professional athletes (Sáenz-López et al., 2006; Subijana and Lorenzo-Calvo, 2018). In European youth national basketball teams, the re-selection process is influenced by the initial selection age, inverse RAE, and the country long-term performance (Kalén et al., 2020).

The basketball is a cultural and traditional sport in Brazil, which achieved significant international results in the 20th century (Beneli, 2018). Since the second decade of the 21st century, the Brazilian basketball has recovered its international representativeness. The following events were important for this recovery: (1) the exportation of a significant number of players to the major basketball leagues worldwide; (2) the establishment (in 2008) of the national basketball league [organized by clubs with the Brazilian Basketball Confederation (CBB) seal], which organizes the main professional adult Championship—NBB; and (3) the improvement of international results in the competitive scenario by the national team, Brazilian clubs, and youth national teams.

According to the CBB, Brazil has over 3 million basketball practitioners, over 1,000 teams across the country, 31 million fans, and 13 million super fans, which create the context of Brazilian basketball as an "open sea" for the player development opportunity. At the same time, there is little organization in regard to development and monitoring of the young basketball players in Brazil, from early development stages to achieve the high level of competition (Ribeiro Júnior, 2020). It is possible to highlight some efforts by the scientific community in the characterization of high-level senior players, as well as the training and development process of young Brazilian basketball players (Cunha et al., 2017; Beneli et al., 2020). Subsequently, it will be a long haul for the sports science community to better understand the path of the Brazilian basketball long-term development of youth basketball players in Brazil.

Despite previous studies, it is necessary to investigate factors that influence the development of the athlete from talent to expert level within a multifactorial, longitudinal, and constraint-based approach to better understand how the career progression in youth Brazilian basketball players occurs. According to our knowledge, this is the first study conducted in team sports with this direction, especially in the Brazilian context, thus making this unique. This prospective analysis could provide answers to certain questions in the talent identification systems and in the training process that help to mitigate the negative effects and provide more productive sport trails. Therefore, this study examined individual, task, and environmental constraints that influence the career progression of youth Brazilian elite basketball players and the probability of reaching the NBB and to determine if the association of RAE is a key factor in the career progression.

MATERIALS AND METHODS

Design

This study presents a prospective associative strategy design (Ato et al., 2013) that analyzes, from a multifactorial perspective, the different factors that influence throughout the sport career of youth Brazilian basketball player to reach a high level (NBB).

Sample

The sample consisted of 4,692 male players who were registered to participate in at least one U15, U17, or U22 youth Brazilian basketball championship from 2004 to 2018, all Brazilians, and were born between 1982 and 2003. The players were ranked within each category when they appeared for the first time on the database, despite having played in another category or not. Therefore, every available player registered was considered and no player was excluded; instead, all players were included. In the U15 and U17 categories, the athletes selected to represent their respective state selection teams in the Brazilian Basketball Championships organized by the CBB were included, only until 2015, and in the years 2010 and 2014, the U15 was not performed. In the U22 category, those who competed in the Basketball Development League (LDB) for their respective clubs, organized by the National Basketball League (LNB) were included, which was raised only in 2008 (the first NBB championship), and the U22 was raised for the LNB only in 2011. The CBB organized the U19 Brazilian Basketball Championships state selection teams in 2010 and 2011; these players were not included in the sample of this present study. Athletes were categorized according to their career progression in the NBB players—those who progressed in their careers from the youth categories to the high-level (NBB—Brazilian Professional Basketball League) ($n = 452$) and lower-level players—athletes who did not reach the NBB ($n = 4{,}240$). The lower-level category careers were defined by the progression of each player within the youth categories (U15, U17, and U22—youth state national championships) from 2004 to 2018, once, twice, or three times. The use of public data available on the Internet has been described in other studies without the need for research approval by an ethics committee (Côté et al., 2006; Werneck et al., 2016). The data were obtained according to Resolution No. 510, on April 7, 2016, from the National Council of Health, Brazil. All the research procedures were conducted in accordance with the Declaration of Helsinki.

Variables and Procedures

Data from U15 and U17 competitions were taken from the CBB website (http://www.cbb.com.br). Data from U22 and NBB were obtained from the website of the LNB (http://www.lnb.com.br). The data set had 10,856 data points from 4,692 athletes registered in the official database of the CBB and LNB between 2004 and 2018. In order to analyze the sport career of the athlete, the category that the athlete competed (competitive level) was considered: if he played the U15, U17, or U22 or not and whether he played the NBB or not. The first and last participation of the players in a championship from 2004 until 2018 was considered a reference in order to calculate dichotomous variables from the original ones. For example, changed geographic region = 1 could be a U15 player from the south region who has changed to the southeast region at U22. In order to conduct a multifactorial analysis, a constraint-based theoretical model was utilized (Wattie et al., 2015).

Individual Constraints

The birthdates, height, and body weight of the players were reported by teams at the moment of the competition registration. Player age was calculated by subtracting the birth year of the player from the championship year. The BioFit® software[1] was used to assess the U15 and U17 biological maturation of the

[1]Projeto Atletas de Ouro®. *BioFit®–Avaliação da Maturação Biológica*. Available online at: https://labespee.ufop.br/atletas-de-ouro (accessed September 1, 2020).

players (https://labespee.ufop.br/atletas-de-ouro). This software estimates predicted age at peak height velocity (APHV) from maturity offset—years from APHV. The following equation was used: maturity offset (years) = −7.999994 + [0.0036124 × (age × stature)] (Moore et al., 2015). The maturity status was classified as early (APHV < 13.1 years), on time (13.1 ≤ APHV ≤ 15.1 years), or late (APHV > 15.1 years) (Kozieł and Malina, 2018).

Task Constraints

Based on the sport context, positions of the players (point guard, shooting guard, small forward, power forward, and center), competition year, and competition category (U15, U17, and U22) were obtained. Previously, the dichotomous variable was designed [played as a center (yes or no) and changed position (yes or no)] for the playing positions of the athletes. This strategy was used to identify which player position could have a significant impact in the distribution of dependent groups and latter logistic regression. The first and last competition categories of the players in a championship were recorded as their initial and final competition category from 2004 until 2018, respectively. The number of competition categories that athletes competed was created: once, twice, or three times.

Environmental Constraints

The state and geographic regions of the teams (north, south, southeast, northeast, and midwest) were used to calculate the variables changed state (yes or no), changed region (yes or not), and played in the southeast (yes or no). In order to analyze the influence of the RAE on career progression, players born in January–March were categorized as quarter 1, April–June as quarter 2, July–September as quarter 3, and October–December as quarter 4. Semester 1 (January–June) and semester 2 (July–December) were calculated.

Sport Performance

Regarding the sport performance, it was registered according to team performance based on the ranking of the teams in the championship (range: 1st to 24th place). The players were assigned to two categories according to the obtained results of the teams: medalists (first, second, or third places) or non-medalists (fourth place or less). They were coded as improved performance (yes or no) if the team performance in the last championship was better than in the first one.

Statistical Analysis

Data are presented as mean ± standard deviation and percentages. First, the differences between groups were investigated with the *Student t-test*. The effect size was evaluated by *Cohen's d* (Cohen, 1992). Second, *chi-square test* (χ^2) was used to test bivariate association between predictors and career progression. The effect size was evaluated by *phi de Cramer Coefficient* (ϕc) (Newell et al., 2014). The level of association was interpreted by the Crewson (2006). The *odds ratio* (OR) with a 95% confidence interval (95% CI) was calculated and interpreted as follows: <1.23 (very small), 1.23–1.85 (small), 1.86–2.99 (medium), and >2.99 (large) (Olivier and Bell, 2013). In the multivariate analysis, a binary logistic regression was used to examine the influence of each predictor on the probability of a youth Brazilian basketball player to reach the NBB. A backward stepwise elimination method was employed to build the model. The model fit was assessed as the model chi-square, −2 log-likelihood value, Nagelkerke's R^2, and Hosmer and Lemeshow's test. The 10% cutoff limit was considered for the athlete to be classified as "NBB player." When replacing the values of predictor variables in the formula, results >0.1 would be classified as "NBB player"; otherwise, they would be classified as "lower-level players." The discriminant ability of the model was assessed by generating a receiver operating characteristic (ROC) curve to plot the true positive rate (sensitivity) against the false positive rate (1–specificity). An area under the curve (AUC) was calculated with an AUC of 1 (100%) representing perfect discriminant ability. Effect sizes were assessed using OR defined as the exponential of the regression coefficient e^B. It was reported that when an OR was >1.0, it increased the odds of reaching the NBB. Conversely, when an OR was <1.0, it decreased the odds of reaching the NBB. For an OR to be significant, 95% CI would not contain the null OR of 1.0. All statistical analyses were conducted using IBM SPSS statistical software (version 24.0, IBM SPSS, Armonk, NY, USA). The statistical significance was set at $p < 0.05$.

RESULTS

Sample characteristics are presented in **Table 1**. Descriptive results obtained of level of participation of Brazilian basketball players in U15, U17, and U22 national championships are demonstrated in **Table 2**. Of the total sample, considering lower-level categories in the career progression, 72.2% (n = 3,391) played only one category, 23.3% (n = 1,094) played two categories, and only 4.4% (n = 207) played U15, U17, and U22. Considering the career of the NBB players, 9.6% of all athletes who participated in an official national championship U15, U17, or U22 from 2004 to 2018 reached NBB.

As illustrated in **Figure 1**, there was an association between birth quartile and number of competition categories played ($\chi^2 = 20.313$; $p = 0.002$; $\phi c = 0.05$), but not with the career progression ($\chi^2 = 3.896$; $p = 0.27$; $\phi c = 0.03$). There was an overrepresentation of players born in the first quartile between athletes who were selected three times for national championship compared with the players who had played once or twice categories and lower representation of players born in the fourth quartile. However, there was no association observed in the distribution of birth quartiles between the players who reached the NBB.

Regarding maturity status, early players have greater chances to progress in their careers (**Figure 2**). There was an overrepresentation of early players and less representation of on-time players between athletes who were selected three times for national championship (lower-level category career progression) ($\chi^2 = 38.454$; $p < 0.001$; $\phi c = 0.24$). With regard to the NBB career progression of the players, there was an overrepresentation of early players and less representation of on-time players between NBB athletes ($\chi^2 = 22.335$; $p < 0.001$;

TABLE 1 | Sample characteristics of youth male Brazilian basketball elite players who have participated in U15, U17, or U22 national championship between 2004 and 2018.

Variable	U15 (*n* = 2,534)	U17 (*n* = 1,480)	U22 (*n* = 678)
Chronological age (years)	15.5 ± 0.7	17.3 ± 0.8	18.9 ± 1.7
APHV (years)	13.2 ± 0.5	13.5 ± 0.6	13.3 ± 0.6
Birth quartile (Q1/Q2/Q3/Q4) (%)	40.0/28.7/18.2/13.1	33.2/27.7/22.0/17.1	30.8/30.8/20.6/17.8
Height	182.7 ± 9.4	185.9 ± 10.3	192.1 ± 9.2
Weight	73.0 ± 13.0	78.6 ± 13.4	87.2 ± 13.3
Player position (PG/SG/SF/PF/C) (%)	20.6/32.6/32.9/7.6/6.3	19.5/34.2/35.3/6.9/4.1	21.5/15.1/30.9/10.9/21.6
Geographic region (N/S/SE/NE/MW) (%)	22.8/12.4/16.5/30.7/17.7	19.6/16/19.7/26.6/18.2	.0/17.6/71.1/9.0/2.4

APHV, age at peak height velocity; Q1, 1st quartile; Q2, 2nd quartile; Q3, 3rd quartile; Q4, 4th quartile; PG, point guard; SG, shooting guard; SF, small forward; PF, power forward; C, center; N, north; S, south; SE, southeast; NE, northeast; MW, midwest.

TABLE 2 | Lower categories (U15 to U22) and NBB players' (U15–U17–U22 to NBB) career progression of youth Brazilian basketball players between 2004 to 2018 national championships.

First national competition	*n*	Last national competition			
		U15	U17	U22	NBB
U15	2,534	1,384 (54.6%)	776 (30.6%)	175 (6.9%)	168 (6.6%)
U17	1,480	–	1,229 (84.4%)	98 (6.7%)	129 (8.9%)
U22	678	–	–	523 (77.1%)	155 (22.9%)

Thirty-one U15 athletes and 24 U17 athletes who participated in the U19 tournament were not included in the current study.
NBB, Novo Basquete Brasil—Brazilian professional Basketball championship.

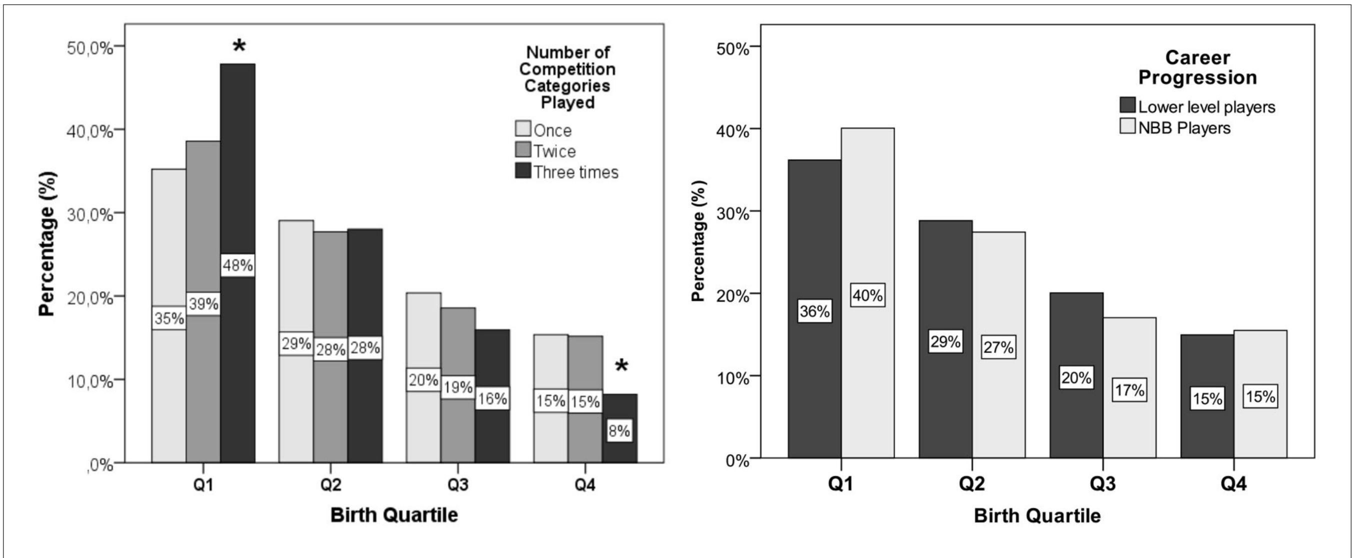

FIGURE 1 | Association between birth quartile and the number of competition categories played **(left)** and career progression **(right)** of U15, U17, U22, and *Novo Basquete Brasil* (NBB) players from 2004 to 2018 championships. *$p < 0.05$.

ϕc = 0.18). Early players were almost three times more likely to reach NBB than on-time players. It is important to show that in the sample analyzed, there were no late-maturing players.

Considering the formative category career, significant differences between NBB players and lower-level players were found (**Table 3**). The bivariate analysis showed that proportionally the NBB players did not compete in the U15 national championship and were selected for the first time only in the U22. Also, they were taller, were from the southeast region, were medalists, and were predominantly centers in comparison

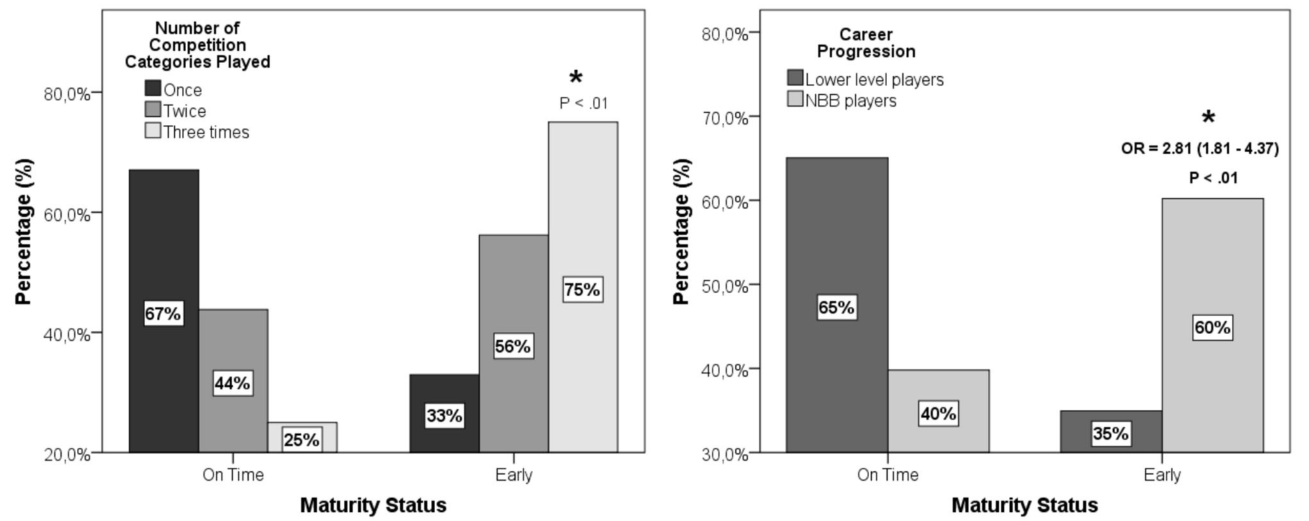

FIGURE 2 | Association between maturity status and the number of competition categories played **(left)** and career progression **(right)** of U15, U17, U22, and *Novo Basquete Brasil* (NBB) players from 2004 to 2018 championships. $^*p < 0.05$.

with the lower-level players. In addition, throughout their careers, NBB players were selected two to three times for national youth championships, improved their collective performance, and changed their state, region, and position on the court. There were no significant differences between groups in chronological age and birth date (quartile and semester).

The individual, task, and environment constraints that influenced the probability of reaching the NBB was a combination of the following characteristics: chronologically younger and taller; played in clubs in the southeast region; selected for the first time to play U22; did not play U15; have been selected more than once to play the U15, U17, or U22 championship; and have changed playing position, club, and region over time (**Table 4**). About 50% of the variability in the chance to play the NBB could be explained by the model ($R^2 = 51.8$). The model proved to be valid in the classification of the career progression of the athletes: sensitivity (87.9%) and specificity (85.5%) (**Table 4**).

In order to predict the probability of a youth Brazilian player in reaching the NBB, the following equation could be used: $Y = 1/\{1 + exp\,[-10.423–0.209 * \text{age at 1st championship (years)} + 0.051 * \text{stature (cm)}–1.009 * \text{played U15 (yes} = 1) + 1.051 * \text{1st competition category U22 (yes} = 1) + 1.145 * \text{no. categories disputed (2 or 3} = 1) + 1.994 * \text{played in the southeast region (yes} = 1) + 1.588 * \text{changed state (yes} = 1) + 0.792 * \text{changed region (yes} = 1) + 1.509 * \text{changed playing position (yes} = 1)]\}$. The value of $Y > 0.10$ is the cutoff to become an NBB player. The ROC curve demonstrated an AUC of 93%—excellent (**Figure 3**).

DISCUSSION

This study examined the association between multifactorial characteristics and career progression of youth Brazilian elite basketball players within a longitudinal and constraint-based approach. The main findings were that (1) individual characteristics—being taller and younger—increased the likelihood of reaching NBB; (2) a late selection, late specialization, and being re-selected for the youth national championship were positively associated with "NBB player's" career; (3) players were more likely to reach NBB if they were from the southeast region and who moved to other state or geographic region; (4) RAE influences lower category career, but it does not determine success; (5) early-maturing players have a greater chance to reach high performance; and (6) only 9.6% of all players from the national youth Brazilian championship U15, U17, and U22 from 2004 to 2018 reached the NBB. A logistic model displayed excellent discriminant ability between NBB players and lower-level players. These results demonstrated that a combination of individual, task, and environmental constraints influences career progression of a young Brazilian basketball player to reach the NBB.

This study is the first in modeling the career progression of youth Brazilian basketball players. The model observed a higher probability of reaching the NBB in athletes with the following characteristic combination: chronologically younger and taller, who play for clubs in the southeast region, are selected for the first time to play U22, not playing U15 national championship, have been re-selected to play the youth national basketball championships, and over time have changed playing position, club, and region. The current understanding is that multidisciplinary and dynamic approach must be used to assess sport potential (Ribeiro Júnior et al., 2019) and development (Sáenz-López et al., 2005) of young basketball players. Talent development and expertise must be taken into account with a wide range of factors (Gulbin et al., 2013; Hambrick et al., 2016).

Regarding individual constraints, athletes who reached the NBB are taller and younger than lower-level players in the first

TABLE 3 | Mean ± standard deviation, and absolute and relative (%) frequency of variables associated with career progression of youth Brazilian elite basketball players from 2004 to 2018.

Variable	NBB players	Lower-level players	*P*-value	OR (CI 95%)	Effect size
Age at 1st championship	16.9 ± 1.6	16.5 ± 1.6	0.26	–	0.25 (small)
Height at 1st championship	1.93 ± 0.09	1.84 ± 0.09	<0.001	–	1.0 (large)
Quartile					
Q1	181 (10.6)	1,534 (89.4)	0.10	1.18 (0.97–1.44)	Very small
Others	271 (9.1)	2,706 (90.6)			
Semester					
1st	305 (10.0)	2,756 (90.0)	0.293	1.12 (1.00–1.37)	Very small
2nd	147 (9.0)	1,484 (91.0)			
Played U15					
Yes	168 (6.6)	2,366 (93.4)	<0.001*	0.47 (0.40–0.57)	Medium
No	284 (13.2)	1,874 (86.8)			
Played U17					
Yes	143 (9.7)	2,261 (90.3)	0.860	1.02 (0.84–1.23)	Very small
No	209 (9.6)	1,979 (90.4)			
1st category U22					
Yes	155 (22.9%)	523 (77.1)	<0.001*	3.71 (2.99–4.60)	Large
No	297 (7.4%)	3,717 (92.6)			
Number of categories competed					
2 or 3	235 (18.1)	1,066 (81.9)	<0.001*	3.22 (2.65–3.93)	Large
1	217 (6.4)	3,174 (93.6)			
Southeast region at 1st championship					
Yes	328 (27.6)	862 (72.4)	<0.001*	10.36 (8.32–12.91)	Large
No	124 (3.5)	3,378 (96.5)			
Changed state					
Yes	203 (52.9)	181 (47.1)	<0.001*	18.30 (14.41–23.30)	Large
No	249 (5.8)	4,059 (94.2)			
Changed region					
Yes	103 (42.9)	137 (57.1)	<0.001*	8.83 (6.69–11.67)	Large
No	349 (7.8)	4,103 (92.2)			
Team performance at 1st championship					
Medalist	230 (13.7)	1,443 (86.3)	<0.001*	2.00 (1.65–2.41)	Medium
Not a medalist	222 (7.4)	2,797 (92.6)			
Improved collective performance					
Yes	125 (14.8)	719 (85.2)	<0.001*	1.87 (1.50–2.33)	Medium
No	327 (8.5)	3,521 (91.5)			
Center position at 1st championship					
Yes	61 (19.6)	250 (80.4)	<0.001*	2.50 (1.84–3.35)	Medium
No	391 (8.9)	3,990 (91.1)			
Changed player position					
Yes	265 (32.2)	558 (67.8)	<0.001*	9.78 (7.82–12.26)	Large
No	141 (4.6)	2,903 (95.4)			

*Line percentages are shown; *statistical significant relationship, $p < 0.05$.*
OR, odds ratio (95% confidence interval).

competition category, after controlling for possible confounders. The odds of reaching NBB increase 5% for each centimeter in height and lower 23% for each chronological year. Previous studies demonstrated that stature is a key factor for high performance (Ribeiro Júnior et al., 2020; Zarić et al., 2020), as well as the selection (Torres-Unda et al., 2013; Baxter-Jones et al., 2020; Ribeiro Júnior et al., 2020), in order to continue participating in basketball (Baxter-Jones et al., 2020). Additionally, young basketball players from 10.5 to 15.5 years of age over the course of 2 years found that the tallest players are more likely to be selected and/or promoted, regardless of their low functional skills (Soares et al., 2020). Body height have had the highest priority during the selection process and when establishing an in-court position (Zarić et al., 2020) In this study,

TABLE 4 | Binary logistic regression model predictive of a youth Brazilian elite basketball player to reach *Novo Basquete Brasil* (NBB).

Predictor	*B*	SE	*p*	Exp (*B*) (95% CI)	Effect size
Age at 1st championship (years)	−0.209	0.072	0.004	0.81 (0.70–0.93)	Small
Height (cm)	0.051	0.008	<0.001	1.05 (1.03–1.07)	Small
Played U15 (yes = 1)	−1.009	0.233	<0.001	0.36 (0.23–0.57)	Medium
First category U22 (yes = 1)	1.051	0.231	<0.001	2.86 (1.82–4.50)	Medium
Number of categories competed (≥2 = 1)	1.145	0.226	<0.001	3.14 (2.02–4.90)	Large
Played in the southeast (yes = 1)	1.994	0.173	<0.001	7.34 (5.23–10.31)	Large
Changed state (yes = 1)	1.588	0.216	<0.001	4.90 (3.20–7.48)	Large
Changed region (yes = 1)	0.792	0.275	0.004	2.21 (1.29–3.78)	Medium
Changed player position (yes = 1)	1.509	0.170	<0.001	4.52 (3.24–6.30)	Large
Constant	−10.423	1.871	<0.001	–	

NBB players were 1 year younger but were selected to compete at the national level 1 year after the lower-level players. These results confirm the findings of Leite and Sampaio (2012), where it was demonstrated that when starting to compete over the U14, the athletes are less likely to reach the highest levels. In general, younger athletes have greater development potential, and when this potential is associated with the process of full- and long-term training, it favors career progression up to high-performance levels (Till et al., 2016).

Regarding task constraints, late selection, being re-selected to youth national championship, and late specialization were positively associated with the career of NBB players. Only 9.6% of all players from the national youth Brazilian championship U15, U17, and U22 from 2004 to 2018 reached NBB. Logistic model displayed excellent discriminant ability between NBB players and lower-level players. Our results are similar to the Spanish basketball (Sáenz-López et al., 2006; Ibáñez et al., 2010), question pyramid-based model of talent development (Bailey and Collins, 2013) and suggest that professional players emerged from repeated procedures from selection and disqualification procedures from talent identification process throughout the specialization as an expert (Güllich, 2014). Regarding the first competition category, the chances of playing NBB increase from the U15 (6.6%) and U17 (8.9%) until U22 (22.9%). Being selected for U15 championship diminishes the probability of playing the NBB. According to Güllich and Emrich (2014) and Cunha et al. (2017), a good performance in the youth categories is not a guarantee of career progression. An early start-age for training and competition favored early adolescent success but did not contribute to individual differences in the success achieved at a senior age (Güllich and Emrich, 2014).

In the present study, the highest percentage of selected athletes for NBB was 22.9% of the athletes who played U22 championship. Hence, the athletes who played the U22 championship increased the chances of playing NBB by 18 times than did the athletes who did not play the U22. The closer the category is to the adult high-performance stage, the greater the chances are of reaching a higher level (Sáenz-López et al., 2006; Feu et al., 2008; Ibáñez et al., 2010). A study conducted with the Spanish basketball players showed that 39.6% of the athletes selected in the junior teams reached the professional league (Subijana and Lorenzo-Calvo, 2018). Findings from Sáenz-López et al. (2006) study demonstrated that in the U22 category, 24% reached the adult category and 94% were established in the professional league, therefore confirming that athletes who have a more active participation in the U22 tend to participate also in the adult category. The U22 category is a way to develop their sporting potential. Even though this athlete was not selected in the previous stages, he remained in the development process, and he became more mature and more experienced, with better technical and tactical skills.

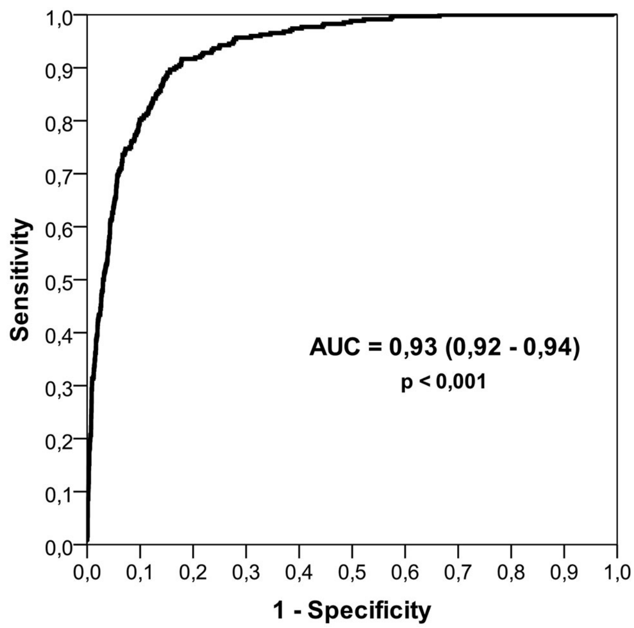

FIGURE 3 | Receiver operating characteristic (ROC) curve indicating area under the curve (AUC)—ability of the model to discriminate between youth Brazilian elite player who reached *Novo Basquete Brasil* (NBB) (high performance) and those who did not.

Re-selection seems to be an important factor for a career progression in the youth Brazilian basketball. In the present study, the odds of reaching the NBB are three times greater for an athlete who has played two or more competition categories. These results suggest that the athletes who really combine long-term sport potential and current performance make experience a key factor to keep them in high-performance levels. In soccer, athletes who progressed to professional status at 16 years of age accumulated more hours per year in soccer playing activities between 6 and 12 years of age than did those who did not progress (Ford et al., 2009). These findings reinforce the importance of a deliberate play and appropriate practice according to the reality of the individual, which provides stability between the process of developing sports potential and competitive performance (Moxley and Towne, 2015). In European basketball youth national teams, 75% of male players were re-selected the following year, but the chance of re-selection until age 20 is lower for players initially selected at age 16 compared with all other ages (Kalén et al., 2020). Consequently, the re-selection is not a prerequisite to reach high performance. The study performed by Gulbin et al. (2013) investigating 256 elite athletes across 27 different sports found that non-linear careers were experienced by the majority of the athletes and linearity of junior to senior competition transition was observed in <7% of the cases.

Considering the playing position at the first competition category, centers (usually with greater stature) have seven times more chances to play NBB than point guards, small forwards, forwards, and power forwards. At the same time, it cannot be said that when they have reached the NBB, these athletes who were considered "centers" in the youth categories remain centers in the adult level. In general, the high stature becomes a prerequisite to play the game, although it must be associated with specific skills to perform various functions in the game (Zarić et al., 2020). The findings of the present study pointed out that athletes who changed their playing position throughout their career present up to 4.5 more chances of reaching the NBB. Late specialization seems to be a key to success. Elite athletes were shown to intensify their training regime during late adolescence (Moesch et al., 2011). The multilateral stimulus during early ages is very important to the acquisition and development of fundamental movement skills in basketball (Arede et al., 2019). Thus, universal talent development (without specializing by position) should be a rule and not an option. The optimal career path is a combination between amount, quality, and when training regimes occur (Moesch et al., 2011).

Regarding environmental constraints, some studies have assessed whether "where" an athlete is born influences their likelihood of playing a professional team sport—this is called *birthplace effect*. A comparative analysis suggested that sociocultural factors, like place of birth, contribute more to the achievement of an elite level of sport performance than does relative age, for example (Côté et al., 2006; Baker et al., 2009). The quality of evidence that birthplace offers an advantage in regard to the development of a super-elite performance in sport is high to moderate, in spite of the fact that birthplace itself may not be as critical as the early development place. It is important to study and understand the effects of how the environment and neighborhoods in which the prospect athlete was raised can affect their future performance (Rees et al., 2016).

Our results showed that athletes from the southeast region and who moved to more developed Brazilian basketball centers all enhanced their chances of reaching the NBB. Athletes who had played in the southeast during the first competition category were the most important predictor for the "NBB players" career (large effect size). Besides, athletes who changed from one state to another and those that changed to other geographic region had better chances of reaching the NBB in relation to their peers. In Brazil, high-performance sport is centered in the southeast—a region of greater economic power in the country. The results of NBB 2014/2015 season indicated that there is a predominance of clubs from São Paulo state in the training of athletes, especially the city of Franca (Cunha et al., 2017). However, this centralized sport scenario did not favor the development of the Brazilian basketball (Beneli, 2018). A talented player needs to have an early exposure in an environment with more opportunities to develop to their full potential in basketball. Policy makers and practitioners must take into consideration the contextual factors when designing talent selection and development process.

In the present study, RAE influences the lower-level category career, but it does not determine success. The re-selected players who participated in the U15, U17, and U22 championship were 48% from Q1 and only 8% from Q4. The RAE relates to selection bias toward individual athletes born earlier in the year—chronologically older in the same competition category. This is a prevalent phenomenon in the Brazilian basketball (Oliveira et al., 2017, 2019; Ribeiro Júnior, 2020; Ribeiro Júnior et al., 2020). The coaches tend to select athletes born in the first quartile/semester in the youth categories, and this study confirms their influence on immediate success. However, RAE is not decisive for reaching the highest level. The de la Rubia et al. (2020) systematic review observed that the presence of the RAE is related to the competitive performance in the short term; in the contrary, in the long term, this effect is reverse in team sports. In the European youth national teams, the re-selection process is 20–25% greater for players born in the fourth quarter up until age 20 than for the players born in the first quarter (Kalén et al., 2020).

When observing the birth date in the Brazilian basketball, those born in the first months of the year are not necessarily those who played the NBB. For example, two younger athletes, even born in the same day, may have markedly different developmental experiences (Wattie et al., 2015). The direct and indirect RAE is on performance diagnostics during the talent identification process, especially body size and motor performance; and it is less evident in technical skills (Votteler and Höner, 2014). Athletes selected and competing in the youth categories, especially U15 and U17, are in general selected focusing on immediate results from temporary advantages provided by the RAE, while not favoring the development of the sport potential of Brazilian basketball. Young athletes may depart the sport prior to full maturity without having the opportunity to nurture their skills and inherent interest (Cobley et al., 2009). It is important to identify and develop talents providing a greater equality of opportunities to all athletes regardless of the birth month (de la Rubia et al., 2020). The search for immediate results by the scouters/coaches (Subijana and Lorenzo-Calvo, 2018), competitive environment of natural selection (Cobley et al., 2009; de la Rubia et al., 2020), lack of knowledge about the consequences of RAE (Hancock et al., 2013), and how much the lack of this knowledge can hinder the long-term training process are important aspects when overestimated or ignored. Coaches, scouters, and managers have to pay special attention to the RAE phenomenon in the selection processes.

There is a constraint-based developmental system model for RAE in sport with hypothetical causal components and interactive contribution to each individual, task, and environment constraint (Wattie et al., 2015). Another theoretical model proposes that social agents (parents, coaches, and athletes) have the largest influence on RAE (Hancock et al., 2013). One of the possible explanations of RAE, especially in team sports, is the hypothesis of biological maturation (Baxter-Jones et al., 2020). Our results showed that early-maturing players have three times more chance to reach high performance than on-time players. Maturational status seems to be a key aspect in physiological performance and selection in elite male basketball players (Arede et al., 2019). Coaches rating long-term potential of early maturing players as greater cause late-maturing athletes to have an increased risk of de-selection (Cripps et al., 2016). Early maturing players are frequently considered the "best" due to the advantages of strength, coordination, speed, and power, which favor being chosen to represent teams in their respective categories.

According to Subijana and Lorenzo-Calvo (2018), the athletes who participate in regional, state, and national teams have more time for deliberate practice and gain more learning experience. This fact may keep them during the career progression process, increasing the chances of these athletes to reach the high level contrary to the late-maturing ones. Nevertheless, future researches should observe the profile of these advanced athletes who reached the NBB in terms of their high-performance career, their continuity, and their competitive importance at this level, in order to solve doubts, if these advanced athletes have a representative career in the NBB, or just reached the high adult level of the Brazilian basketball, but do not remain competing. In rugby, late-maturing athletes appear to show more progression and "catch up" to the early-maturing player during adolescence over a 2-year period (Till et al., 2014). Coaches should be educated that slower responders may possess as much or more ability as fast responders to training programs. Both late developers and slower responders should be maintained in the process (Pearson et al., 2006).

The analysis presented in this study used a longitudinal and constraint-based approach to examine a number of available parameters. However, it is important to acknowledge that career progression of youth Brazilian basketball may be influenced by many others factors that are beyond the scope of this study. For example, motor performance, technical skills, tactical skills, psychological and sociological indicators, and individual performance are likely to influence the selection process and career progression of young basketball players.

Furthermore, individual, task, and environmental constraints should be used in a combined and longitudinal way for a better understanding of sport potential and career progression of young Brazilian basketball players. It is important to highlight not only the athletes who present immediate results in the initial stages of training process. The selection of athletes based on criteria, such as RAE, biological maturation, and high stature at the youth categories may diminish the opportunities of athletes with high sport potential in not participating in the national youth championships. Coaches need to assess the biological maturation of each player in order to minimize the risk of mistaken judgments and errors in the selection process, as well as the early exclusion of high potential young athletes. Athletes who show a late growth may not have the opportunity to develop their skills due to less playing time and participation in national-level championships. Thus, new opportunities for selection and re-selection of younger and late-maturing athletes should be given because they have a doubly temporary disadvantaged (Rubajczyk et al., 2017).

LIMITATIONS

First, the lack of sequences in the national competitions could provide some missing data that would provide more relevant information in the all level/category evaluated. Second, we did not consider a group of minors (players who played in above category) that could be addressed to control the chronological age and competitive level. This information is really important, although it was not the focus in the main objective of this present study; and it needs further investigation. Third, the database did not contain the individual performance in competition, and it was not provided from the organizers of the tournaments. This kind of data would be very important to present not only the presence of player in career progression but also the real impact of this participation on court.

CONCLUSION

The main study findings were a combination of individual, task, and environmental characteristics that influence the sport career of a young Brazilian basketball player in reaching excellence. The taller younger players, not selected for the U15 championship, who played U22 championship as the first competition category and are from the southeast region, while having played two or three youth national championships, not specializing too early in the playing position, and have moved to more developed Brazilian basketball centers all enhanced their chance of reaching the NBB. The birth dates of the athletes influence selection and re-selection to youth national championship, but they do not determine the "NBB players" career progression. In contrast, biological maturation is a key factor to reaching a higher performance level. Only 10% of the players in the youth Brazilian basketball championships U15, U17, and U22 reached the NBB from 2004 to 2018. These results present a holistic viewpoint from talent identification through the expert performance career and have the ability to assist in decisions for optimizing the career progression of youth Brazilian basketball players.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

DR, FW, HO, SI, and JV: conceptualization, formal analysis, methodology, project administration, supervision, validation, visualization, and writing—review and editing. DR, HO, and FW: investigation, resources, and writing—original draft preparation. All authors contributed to the article and approved the submitted version.

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The Influence of Contextual Aspects in Talent Development: Interaction Between Relative Age and Birthplace Effects in NBA-Drafted Players

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The aims of this study were two-fold: (1) to inspect separately for the relative age and birthplace effects for players selected in the National Basketball Association (NBA) draft; (2) to explore the interaction among these factors and analyse this interaction in players' career performance. The database was obtained from the official records of the players ($n = 1{,}738$), who were selected during the annual editions of the NBA Draft from 1990 to 2019. The participants' date of birth was analyzed according to the month of birth and divided into four quartiles. The place of birth was compared to the distribution of the general population' places of birth based on different communities' sizes. Chi-square analysis were used to determine if the relative age and birthplace of the players drafted differed in any systematic way from official census population distributions. Cluster analysis and standardized residuals were calculated to analyse the interaction among the contextual factors and the players' career performance. The data revealed that early-born players (Q1 and Q2) were over-represented. Moreover, players born in smaller cities (<100,000) were over-represented. The interaction analysis revealed that the players born in the bigger communities relate mainly with relatively younger players, and clusters that correspond to players born in smaller communities integrated the relatively older players. No differences were found in the players' career performance. Researchers, coaches and practitioners should be aware of the interaction between contextual factors to help nurture the development of sport talent regardless of age-related issues or communities' size.

Keywords: environmental factors, talent development, date of birth, place of birth, interaction, selection, basketball

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INTRODUCTION

A growing core of scientific research has shown that contextual factors play a key role in talent development (Baker et al., 2009; Rees et al., 2016; Williams et al., 2020). In particular, the role of contextual variables such as the date of birth (Castillo et al., 2019; De la Rubia et al., 2020a), and the place of birth (Rossing et al., 2015; Pennell et al., 2017; Wattie et al., 2018) have been consistently associated with improved chances of attaining elite sport.

The biased distribution of the dates of birth, known as the relative age effect (RAE), has been confirmed in several studies in the field of sports sciences and other domains, such as in academic performance (for references see Nakata et al., 2017). In that way, evidence confirm this phenomenon, in which individuals born earlier in the selection year relative to a predetermined cut-off date (e.g., January 1–December 31) are often overrepresented compared to those born later in the same selection year (Fumarco et al., 2017; please see De la Rubia et al., 2020a). In this sense, relatively older athletes are systematically associated with higher stature and better aerobic capacity, endurance and speed, what provides them with a competitive advantage in physical performance (Rada et al., 2018). Related to physical advantages, critical in childhood and adolescence, the relatively older athletes are generally considered to have greater potential and consequently with an increased likelihood of being selected to play and practice in a more challenging environment, and to be supervised by more experienced coaches, what may eventually lead to improved feedback mechanism and competitiveness (Musch and Grondin, 2001; Bezuglov et al., 2019). In contrast, relatively late-born athletes are more unlikely to obtain similar early opportunities, which will inevitably make their road to success more difficult (Arede et al., 2019a).

Scientific evidence in the literature has shown that contextual factors such as the place of birth (known as birthplace effects where the subject was born and grew up during the developmental years, Lidor et al., 2014) also can influence an athlete's likelihood of elite sporting attainment (Côté et al., 2006; MacDonald et al., 2009b; Imtiaz et al., 2014; Turnnidge et al., 2014; Ishigami, 2016; Wattie et al., 2018; Kaida and Kitchen, 2020). In that way, mixed results have been reported for the birthplace effects. For example, early studies (Côté et al., 2006) revealed that athletes born in cities of less than 500,000 inhabitants were more likely to play for professional leagues than athletes born in larger cities. Researchers reported that higher developmental opportunities may be associated with smaller cities, including improved mobility and safety conditions for play and practice, cultural and closer personal relationship between athletes and coaches (Davids and Baker, 2007). Nevertheless, recent studies showed different results as larger cities were just as effective in producing elite athletes in smaller cities (e.g., Schorer et al., 2010). The authors highlighted the fact that bigger cities can offer better-designed and equipped sporting facilities (e.g., arenas, fields, and swimming pools) and more experienced coaches (see Baker et al., 2009; Schorer et al., 2010). Despite such assumptions, the extent to which these trends apply to other sports and sport development systems in other countries remains to be determined. Though some authors have already identified some inconsistencies in the birthplace definition (Rossing et al., 2015), fundamentally due to the differences found among the place of birth, the athlete's place of development, the first club, and the inaccurate interpretation that may arise from this misconception, the fact is that birthplace studies are still scarce and further contributions can be potentially decisive to improve the process of talent identification and development.

Over the past few years, some studies have examined the RAE and the birthplace effects with the same group of athletes (Côté et al., 2006; Baker et al., 2009; MacDonald et al., 2009a; Lidor et al., 2014; Turnnidge et al., 2014; Ishigami, 2016). However, most of these studies analyzed these contextual factors on limited geographical areas. In fact, there is an important gap to cover in the scientific literature that could be bridged in comparing youth sport policies and developmental systems. For instance, the development of high-level athletes in European countries is mainly based on club teams, while in the USA, they emerge from the school system. Moreover, while prior studies have confirmed the influence of these factors in a number of different sports in various countries, they have not demonstrated how these aspects interact (Bruner et al., 2011) and affect the chances of playing in a professional league like the NBA (*National Basketball Association*). The odds of a pre-high school player being chosen to play at a professional level in the NBA are intrinsically low, and only a small part of these players is selected through the NBA Draft (Koz et al., 2012). This is competitive event, where the league franchises obtain the professional rights of players who do not yet have a contract with any team in the competition. A total of 60 players are selected each year and the order of selection of these players is stipulated by the lottery draft that takes in account the teams' final balance of victories and defeats from the last NBA season.

To the best of our knowledge, this is the first study dedicated in examining the long-term effect of both contextual factors, in the NBA career performance. Thus, the aims of this study were two-fold: (1) to inspect separately for the RAE and birthplace effects for USA players and for players born in the European countries; (2) to explore the interaction among these contextual factors and the long-term effect in the players' career performance. Drawing upon existing literature in sport sciences, it was hypothesized that the RAE and the birthplace effects influence the likelihood of being selected to play in the NBA; and, that the interaction among these factors exist and that it can also be observed in the players' career performance.

METHODS

Participants

The database was obtained from the records of all players ($n =$ 1,738), selected during the annual editions of the NBA Draft, from 1990 to 2019. The database included players born in 67 different countries, 1,389 players born in the USA, 237 born in the European countries, 37 in African countries, 44 in South American countries, and finally 29 in Asian countries (**Figure 1** and **Table 1**).

The players who were selected in the NBA Draft but failed in accumulating a significant experience in the league, i.e., never played in any NBA team or did not completed 1 full and consecutive season (minimum 82 games) were not considered for analysing the *second aim of this study*, i.e., the interaction among the contextual factors and the players' career performance. The present study was approved by the institutional research ethics committee (UID04045/2020) and conformed to the recommendations of the Declaration of Helsinki, with the Fortaleza actualization (Hellmann et al., 2014).

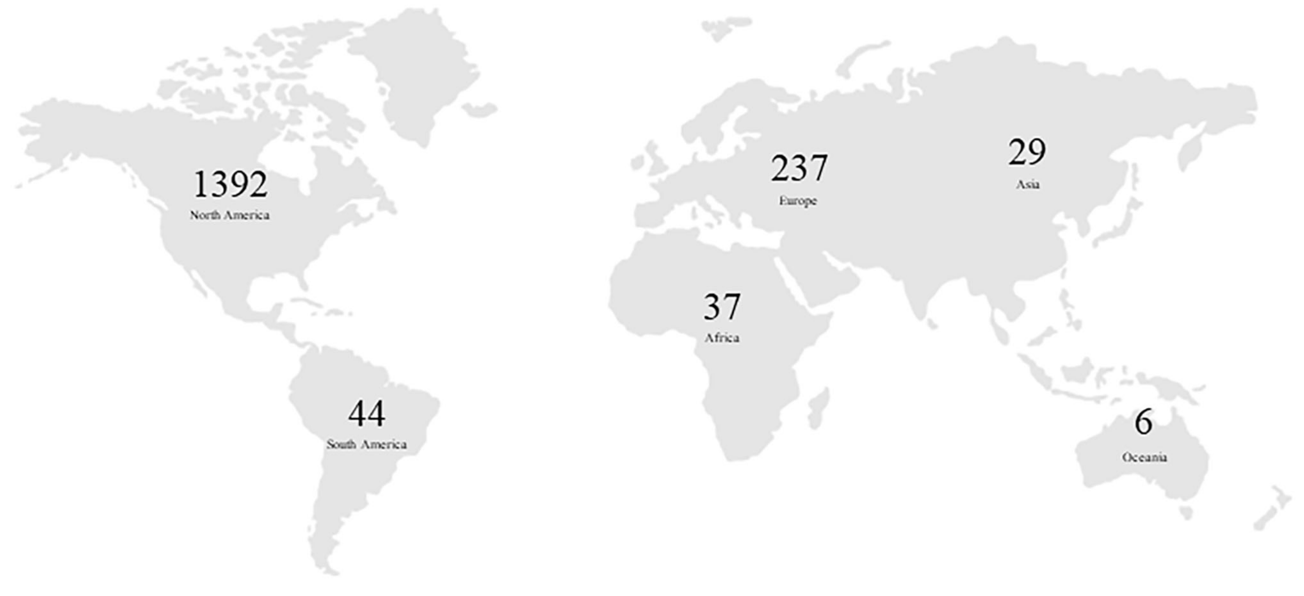

FIGURE 1 | Number of players drafted per continent (between 1990 and 2019).

TABLE 1 | Number of players drafted per country (between 1990 and 2019).

Country	# Players
USA	1,389
France	30
Serbia	26
Bosnia-Herzegovina	17
Spain	16
Lithuania	14
Croatia, Germany, Slovenia	12
Greece, Turkey	11
Brazil, Nigeria, Ukraine	10
Montenegro	9
England, Senegal	8
China, Russia	7
Italy, Latvia	6
Czechoslovakia, Israel	5
Argentina, Australia, Belgium, Congo, Georgia, Switzerland, Sudan, Sweden, Dominican Republic	4
Canada, Finland, Ghana, Haiti, Guadeloupe, Netherlands, Mali, Poland, Puerto Rico	3
Egypt, Jamaica, New Zealand, Romania, Trinidad and Tobago, Zaire	2
Angola, Austria, Belarus, Cape Verde, Central African Republic, Denmark, Estonia, Guinea, Hungary, India, Iran, Japan, Korea, Uzbekistan, Venezuela, Taiwan, South Africa, Saint Vincent and the Grenadines, Mexico, Luxembourg	1

Procedure

Official players' data collection was completed in two consecutive steps. First, the date and place of birth of the players selected to the NBA Draft, were collected from the Basketball reference website (https://www.basketball-reference.com/). Second, individual career stats accumulated in the NBA were collected form the official league website (https://www.nba.com/). The participants' date of birth was first analyzed according to the month of birth. The cut-off date was January 1st. Thus, the year was divided into four quartiles: Q1, January 1st–March 31st; Q2, April 1st–June 30th; Q3, July 1st–September 30th; and Q4, October 1st–December 31st (**Figure 2**).

The place of birth was compared to the distribution of the general population' places of birth according to different city or communities' sizes categorization (Côté et al., 2006), into 1 of 8 census population categories: (1) more than 5,000,000 million of inhabitants; (2) between 2,500,000 and 4,999,999; (3) 1,000,000–2,499,000; (4) 500,000–999,999; (5) 250,000–499,999; (6) 100,000–249,999; (7) 50,000–99,999; (8) less than 50,000 inhabitants.

To investigate the *first hypothesis* and considering the considerable number of players born in European countries drafted by NBA teams and simultaneously the interest of comparing the RAE and birthplace across countries and continents, we conducted a separate analysis for players born in the USA and born in the European countries. However, the singularity of each European country registration system, the methods of defining demographic maps as well as, the particularities of the territorial organization limited a more comprehensive analysis of the interaction among the RAE and the birthplace also for the players born in European countries (i.e., the *second hypothesis*). This procedure was also supported by the lack of consistency of the evidence found in several studies examining the birthplace effects in European born players in comparison with, for example USA (Baker et al., 2009; Lidor et al., 2010, 2014; Schorer et al., 2010; Bruner et al., 2011; Rossing et al., 2015). Contextual factors such as cultural differences intra-

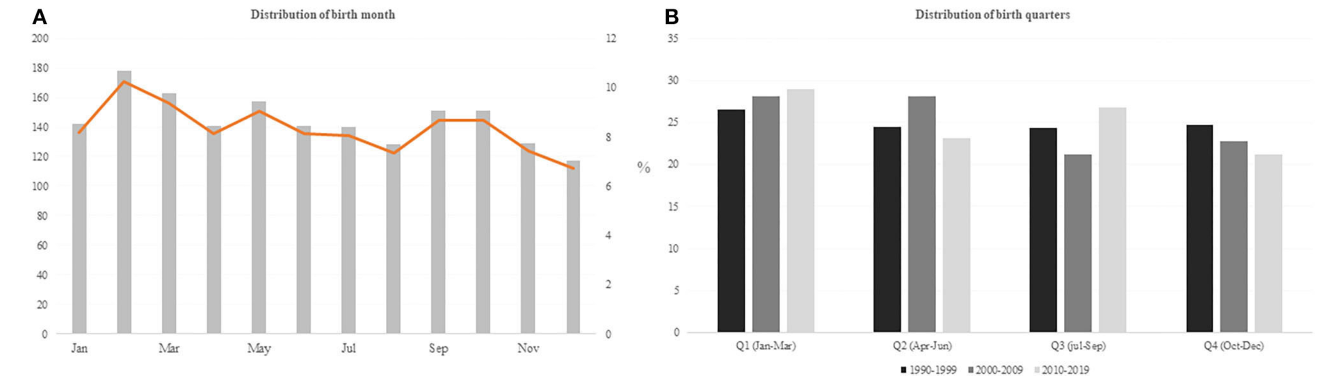

FIGURE 2 | Distribution of **(A)** birth months (left) and **(B)** birth quarters according to the decades of the NBA draft (right).

and inter-regional communities within European countries, distances among communities, the number and quality of sport facilities, the number of experts or the competitive depth of a given sport, represented important obstacles that could further justify this inconsistency in European results. For this reason, to proceed with the *second hypothesis* of this study, we chose to select only the players born in the USA (n = 1,389).

Statistical Analysis

In accordance to the statistical procedures used in previous studies examining the RAE and/or the birthplace (Hancock et al., 2018), we analyzed the differences among the distributions of observed and expected percentages.

After analyzing the variables for skewness, kurtosis, normality distribution through Kolmogorov–Smirnov test, and the equality of variances by Levene test, parametric or nonparametric statistical tests were used when appropriated assuming a confidence level of 0.05. A chi-square test χ^2 was used to analyse de distribution of dates of birth across the 4 quartiles Q1, Q2, Q3, and Q4. Odds ratios (OR) and 95% confidence intervals (CI) were calculated to determine the odds of a player born in Q1 (January–March) playing in the NBA compared to the odds of a player born in Q2, Q3, and Q4. An OR with CI limits (lower and upper) higher than 1 indicates that a disproportionately high number of NBA-drafted players were observed in each quartile compared to that expected due to the general population distribution. Correspondingly, an OR with CI lower and upper limits lower than 1 indicates that a disproportionately low number of drafted players was observed. RAE were compared among the different groups (quartiles) using Wilcoxon and Mann–Whitney U tests.

Similar statistical procedures were used to analyse the differences among the distributions of observed and expected communities' size categories. Thus, χ^2, ES, OR, and 95% CI were calculated to determine the odds of a player born in a smaller community, i.e., < 50,000 inhabitants playing in the NBA compared to the odds of a player from the remaining categories. For analysing RAE and birthplace effects, we selectively used data from USA's 1990 Data and Statistics and Europe's 2000 Eurostat, as they were the closest possible to the average year of birth of the players included in our selective sample.

Cluster analysis was performed using Ward's method—squared Euclidian distance as a distance measure—using RAE and birthplace effects quartiles and communities' size. The χ^2 test was used to examine between-conditions differences in terms of RAE and birthplace effects. Standardized residuals (e) were used to determine which variable(s) in each category contributed most to the value of χ^2. Cells which contained values of standardized residual that were higher than 1.96 (e> 1.96), were considered influent for the model.

Univariate analysis of variance (ANOVA) test and Tukey's *post-hoc* test was used in conjunction to examine the differences between clusters. Statistical analyses were performed using SPSS v.25 software (Inc., Chicago, IL, USA) and significant level was set at $p < 0.05$.

RESULTS

Table 2 presents the frequency and percentage distribution of the drafted players' birth quartiles. The χ^2 analysis confirmed a biased distribution both for USA and European players (p = 0.005 and p = 0.028, respectively). For American players, the distribution of the players' birthdates in Q1 (28.2%) was higher than those in Q2 (23.9%), Q3 (24.7%), and Q4 (23.3%). The analysis of the RAE for players born in European countries revealed similar results, however the higher percentage was observed in Q2 (32.1%). For USA players, the likelihood of player born is Q1 being selected to play in the NBA yielded an OR higher than 1 [OR = 1.236, CI (1.044–1.465)]; similar results were found for European players, as Q1 and Q2 presented an OR higher than 1 [OR = 1.148, CI (0.760–1.734); OR = 1.378, CI (0.924–2.051), respectively].

The distribution of the USA and European players across different communities' size categories are displayed in **Table 3**. Results confirmed a different distribution in the categories between the USA and European census and the players selected for the NBA Draft. Smaller categories are over-represented in the drafted players, especially with less than 100,000 inhabitants, both for USA and European draftees. Moreover, communities with a population above 1,000,000 yielded an OR lower than 1. This means that the likelihood for players born in big city to be selected and play in the NBA was lower than for players born in

TABLE 2 | Descriptive and inferential analysis for dates of birth for USA and European players.

Birth quarter	USA						Europe					
	CDC[a]	%	OR	CI	χ^2	*p*	EU[b]	%	OR	CI	χ^2	*p*
Q1 (Jan–Mar)	24.10	28.2 (392)	1.236	1.044–1.465	12.888	0.005*#	24.36	27.0 (64)	1.148	0.760–1.734	9.13	0.028$
Q2 (Apr–Jun)	24.96	23.9 (332)	0.944	0.794–1.122			25.54	32.1 (76)	1.378	0.924–2.051		
Q3 (Jul–Sept)	26.43	24.7 (343)	0.913	0.770–1.083			25.85	19.4 (46)	0.690	0.447–1.065		
Q4 (Oct–Dec)	24.60	23.3 (324)	0.931	0.782–1.108			24.25	21.5 (51)	0.855	0.556–1.314		

*[a]Data collected from USA's 1990 Data & Statistics. [b]Data collected from Europe's 2000 Eurostat. *Significant difference ($p < 0.05$) between Q1 and Q2; #Significant difference ($p < 0.05$) between Q1 and Q4; $Significant difference ($p < 0.05$) between Q2 and Q3.*
Legend: OR, odds ratio; CI, confidence interval.

TABLE 3 | Descriptive and inferential analysis for places of birth for USA and European players.

Population size	USA				Europe			
	CDC[a]	%	OR	CI	EU[b]	%	OR	CI
>5,000,000	23.19	0.7	0.024	0.013–0.045	0.92	0.7	0.759	0.165–3.496
2,500,000–4,999,999	13.91	9.6	0.657	0.520–0.830	2.30	4.2	1.862	0.987–3.513
1,000,000–2,499,999	15.65	8.5	0.501	0.395–0.635	11.07	9.2	0.796	0.511–1.242
500,000-–999,999	10.49	15.6	1.577	1.260–1.974	14.61	10.9	0.715	0.475–1.076
250,000–499,999	9.12	11.9	1.346	1.054–1.718	14.54	12.6	0.847	0.577–1.244
100,000–249,999	8.94	15.7	1.897	1.501–2.397	10.23	16.7	1.759	1.251–2.475
50,000–99,999	0.7	13.7	2.109	1.632–2.726	1.31	16.7	15.103	10.736–21.248
<50,000	18.00	24.4	1.471	1.224–1.767	45.02	26.8	0.447	0.335–0.596

[a]Data collected from USA's 1990 Data & Statistics. [b]Data collected from Europe's 2000 Eurostat.
Legend: OR, odds ratio; CI, confidence interval.

a smaller community. In addition, the likelihood for players who were born in a smaller city (i.e., 50,000–99,999) was higher than the remaining categories [USA OR = 2.109, CI (1.632–2.726); EU OR = 15.103, CI (10.736–21.248)].

The cluster analysis established different levels of interaction in terms of birth quartiles, communities' size categories and career stats profiles. **Table 4** and **Figure 3** displays these interactions where it stands out (i) clusters corresponding to the players born in the bigger communities relate mainly with relatively younger players; (ii) clusters that correspond to players born in smaller communities integrated the relatively older players; (iii) no differences were found in the career stats.

DISCUSSION

The main aims of this study were two-fold: (1) to inspect separately for the RAE and birthplace effects for players born in the USA and in the European countries; (2) to explore the interaction among these contextual factors and the long-term effect of both these factors in the players' career performance. We found a biased distribution of the birth quartiles, as the number of players born in Q1 or Q2 was higher than that of those born in Q3 or Q4 both for those born in the USA and born in European countries. These results are consistent with previous research confirming an advantage in favor of the earlier born players emerging from the athletic programs of colleges and universities in the United States of America, Canada and European clubs.

The NBA is an extremely competitive professional league, which makes highly demanding the process of preparing and selecting players. The franchises have to choose the best players based on their abilities and potential, but must be able to predict the level of future performance. Thus, the selection process (i.e., the NBA Draft) is highly conditioned by the players' performance and favors the selection of those athletes who were born in the first months of the year and that will have a greater impact on the team's performance (De la Rubia et al., 2020a). In the case of basketball, the presence of the RAE still manifests itself around 20–22 years of age, at the same age category where NBA Draft take place (De la Rubia et al., 2020a). Therefore, there may be a ripple effect that benefits the selection of relatively older athletes, despite it still unknown how it affects the long-term performance of the athlete, that is, in his sports career.

In sports like basketball, the "maturation-selection hypothesis" applies, i.e., relatively elder players are naturally heavier, taller, stronger, and faster than other (Baker and Logan, 2007; Zaric et al., 2020), and can simultaneously benefit from an advantage resulting from being born in an earlier month, but also from an early maturation, to have better opportunities (Arede et al., 2019b). This seems to make sense, given that the anthropometric aspects important factor for the performance in basketball (Teramoto et al., 2017; Zaric et al., 2020). In fact, the results obtained during the annual event hosted by NBA dedicated to assess the players with greatest potential (i.e., NBA Draft Combine) have shown that length-size aspects, such as height, body mass, wingspan, and hand dimensions have the greatest positive correlation with on-court performance in the NBA, in the short and medium term (Teramoto et al., 2017). However, based on present results, we may hypothesize that this initial physical/anthropometric advantage (i.e., the NBA Draft)

TABLE 4 | Descriptive and inferential analysis for career performance, RAE and birthplace for USA players.

		Cluster 1 *n* = 375	Cluster 2 *n* = 184	Cluster 3 *n* = 189	Cluster 4 *n* = 172	Cluster 5 *n* = 247	Cluster 6 *n* = 222	*p*
Career performance	%GS	32.6 ± 30.9	32.9 ± 29.5	32.8 ± 31.1	34.3 ± 30.4	30.8 ± 29.6	33.3 ± 31.1	0.924
	MPG	18.3 ± 9.0	18.5 ± 8.4	18.1 ± 9.0	18.5 ± 8.6	18.3 ± 8.2	19.2 ± 8.7	0.880
	PPG	18.0 ± 4.8	17.3 ± 4.8	18.3 ± 5.8	17.7 ± 6.5	17.5 ± 4.7	18.7 ± 7.5	0.159
	Rebounds	8.1 ± 3.5	8.5 ± 3.7	8.7 ± 3.7	8.4 ± 3.9	8.3 ± 3.4	8.0 ± 3.6	0.429
	Assist:TO	1.4 ± 0.8	1.3 ± 0.7	1.2 ± 0.7	1.3 ± 0.7	1.4 ± 0.7	1.4 ± 0.8	0.127
	PPIndex	41.7 ± 8.8	40.7 ± 9.4	42.3 ± 11.1	41.3 ± 12.0	40.8 ± 9.0	42.4 ± 11.8	0.478
Birth quarter	Q1 (Jan–Mar)	−6.3	**12.2**	−7.3	−7.0	**3.2**	**6.5**	
	Q2 (Apr–Jun)	1.3	0.0	−6.7	−6.4	**2.4**	**7.6**	
	Q3 (Jul–Sep)	**3.5**	−6.7	**8.3**	−0.4	1.7	−7.4	
	Q4 (Oct–Dec)	**2.0**	−6.5	**6.3**	**14.5**	−7.6	−7.2	
Birthplace	>5,000,000	**4.4**	−1.2	−1.2	−1.1	−1.3	−1.3	
	2,500,000–4,999,999	**16.3**	−4.2	−4.3	−4.1	−4.9	−4.6	
	1,000,000–2,499,999	**8.8**	**5.4**	−4.0	−3.8	−4.6	−4.4	
	500,000–999,999	**11.8**	**7.5**	−5.4	−5.2	−6.2	−5.9	
	250,000–499,999	−6.7	**11.9**	**13.9**	−4.5	−5.4	−5.2	
	100,000–249,999	−7.5	−5.3	**13.3**	−5.1	−6.1	**13.2**	
	50,000–99,999	−7.2	−5.0	−5.1	**11.0**	−5.8	**14.9**	
	<50,000	−9.6	−6.7	−6.8	**8.1**	**23.9**	−7.4	

Legend: %GS, % of game starts; MPG, minutes per game; PPG, points scored per game; Steal:TO, ratio steal per turnover; Assist:TO, ratio assist per turnover; PPIndex, player performance index. Data is presented as M ± SD. Bold corresponds to cells which contained values of standardized residual that were higher than 1.96 (e > 1.96).

is circumstantial and does not remain across the professional career; instead, relatively younger players born in Q3 e Q4 (USA) and Q3 (European countries), i.e., may overcome that disadvantage and gradually develop the physical, technical, tactical, and mental skills required to succeed in the NBA (Sampaio et al., 2015). These results are particularly important given that, for the first time, they confirm that in a long-term development perspective, elite basketball seems not to favor the relatively older players.

Previous knowledge about players' potential as well as coaches and scouts' biases, should be considered as another possible reason for our results (Till and Baker, 2020). For example, Mann and van Ginneken (2017) reported that the selection bias could be reduced when scouts watched junior soccer games analyzing the shirt numbers corresponded to the RAE of the players. The authors concluded that the selection bias associated with the RAE can be reduced, if information about age is presented appropriately. Although the RAE investigation is extensive (see De la Rubia et al., 2020b for extensive review on the RAE), many coaches and scouts are not yet fully informed about this phenomenon, and therefore, further investigation and an effective bridge between science and practice is required (Olswang and Prelock, 2015).

The results of our study are consistent with previous literature on birthplace effects, showing that the place where the athlete is born does not hinder the possibility of attaining elite performance (MacDonald et al., 2009b). Interestingly, a great number of players drafted to the NBA born in smaller cities (< 50,000; 24.4 and 26.8% for USA and European players, respectively). The same trend has been observed in different professional sports, such as ice hockey, baseball, golf, football, and soccer (Côté et al., 2006; MacDonald et al., 2009a,b; Wattie et al., 2018).

Globally, evidence from our study confirm that smaller communities can match medium and large communities in early opportunities for talent development. While the notion of the "small town effect" has been examined recently, most of the researchers did not find empirical evidence to support that concept in pathways to sport expertise (Pennell et al., 2017). Several explanations for the contribution of communities of this size to the development of talent in sport have already been proposed, among which we underline larger social support by their peers, families, enabling them to develop their skills and also an increased perception of safety in open-spaced areas (MacDonald et al., 2009a). Moreover, these smaller population areas can also foster more supportive relationships between coaches and athletes, and even with the social context that surrounds the sport that favor the feeling of belonging as well as a much more positive learning context. Under such circumstances, young athletes are more likely to develop a positive self-concept and acquire the necessary motivation for a long-term and positive involvement in sport (Moesch et al., 2013). Additional benefits have been associated to smaller communities. In fact, children seem to allocate more time to the multi-faceted process of learning the sport skills that are relevant to their specific sport or being able to practice sport in a less structured environment ("deliberate play"), in such a way that it favors the development of tactical creativity and perceptual and decision-making capacity (Berry et al., 2008; Greco et al., 2010; Memmert et al., 2010; Ford et al., 2011; Leite and Sampaio, 2012; Arede et al., 2019a).

FIGURE 3 | Violin plots including RAE and BPE density distribution amongst distinct clusters. Note: Birthplace categories should be interpreted as (1) more than 5,000,000 million of inhabitants; (2) between 2,500,000 and 4,999,999; (3) 1,000,000–2,499,000; (4) 500,000–999,999; (5) 250,000–499,999; (6) 100,000–249,999; (7) 50,000–99,999; (8) less than 50,000 inhabitants. Birth quarters should be interpreted as (1) Janury–March; (2) April–June; (3) July–September; (4) October–December.

Simultaneously, playing more often against the same opponents can have a beneficial effect. In a team sport like basketball, having prior knowledge about your opponent strengths and weaknesses, can help the player to be more focused on improving and recognizing offensive and defensive game patterns to explore.

The second aim of the study was to examine the potential interaction between RAE and birthplace in players born in players born in the USA players. The only available study that hypothesized about this interaction was done by Bruner et al. (2011), however, no evidence of interaction was found. Interestingly, our data supported the theoretically driven hypothesis that USA players born in the bigger communities were relatively younger; players born in smaller communities integrated relatively older players; and NBA career performance was similar irrespectively of this interaction. According to Barker's "theory of behavior settings" (Barker, 1968) the number of people in a behavior setting will influence an individual's behavior. Thus, it could be expected that situations with fewer (i.e., smaller) or more than (i.e., bigger) the optimal number of participants needed to complete a task will result in different experiences for individuals involved. Thus, in light of our results, it may be hypothesized that smaller communities may be more likely to promote greater youth developmental opportunities for relatively older athletes, while bigger communities may be more appropriate environment for relatively younger athletes. Smaller cities seem to provide an environment in which, despite infrastructural resources, the number of teams and players being smaller, the need to select athletes based on their skill and maturation levels is higher. Consequently, RAE may be reduced or even removed in higher cities where these variables are not an issue, and therefore, seem to be more appropriate to further develop talent. Despite the interest and usefulness of these results for talent development, future studies are warranted to test this interaction.

The interaction little explains about the NBA career, however their experiences until getting there may have been influenced by these two factors. Both players who came from bigger cities or born in last quarters can be exposed to adverse experiences in their development, due to their disadvantageous status (McCarthy and Collins, 2014; McCarthy et al., 2016; Collins and Macnamara, 2017). However, they can perform a greater effort in the learning process, but also develop psychological skills becoming more able to overcome difficulties (Cobley et al., 2009; Gibbs et al., 2012), what can become a long-term advantage. The possible additional pressure experienced by the player born at the end of the year, can be an advantage in the long term. Undoubtedly, the challenge would be to know which of these two types of populations is likely to have a higher performance in the long term or to have longer and more successful sports careers.

The results of this study provide compelling evidence that contextual factors influence the likelihood to being selected to play in NBA. However, we must address potential limitations of our study, which must be acknowledged. First, the NBA Draft is an highly selective event, in which teams try to address their particular needs and not only look into de best prospect available in the board, regardless of the RAE and birthplace effects (Zhang et al., 2018). This logic is also observed in elite football that favors late maturing boys succeed in achieving elite level, despite not having benefited from a maturation bias through development process (Ostojic et al., 2014). That said, as the level of performance increases, performance in the short and medium term, considering the needs of the team can be decisive, more than other contextual factors.

Second, a challenge in birthplace effects studies is the analysis of population categories. We followed previous categorization used in studies with North-American athletes, but in each state, there are significant variations not only in terms of communities' sizes and also in population density. Researchers should be encouraged to explore methods by which to limit such variability, enabling stronger within-category consistency. This sizeable variation is even more critical in European countries, however, while we admit this limitation, we believe that this could trigger further studies that could highlight differences within European sport policies and youth development programs.

Additionally, it is important to acknowledge that birthplace does not always coincide with the athlete's place of development and that athletes may migrate among locations. For example, athletes born in small rural communities may move to larger urban centers during their childhood (Schorer et al., 2010). Another limitation may be the fact that this research is based on the interaction of the RAE and the birthplace effects in the short term, at a very specific moment such as the choice of the NBA Draft, but it would probably be more interesting to know the interaction of these effects in the long term, throughout the athlete's career, to know which players can have a longer sports career or have a higher performance.

CONCLUSIONS

The results of the current study confirm a biased distribution for players born in the initial months in each selection year against those born in smaller cities in the NBA. Evidence from this study is consistent with previous literature providing important considerations about the influence of contextual factors in achieving expertise in sport. Understanding the interaction between RAE and birthplace effects, can help researchers and practitioners on how to design sports systems and practice approaches to help nurture talent. Creating the most favorable environment for talent development is highly complex, due to performance multidimensionality. Delaying the selection of players until ages like those used in NBA Draft (mostly after 19–20 years) is a suggestion systematically repeated by experts, but at the same time we must continue on a path to discover and integrate new variables in performance analysis. The results of this study represent an important contribution in this field since this interaction between contextual factors hasn't been described in the literature and in addition to helping us to know better the system, it can contribute to increase retention and improve coaches decision making.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Trás-os-Montes and Alto Douro. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

NL, JA, and XS: conceptualization. NL, JA, and XS: investigation. NL and JA: methodology. NL, XS, and JA: data curation. NL, JA, XS, JC-G, and AL: formal analysis. NL and JA: software. NL and XS: writing—original draft. NL, JA, JC-G, and AL: writing—review and editing: All authors contributed to the article and approved the submitted version.

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Selected, Deselected, and Reselected: A Case Study Analysis of Attributes Associated With Player Reselection Following Closure of a Youth Soccer Academy

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Considering the perceived benefit of early recruitment and the time and resources spent developing youth players, individuals released from talent development programmes are often re-recruited by rival academies. However, due to the contractual nature of many talent development programmes, limited empirical data exists on players deselected from (or reselected to) youth soccer academies. Adopting a novel case study approach, differences in skill, psychological, and physical attributes associated with reselection following closure of a junior-elite soccer academy were explored. Overall subjective coach ratings for skill, psychological, and physical abilities; subjective coach ratings for skill and psychological attributes; and physical fitness test performance of 79 junior-elite soccer players (U11–U17) were assessed as part of regular scheduled testing and monitoring practices prior to the academy closure. Reselection status was monitored and recorded for all players in the 6 months following the academy closure and was classified as a persistence/progression ("Reselected") or attrition ("Deselected") in playing level. Of the 79 released players, a total of 60 players (76%) were re-signed to a junior-elite academy within 6 months. Differences were observed for overall ratings of skill, psychological, and physical abilities in favor of the "Reselected" player group. "Reselected" players were also rated higher by coaches for all attributes categorized as skill and psychological, as well as performing better at all physical fitness tests. However, "Reselected" players were lesser in stature and body mass and less mature than "Deselected" players. Our findings suggest that reselection is not a product of anthropometric criteria and, therefore, a pathway for selection remains open for later maturing players. We also inform upon desirable qualities associated with player reselection and provide a case study approach of a unique, yet highly relevant, scenario for talent identification and development in youth soccer.

Keywords: talent identification, talent development, selection, recruitment, football, decision making

INTRODUCTION

Talent identification (TI) and talent development (TD) of youth players are important factors when considering future financial and competitive benefits for soccer clubs (Unnithan et al., 2012). In soccer, professional clubs operate academy systems providing systematic training programmes for youth players starting as young as age four, and progressing toward professional transition at ∼18 years of age. Early recruitment and prolonged exposure to TD programmes is highly desirable for coaches and recruiters, as it provides a greater timeframe to develop skills and expertise necessary to succeed at the professional level (Vaeyens et al., 2008; Burgess and Naughton, 2010; Williams et al., 2020). However, high turnover of youth players is reported within professional soccer academies, with only ∼10% of players successful in obtaining professional contracts (Grossmann and Lames, 2015).

It is well-established that potential predictors of talent are multidimensional in nature (Reilly et al., 2000; Unnithan et al., 2012; Sieghartsleitner et al., 2019). Therefore, consideration is given to physical, sociological, and psychological attributes along with technical skill abilities when making decisions around TI and (de)selection in soccer (Williams et al., 2020). Evidence from the extant literature suggest that differences in multidimensional characteristics are evident between distinct playing standards of youth soccer players (Waldron and Worsfold, 2010; Huijgen et al., 2015; Dugdale et al., 2019), and they develop resultant of exposure to TD programmes (Burgess and Naughton, 2010; Williams et al., 2020). However, due to the contracted nature of many TD programmes, limited empirical data exist on players deselected from (or reselected to) youth soccer academies.

In their study of elite Dutch soccer players, Huijgen et al. (2014) suggested that differences in technical, tactical, and physiological characteristics may exist between players selected vs. deselected from TD programmes, supporting the value of multidimensional performance assessments to inform selection decisions in more homogenous groups. Similarly, Figueiredo et al. (2009) found that Portuguese youth soccer players selected to a higher competitive playing level performed better in functional capacities and skills tests comparative to players who persisted or regressed in playing level. Finally, when considering the impact of deselection and reselection on long-term TD, Güllich (2014) found that players who were successful at the professional level experienced repeated selection and deselection through youth, as opposed to early selection and continuous, long-term nurture within German TD programmes, advocating the value of reselecting previously deselected players within TI processes.

Biological and anthropometric factors may also influence TI and (de)selection processes within academy soccer. A plethora of evidence suggests that soccer players selected to academy programmes are larger in body size and biologically more mature compared to players of a lesser playing level (see Malina et al., 2017 for a review). Furthermore, an asymmetry in birthdate distribution favoring those born earlier in the selection year, commonly referred to as the relative age effect (RAE), is widely reported within academy soccer (Helsen et al., 2005; Carling et al., 2009; Lovell et al., 2015). Scientists suggest that these factors (un)consciously affect decision making during TI and TD processes due to acute performance benefits, despite concerns around the value of these attributes to youth-professional transition (Meylan et al., 2010; Kelly and Williams, 2020). However, although the extant literature on deselected and reselected players is scare, evidence suggests that biological, anthropometric attributes or birthdate distributions do not differentiate between these player groups, likely due to the physical and biological homogeneity of academy soccer players (Huijgen et al., 2014; Platvoet et al., 2020).

Considering the influence that financial decisions play on soccer academy operations (Reeves et al., 2018b), several clubs have recently made the decision to close their academies, prioritizing investment in their first team and sourcing players externally as opposed to investing in home-grown talent. In contrast, there are many clubs who greatly value their academies, placing TI and TD at the forefront of their philosophy and operations (Cushion et al., 2012; Larkin and Reeves, 2018; Reeves et al., 2018b). This may result in a core of players who possess the same ethos and an affinity for the club, potentially leading to talented academy graduates or income generation through player sales and transfers (Grossmann and Lames, 2015). Considering this disparity in philosophy and the perceived benefit of systematic TD, clubs invested in youth academy infrastructures may view deselected players favorably. As a result, individuals released from academy programmes are often recruited by rival clubs (Vaeyens et al., 2008; Unnithan et al., 2012). Providing information regarding multidimensional attributes associated with reselection of players deselected from TD systems would, therefore, be valuable for coaches and practitioners working within TI and TD.

Adopting a novel case study design, we explored differences in multidimensional attributes of players related to persistence/progression ("Reselected") or attrition ("Deselected") in playing level following closure of a youth soccer academy. Considering the rarity of this scenario, our findings may inform upon desirable qualities associated with player reselection and provide a case study approach of a unique yet highly relevant scenario for talent identification and development in youth soccer.

METHODS

Participants

A total of 79 male youth soccer players aged 10.2 to 16.7 years (M: 13.2 ± 1.9) were recruited. At the time of data collection, players were affiliated to a "Progressive" junior-elite soccer academy as classified by the "Project Brave" initiative of the Scottish Football Association (SFA) (SFA, 2017). Participants were categorized into age groups as specified by the SFA: U11 (n = 16); U12 (n = 14); U13 (n = 10); U14 (n = 12); U15 (n = 12); and U17 (n = 15). Informed participant assent, parental/guardian consent, and Academy Director gatekeeper consent was gained. The study received institutional ethical approval from the local university ethics board (GUEP 533R).

Procedures

We used an exploratory case study design (Yin, 2009; Reeves et al., 2019) using players affiliated to a junior-elite soccer academy in Scotland. In December 2017, the club made the decision to close the academy, releasing players from their contracts. Subsequently, between December 2017 and June 2018 players either (a) re-signed with a SFA "Elite" or "Progressive" junior-elite academy (considered as persistence or progression in playing level—"Reselected") or (b) signed with a SFA "Performance" junior-elite soccer academy, signed with an amateur club, or took a break from playing altogether (considered an attrition in playing level—"Deselected"). We collected physical fitness test, anthropometrics and maturity offset, and subjective coach rating data as part of routine Academy operations in December 2017, prior to the winter break of play. Academy staff monitored players' status and club affiliations for the subsequent 6 months following the academy closure, and the Academy Director provided the authors with these details for all players in June 2018.

Fitness Tests

We collected data on five measures of physical fitness using established methods: Yo-Yo Intermittent Recovery Test Level 1 (YYIRT L1; Krustrup et al., 2003); countermovement vertical jump (CMJ; Murtagh et al., 2018); Functional Movement Screen™ (FMS; Cook et al., 2006); and 5 m/20 m linear sprint tests (Enright et al., 2018). Such measures have been applied to samples of youth athletes and are valid and reliable tests (Krustrup et al., 2003; Lloyd et al., 2015; Enright et al., 2018; Dugdale et al., 2019). Moreover, we recorded body mass, standing stature, and seated height. A regression equation was used to provide somatic maturity estimates, presented as maturity offset (years from age at peak height velocity; Mirwald et al., 2002).

Fitness testing for all participants was completed as part of routine testing and monitoring practices by the Academy in December 2017, prior to players being released from their contracts. The fitness testing session was completed a minimum of 48 h following a competitive game and in the absence of strenuous exercise within 24 h prior. Fitness testing was conducted indoors on a non-slip surface with an ambient temperature of ∼18°C. All players received the same standardized warm-up consisting of light aerobic activity, dynamic stretching, progressive sprinting, and sub-maximal jump variations. Tests were completed in a standardized order and arranged from least-to-most physically demanding by the research team to manage fatigue (anthropometrics > FMS > CMJ > linear sprint > YIIRT L1). For the linear sprint and CMJ tests, participants completed three attempts with the best attempt for each test being selected for analysis.

Coach Ratings

Coaches rated players on 29 multidimensional attributes identified as important to the recruitment process of youth soccer players by Larkin and O'Connor (2017). Coaches used a 5-point Likert scale to rate the attributes of each player relative to their age and stage of development: 1 – *poor*; 2 – *below average*; 3 – *average*; 4 – *very good*; 5 – *excellent*. Such coach-based rating methods have previously been adopted by researchers and they demonstrate good reliability and validity (Unnithan et al., 2012; Fenner et al., 2016; Hendry et al., 2018; Dugdale et al., 2020). Coaches were provided with definitions of the attributes established by Larkin and O'Connor (2017) and allowed to ask questions to the research team prior to assigning their ratings. The research team also provided hypothetical examples to the coaches of what would be considered "poor" or "excellent" for each attribute to ensure clarity. For example, "excellent" "1 v 1" ability was described to coaches as "a player who regularly beats the opposition during an individual match-up leading to progression of position or opportunity for their team, particularly during pressurized situations." Further, "poor" "concentration" was described as "a player who makes regular errors due to inconsistent mental effort applied during training and competition, often leading to the loss of possession or opponent goal scoring opportunities."

Coaches also provided an overall category rating for players' "skill," "psychological," and "physical" abilities on an identical 5-point Likert scale. The coaches completed their subjective ratings independently without confirmation with the research team, other coaches, or support staff.

Attribute Categorization

Models of TI in soccer were identified and reviewed by the research team (JD, AMcR, VU). The Williams et al. (2020) model was selected for implementation in this study due to being the most recently published model. The category of "sociological" identified within the Williams et al. (2020) model was removed resultant of the inability of coaches to appropriately rate sociological attributes. Attributes were then categorized by the research team as either "physical," "skill," or "psychological" according to the model of potential predictors of talent in soccer by Williams et al. (2020). Attributes were categorized using a three-stage approach: (1) the research team individually categorized attributes, resulting in unanimous agreement for 24/29 attributes; (2) the research team discussed the remaining attributes electronically ($n = 5$) with reference to the attribute definitions provided by Larkin and O'Connor (2017) and with reference to the Williams et al. (2020) model, resulting in agreement for a further 4 attributes; and (3) the research team met face-to-face to discuss the remaining attribute, resulting in agreement. Following this three-stage process, the research team reached agreement for all 29 attributes. As a consequence of the separately collected, objective fitness test data utilized in this study, attributes categorized into the "physical" category ($n = 4$) were removed prior to analysis. A total of 25 subjectively rated attributes (skill: $n = 14$; psychological: $n = 11$) were included for analysis.

Statistical Analysis

Considering the exploratory nature of this study, we provide descriptive statistics for "Reselected" and "Deselected" players. "Reselected" and "Deselected" players are reported as frequencies and percentages (%). Subjective ratings are reported as means and standard deviations (SD) for both "Reselected" and "Deselected" player groups. For objective physical measures, test scores were standardized using z-scores ± SD. This involved allocating within-age group standardized scores and collapsing across levels prior to analysis. This allowed for comparisons between "Reselected" and "Deselected" players by removing potential age effects associated with performance due to the disparity of comparison groups. Standardized effect size, reported as Cohen's d using the pooled SD as the denominator, was calculated to evaluate the magnitude of difference between the two groups. Qualitative interpretation of d was based on the guidelines provided by Hopkins et al. (2009): 0–0.19 trivial; 0.20–0.59 small; 0.60–1.19 moderate; 1.20–1.99 large; ≥2.00 very large.

Birthdates for all players were categorized into the following relative age quartiles from the start of the selection year specified by the SFA (Dugdale et al., 2021): Q1 = Jan–Mar; Q2 = Apr–Jun; Q3 = Jul–Sep; Q4 = Oct–Dec, and reported as frequencies and percentages (%). The Chi squared (χ^2) test was used to assess differences between observed and expected birthdate distributions across quartiles for both "Reselected" and "Deselected" players. Odds ratios (OR) and 95% confidence intervals (95%CI) were calculated to compare the birthdate distribution of a quartile (Q1, Q2, or Q3) with the reference group, consisting of the relatively youngest players (Q4). Data were analyzed via SPSS Statistics Version 25.0 for Windows (IBM, Chicago, Illinois, USA).

RESULTS

Of the 79 players within our study, a total of 60 players (76%) were "Reselected" in the 6 months following the academy closure. "Reselected" players represented: U11 – n = 11/16; U12 – n = 11/14; U13 – n = 9/10; U14 – n = 7/12; U15 – n = 9/12; and U17 – n = 13/15 of each age group within our sample. Overall subjective coach ratings for the three multidimensional categories were: 3.5 ± 0.8 vs. 2.8 ± 0.8 (Skill); 3.4 ± 0.8 vs. 2.8 ± 1.0 (Psychological); and 3.4 ± 0.9 vs. 2.9 ± 0.9 (Physical) for "Reselected" vs. "Deselected" players, respectively (**Figure 1**).

"Reselected" players were rated higher than "Deselected" players by coaches for all attributes within the "Skill" category (**Table 1**, **Figure 2**). The largest difference in rating between "Reselected" and "Deselected" players was observed between attributes of "General Game Understanding" (+0.8, d = 1.05; *moderate*), "Game Sense/Awareness" (+0.8, d = 1.06; *moderate*), and "Anticipation" (+0.8, d = 1.14; *moderate*). The smallest difference in rating was observed for "Striking the Ball" (+0.1, d = 0.14; *trivial*). "Reselected" players were also rated higher than "Deselected" players by coaches for all attributes within the "Psychological" category (**Table 1**, **Figure 3**). The largest difference in rating between "Reselected" and "Deselected" players was observed for "Professionalism" (+0.9, d = 1.05; *moderate*). The smallest difference in rating was observed between attributes of "Personality/Character" (+0.1, d =0.10; *trivial*) and "Communication" (+0.1, d = 0.09; *trivial*). When examining "Physical" attributes standardized by age group, "Reselected" players performed better than "Deselected" players on all fitness tests. The largest difference in fitness test performance between "Reselected" and "Deselected" players was observed between "CMJ" (+0.5, d = 0.51; *small*), "5 m Sprint" (+0.5, d = 0.54; *small*), and "20 m Sprint" (+0.5, d = 0.53; *small*). However, "Reselected" players were lesser in "Mass" (−0.1, d = 0.11; *trivial*), "Stature" (−0.1, d = 0.09; *trivial*), and "Maturity Offset" (−0.35, d = 0.39; *small*) than "Deselected" players (**Table 1**, **Figure 4**).

The frequency and percentage distributions of players' birth quartiles for both "Reselected" and "Deselected" player groups are presented in **Table 2**. Players born in Q1 and Q2 were overrepresented for both "Reselected" and "Deselected" player groups. The Chi-squared statistic also demonstrated significant deviations across quartiles for both "Reselected" and "Deselected" player groups.

DISCUSSION

This exploratory case study examined differences in multidimensional attributes of players related to persistence/progression ("Reselected") or attrition ("Deselected") in playing level following closure of a youth soccer academy. The majority of the players within our study (76%) were "Reselected" to a junior-elite academy in the subsequent 6 months after being released. Our findings also showed that "Reselected" players were rated higher during subjective coach evaluations across all attributes within this study which were categorized as "Skill" or "Psychological." We observed that "Reselected" players performed better than "Deselected" players in all objective physical fitness tests within our study; however, "Reselected" players were lesser in "Mass," "Stature," and "Maturity Offset" (further away from peak height velocity) than "Deselected" players. Finally, a similar asymmetry in birthdate distribution was observed for both "Reselected" and "Deselected" players favoring those born in the first half of the selection year.

The finding that the majority of our sample were re-signed in the 6 months following the academy closure supports the notion that individuals released from TD programmes are often recruited by rival clubs (Vaeyens et al., 2008; Unnithan et al., 2012). Coaches and practitioners attempt to identify and detect relevant characteristics of future soccer performance as early as possible through TI processes (Figueiredo et al., 2014). Moreover, prolonged exposure to systematic TD is considered crucial to successful reselection and youth-professional transition (Williams and Reilly, 2000; Baker et al., 2012). The players within our study were released from their contracts due to closure of the soccer academy, opposed to being deselected for performance reasons. Therefore, these players may have been more appealing to rival academies than amateur players due to their prior selection to, and engagement in, a systematic TD programme. Scouting processes traditionally inform selection and recruitment decisions in academy soccer (Reeves and Roberts, 2019; Williams et al., 2020). Similarly, coaches and recruiters have been shown to engage in informal evaluation processes of players during competition (Reeves et al., 2019). Therefore, it is possible that rival academies may have been familiar with the players within our study and may have had preconceived subjective opinions of their abilities prior to their

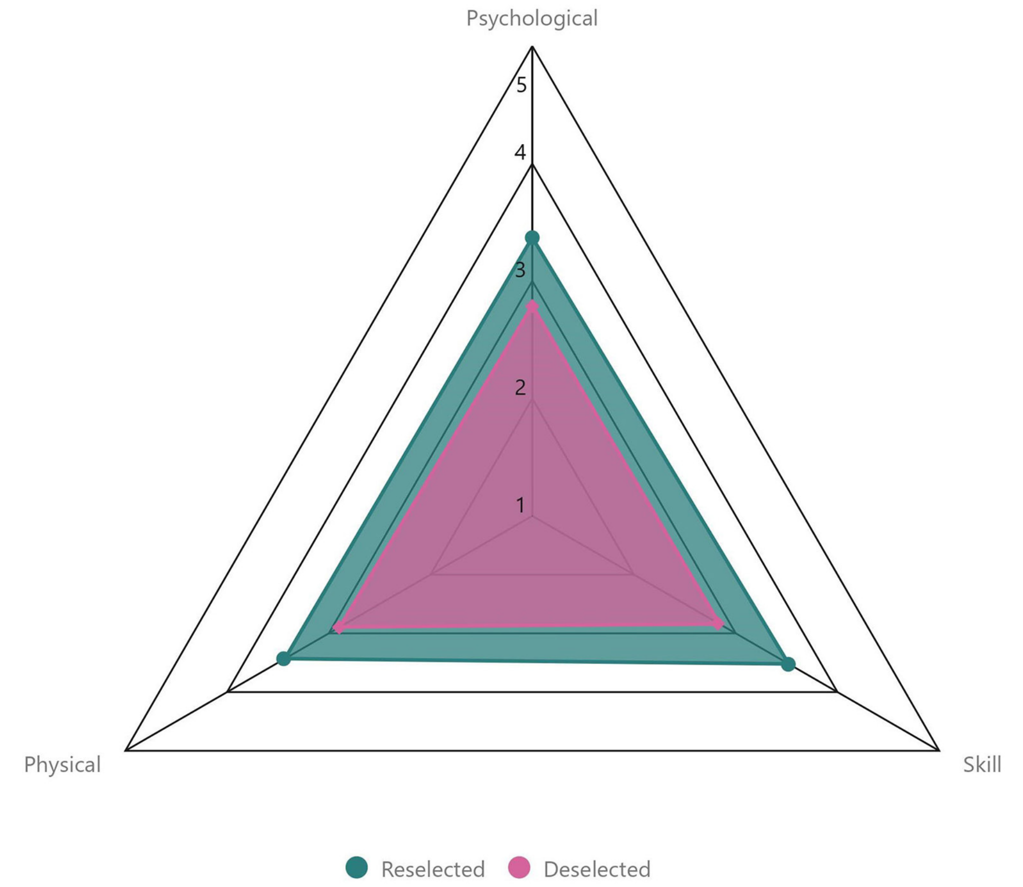

FIGURE 1 | Comparison of overall coach category ratings between "Reselected" and "Deselected" players.

release. It is also possible that as a duty of care, the Academy Director and age group coaches may have utilized their network to assist players in continuing to play academy-level soccer. Such processes have previously been reported by deselected athletes across other sports (Williams and MacNamara, 2020). We propose that previous exposure to a TD programme may explain the prevalence of reselection we observed. However, we acknowledge the potential sociological factors that may have influenced (de)selection and recruitment decisions within our study.

Our findings evidence no age-related trends in persistence/progression or attrition in playing level following the academy closure. The accumulation of appropriate practice hours is deemed crucial to successful transition to professional soccer (Ford and Williams, 2012; Haugaasen et al., 2014). However, high turnover of youth players is reported within professional soccer academies, with only ∼10% of players successful in obtaining professional contracts (Grossmann and Lames, 2015). The probability of successful youth-professional transition is increased in the latter years of youth soccer academy development (Kannekens et al., 2011). Yet, we observed comparable reselection rates at U13 and U17, and U12 and U15 age groups, respectively. When observing age category transitions for German junior-elite academy soccer players, 67–83% of players were successful in being selected to the subsequent age group (Güllich, 2014). Consequently, reselection rates observed in our study (reselection to another academy TD programme due to non-performance-related deselection) may be more comparable to age category transitions than traditional deselection/reselection observations.

"Reselected" players received a higher overall subjective coach category rating than "Deselected" players for "Skill," "Psychological," and "Physical" abilities during our study. Both "Skill" and "Psychological" attributes are identified as important by coaches and recruiters when making decisions around (de)selection in youth soccer (Larkin and O'Connor, 2017; Roberts et al., 2019). However, these authors suggest that although coaches and recruiters deem physical abilities necessary for soccer, they may value them less than skill or psychological attributes. A number of longitudinal studies have reported that future professional players perform better and receive higher coach ratings for both skill (Van Yperen, 2009; Forsman et al., 2016; Höner et al., 2017; Sieghartsleitner et al., 2019) and psychological (Gledhill et al., 2017; Murr et al., 2018a) attributes. Yet, despite lower perceived importance by coaches and recruiters, future professional players also exhibit greater

TABLE 1 | Comparison between "Reselected" and "Deselected" players for coach subjective ratings of attributes categorized as "Skill," "Psychological," and "Physical."

		Reselected	Deselected	Effect size	
		(*n* = 60)	(*n* = 19)	(*d*)	
Skill	First touch	3.4 ± 0.7	3.1 ± 0.8	0.40	Small
	Striking the ball	3.4 ± 0.7	3.3 ± 0.7	0.14	Trivial
	1 v 1	3.2 ± 0.8	2.6 ± 0.7	0.80	Moderate
	Decision making	3.3 ± 0.8	2.6 ± 0.7	0.93	Moderate
	Technique under pressure	3.2 ± 0.9	2.8 ± 0.4	0.57	Small
	Running with the ball	3.3 ± 0.9	2.8 ± 0.8	0.59	Small
	X-Factor	2.9 ± 1.1	2.2 ± 0.7	0.76	Moderate
	General game understanding	3.5 ± 0.9	2.7 ± 0.6	1.05	Moderate
	Game sense/awareness	3.4 ± 0.8	2.6 ± 0.7	1.06	Moderate
	Anticipation	3.3 ± 0.7	2.5 ± 0.7	1.14	Moderate
	Consistent execution	3.3 ± 0.8	2.8 ± 0.4	0.79	Moderate
	Vision	3.2 ± 0.6	2.5 ± 0.7	1.07	Moderate
	Team understanding	3.5 ± 0.8	2.8 ± 0.5	1.05	Moderate
	Defensive ability	3.1 ± 0.9	2.8 ± 0.8	0.35	Small
Psychological	Coachability	3.6 ± 1.0	3.2 ± 1.0	0.40	Small
	Positive attitude	3.5 ± 1.1	2.8 ± 0.9	0.70	Moderate
	Love of the game	3.6 ± 1.1	3.2 ± 0.8	0.42	Small
	Confidence	3.3 ± 0.9	3.0 ± 0.9	0.33	Small
	Competitive	3.8 ± 1.0	3.3 ± 0.8	0.55	Small
	Personality/character	3.3 ± 1.1	3.2 ± 0.8	0.10	Trivial
	Adaptability	3.3 ± 0.9	3.0 ± 0.5	0.41	Small
	Concentration	3.4 ± 1.0	2.8 ± 1.0	0.60	Moderate
	Professionalism	3.8 ± 1.1	2.9 ± 0.5	1.05	Moderate
	Communication	2.6 ± 1.2	2.5 ± 0.9	0.09	Trivial
	Pressure	3.0 ± 0.8	2.7 ± 0.6	0.42	Small
Physical	Mass	−0.03 ± 0.9	0.08 ± 1.1	0.11	Trivial
	Stature	−0.02 ± 1.0	0.07 ± 0.9	0.09	Trivial
	Maturity offset	−0.09 ± 1.0	0.26 ± 0.8	0.39	Small
	FMS	0.06 ± 0.9	−0.18 ± 1.1	0.24	Small
	CMJ	0.11 ± 1.0	−0.35 ± 0.8	0.51	Small
	5 m Sprint	0.37 ± 1.0	−0.12 ± 0.8	0.54	Small
	20 m Sprint	0.12 ± 1.0	−0.38 ± 0.9	0.53	Small
	YYIRT L1	0.06 ± 1.0	−0.2 ± 0.9	0.27	Small

"Skill" and "Psychological" data are presented as Mean ± SD, "Physical" data are presented as within-group z-scores standardized by age group and presented as Mean ± SD.

physical performance when compared to non-professional players (Gravina et al., 2008; le Gall et al., 2010; Gonaus and Müller, 2012; Emmonds et al., 2016). Differing approaches to talent identification and selection/deselection processes have been observed in soccer, largely influenced by varied philosophies held by coaches or clubs, or by the perceived competition demands of the nation or league observed (Unnithan et al., 2012; Reeves et al., 2018a). We observed similar differences between "Reselected" and "Deselected" players for all overall category ratings. Therefore, our results suggest that, in a Scottish context, "Skill," "Psychological," and "Physical" abilities may be of similar importance to TI and the (de)selection process in soccer.

When examining coach ratings for attributes categorized within "Skill," we observed the largest differences between "Reselected" and "Deselected" players for "Game Understanding," "Game Sense/Awareness," and "Anticipation," and we observed the smallest difference for the rating of "Striking the Ball." Attributes we observed as the largest differences between groups have previously been categorized as "perceptual-cognitive skills" in soccer (Roca et al., 2012; Williams et al., 2012; Roberts et al., 2019). Perceptual-cognitive skills typically refer to the ability of performers to identify and process environmental information for integration with existing knowledge to facilitate the selection of appropriate responses under time pressure (Williams, 2000; Williams et al., 2012). Acknowledging the intermittent and high intensity demands of soccer competition (Di Salvo et al., 2009), perceptual-cognitive abilities have been championed when comparing skilled and less skilled soccer players (Williams, 2000; Williams et al., 2020). On the contrary,

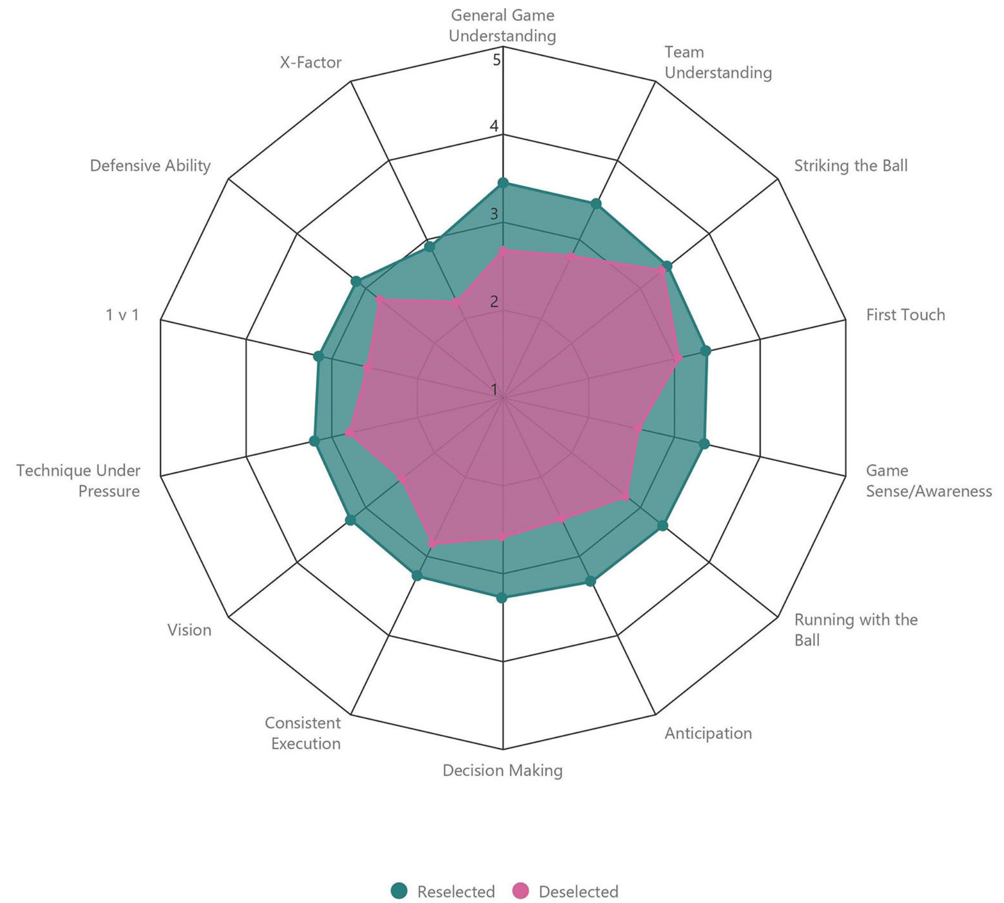

FIGURE 2 | Comparison of coach ratings for attributes categorized as "Skill" between "Reselected" and "Deselected" players.

scientists report that technical skills performed in isolation are least representative of *in-situ* performance (Williams and Reilly, 2000; Unnithan et al., 2012), perhaps explaining the small difference we observed between "Reselected" and "Deselected" players for the rating of "Striking the Ball." Our results reiterate the importance of multidimensional opposed to isolated skill qualities in soccer, with a particular emphasis on the (de)selection process.

Coach ratings of "Professionalism" demonstrated the largest difference between "Reselected" and "Deselected" players for attributes categorized as "Psychological." Within soccer, "Professionalism" may encompass a range of player behaviors during both training and competition, such as conduct, mannerisms, and autonomy (Martindale et al., 2007; Larkin and O'Connor, 2017). Considering that "Professionalism" is not explicitly identified when identifying potential psychological predictors in soccer (Höner and Feichtinger, 2016; Murr et al., 2018a), the definition of "Professionalism" we provided to coaches (Larkin and O'Connor, 2017) may have been vaguely interpreted, potentially capturing elements of wider psychological attributes. On the contrary, the smallest difference in coach ratings between "Reselected" and "Deselected" players was observed between attributes of "Personality/Character" and "Communication." Interestingly, elements of the definitions provided to coaches for these two attributes are similar to the definition of "Professionalism" (Larkin and O'Connor, 2017). In light of these observations, we suggest that a degree of ambiguity and individual interpretation may have occurred during the coach rating process. Despite presenting previously identified attributes and definitions related to the soccer recruitment process in soccer, we suggest that, in line with recent work, predictors may need to be identified and established by the coaches in a two-part process (Reeves et al., 2018b; Roberts et al., 2019).

Finally, the greatest difference in objective "Physical" fitness performance between "Reselected" and "Deselected" players was observed for the "CMJ," "5 m Sprint," and "20 m Sprint" tests. Neuromuscular qualities, such as speed and power, receive particular interest during TI and TD compared to other physical attributes (Murr et al., 2018b). Furthermore, soccer players playing at a higher competitive level often outperform those playing at a lower competitive level on CMJ and sprint tests (Coelho E Silva et al., 2010; le Gall et al., 2010; Dugdale et al., 2019). We suggest that as a result of the recent increases in physical demands of adult soccer match play (Barnes et al., 2014; Bush et al., 2015), differences in speed and power

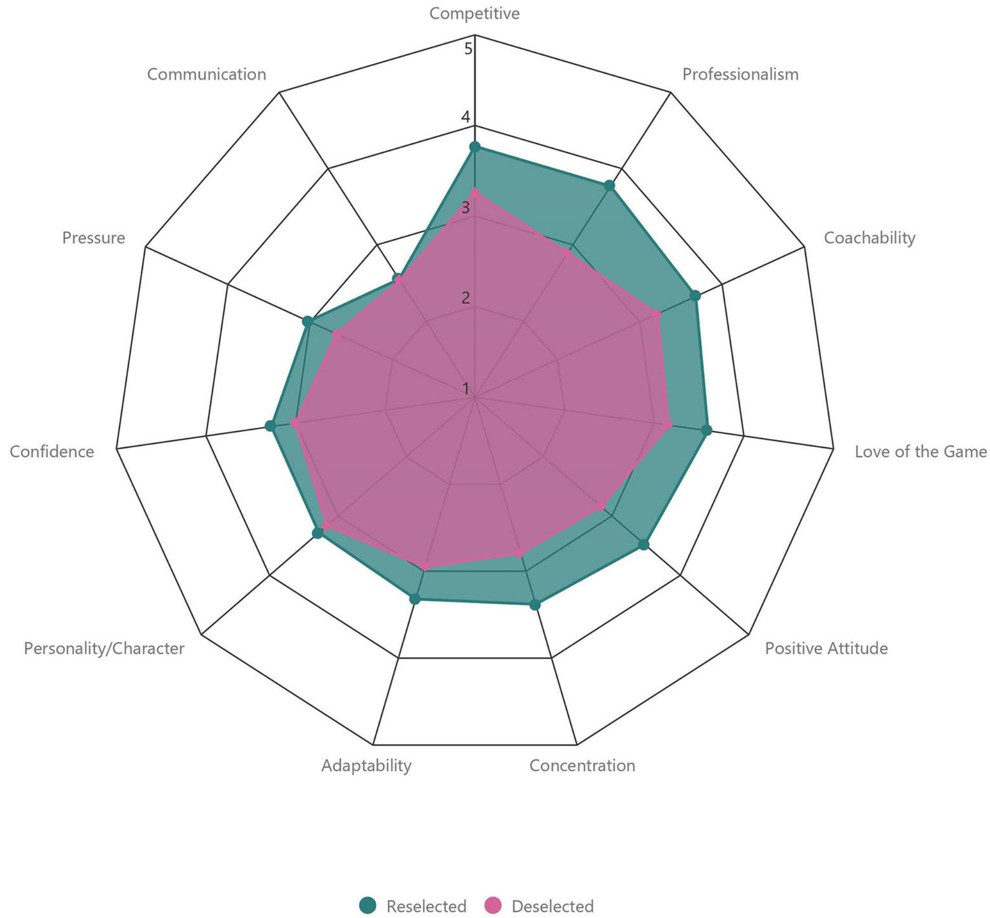

FIGURE 3 | Comparison of coach ratings for attributes categorized as "Psychological" between "Reselected" and "Deselected" players.

performance may provide useful information to contribute to TI and (de)selection decision making in soccer.

Despite outperforming "Deselected" players during physical fitness tests, "Reselected" players were lesser in "stature," "mass," and "maturity offset" than "Deselected" players within our study. Typically, relationships are observed between more mature players of larger body size and physical performance (see Kelly and Williams, 2020 for a review). However, exceptions to this observation have been reported (Reilly et al., 2000; Malina et al., 2007; Figueiredo et al., 2009; Deprez et al., 2014). Furthermore, anthropometric profiles have been suggested to be position-specific, with physical attributes being favorable for certain positions (Gil et al., 2007; Deprez et al., 2014). A wealth of evidence suggests that adolescent soccer players may be selected to TD programmes due to superior anthropometric profiles and maturity status (Malina et al., 2017; Kelly and Williams, 2020). Yet, this selection bias lacks efficacy (Burgess and Naughton, 2010; Meylan et al., 2010). Our observations that "Deselected" players were taller, heavier, and more mature than "Reselected" players further support this premise. We also observed a prevalent asymmetry in birthdate distribution for our entire sample, but no difference between "Reselected" and "Deselected" players. This suggests that recruitment to the academy in the first instance may have conformed to these aforementioned biases (Deprez et al., 2014; Castillo et al., 2019); however, birth month did not influence (de)selection of players within our study.

Our study is not without limitations. One limitation of the present study relates to the sample size and disparity between "Reselected" and "Deselected" player groups. In light of this limitation, we present a novel yet highly relevant case study following the closure of a junior-elite soccer academy. Although a greater sample size and ability to explore differences between groups would strengthen this study, the inability to control these factors and novelty of this situation must be acknowledged. As a result, we encourage readers of our study to treat our results with appropriate caution given the design utilized. Further research should attempt to identify larger samples for a more thorough comparison between "Reselected" and "Deselected" players including sub-analyses for factors such as age and playing position. Secondly, we must acknowledge the subjective nature of ratings for some of the attributes within our study, as opposed to objective measures of performance previously used to evaluate differences between reselected and

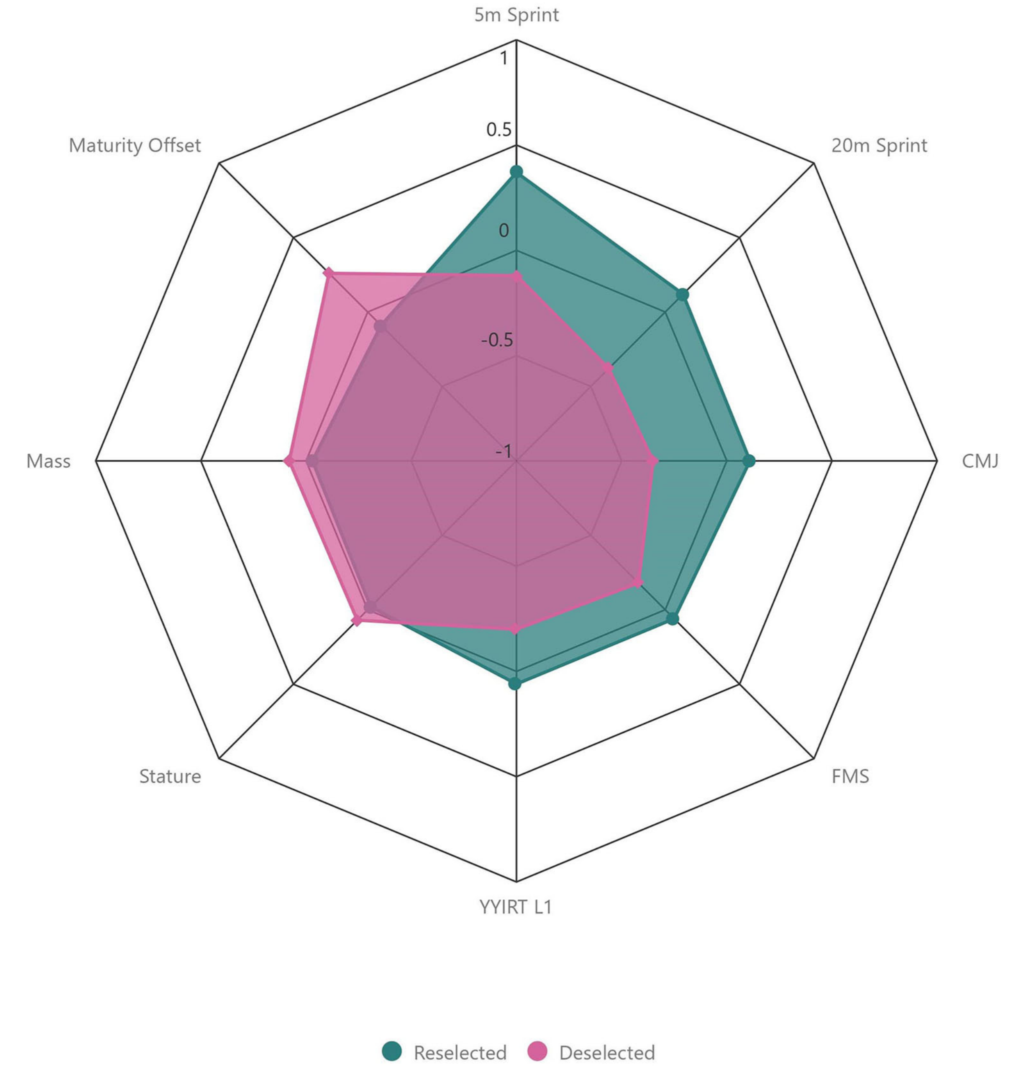

FIGURE 4 | Comparison of objective physical data between "Reselected" and "Deselected" players. Data are presented as z-scores standardized by age group.

TABLE 2 | Birth quartile distributions for "Reselected" and "Deselected" players.

		Birthdate distribution (%)				Odds ratio (95% CI)			Chi-squared
Playing level	***n***	**Q1**	**Q2**	**Q3**	**Q4**	**Q1 vs. Q4**	**Q2 vs. Q4**	**Q3 vs. Q4**	χ^2
Reselected	60	18 (30.0)	25 (41.7)	9 (15.0)	8 (13.3)	2.3 (1.0–5.3)	3.1 (1.4–7.2)	1.1 (0.5–2.8)	21.6*
Deselected	19	7 (36.8)	7 (36.8)	3 (15.8)	2 (10.5)	3.5 (1.5–8.5)	3.5 (1.5–8.5)	1.5 (0.6–3.9)	22.9*

**Significant at an alpha level of $p < 0.05$. Q1 = Jan-Mar; Q2 = Apr-Jun; Q3 = Jul-Sep; Q4 = Oct-Nov.*

deselected players (Figueiredo et al., 2009; Huijgen et al., 2014). Deriving attribute ratings via subjective methods is typical of traditional scouting methods utilized during the recruitment and selection/deselection processes of youth soccer players, therefore relevant to applied practice (Reeves and Roberts, 2019). We suggest that readers acknowledge the potential limitations associated with this rating method when interpreting our results (Dugdale et al., 2020).

PRACTICAL IMPLICATIONS

Our findings reiterate the longstanding notion that potential predictors associated with TI and TD in soccer should be multidimensional in nature, and attempt to progress the repeated call for more multidisciplinary research in soccer. Furthermore, we encourage the use of both subjective and objective data to provide a time and resource efficient method of gathering information that may be of value to decision making during (de)selection processes. The visualization methods implemented in this study (radar plots) may assist when presenting a large volume of multidisciplinary data. This may assist coaches and recruiters to better understand strengths and weaknesses of youth soccer players but also visually convey compensatory mechanisms (i.e., superior strengths that counteract weaknesses in other areas) that may previously have been overlooked. Finally, given the constant and increasing financial pressures placed on professional football clubs, we provide a case study approach of a unique yet highly relevant scenario for talent identification and development in youth soccer.

CONCLUSION

In summary, the majority of players persisted or progressed in playing level following closure of a junior-elite soccer academy. These players were rated higher by coaches for all "Skill" and "Psychological" attributes, as well as performing better in "Physical" fitness tests. However, anthropometric and maturity variables were more pronounced for players who experienced an attrition in playing level. Our findings further support the multidisciplinary nature of talent in soccer and promote the requirement for multiple assessment methods when making (de)selection decisions during TI. Moreover, we encourage coaches and recruiters to acknowledge the potential limitations of making (de)selection decisions influenced only by physical factors related to growth and maturation.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Stirling cross-faculty ethics committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

JD, AM, and VU contributed to the conception and design of the study. JD performed the data collection and wrote the first draft of the paper. JD and AM performed the data analysis. All authors contributed to manuscript revision and read and approved the submitted version.

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"Looking for a *Golden* Needle in the Haystack": Perspectives on Talent Identification and Development in Paralympic Sport

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Despite rapid increases in research on talent identification and development in able-bodied sports, there remains limited knowledge regarding how talent is identified and developed in Paralympic contexts. The purpose of this study was to capture the perspectives of experts (coaches, high-performance managers, and pathway specialists) working in elite Paralympic sport to better understand how they conceptualize, measure, and develop talent. Eight coaches and three performance directors from six Paralympic sports, along with two pathway specialists from Paralympics Australia participated in semi-structured interviews. The results suggest impairment type and, therefore, classification are key indicators of identification and anticipated success, highlighting the importance of educating talent selectors in these areas. In addition, familial (e.g., overprotectiveness, sporting background) and biopsychosocial factors (e.g., resilience, work-ethic, sport-specific skills, other life commitments) were noted as being influential when selecting athletes. There were concerns regarding the disproportionately low number of female athletes in the system, suggesting a need for new initiatives to support early-entry points for female athletes (e.g., education on the benefits of sport participation, supportive environments). High-performance staff also lacked resources to better understand the nuances associated with different impairments and their implications (physiological response to training, associated psychological stresses from injury, identity change). Recruitment strategies included "talent search" days, collaborations with school programs and rehabilitation centers, and helping local clubs support "drop-in" athletes. However, limited funding impacted the sustainability of programs, resulting in a regular turnover of staff, loss of intellectual property, and a weakened pathway system. Results from this study generated several practical implications and future directions for research.

Keywords: athlete development, athlete selection, sport classification, recruitment strategies, disability sport, athletes with impairments, para sport, female athletes

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INTRODUCTION

Identifying early-career performance indicators that predict future performance in high-performance sport has been difficult (Schorer et al., 2017; Johnston et al., 2018; Johnston and Baker, 2020). This has led to increased attention to understanding the meaning of "talent" and its indicators, as well as the optimal environments to nurture and maximize athletes' potential

(Abbott and Collins, 2004; Baker et al., 2018). From an identification perspective, coaches and scouts assess and select primarily based on physical and physiological attributes (Baker et al., 2020) using a blend of techniques and protocols including intuition (Christensen, 2015; Lund and Söderström, 2017) and testing batteries (Gabbett, 2009). From a developmental perspective, there is a wide range of variables that influence athletes' trajectories including demographic (e.g., socioeconomic status, family status, sporting background, Côté, 1999; Post et al., 2018), physical and psychological (e.g., resilience, growth and maturation, Baxter-Jones et al., 2002; Roberts et al., 2019), sporting (e.g., quality coaching, coach-athlete relationship, Erickson and Côté, 2016), social (e.g., peers, Ullrich-French and Smith, 2009), environmental (e.g., access to facilities, Estabrooks et al., 2003), and political factors (e.g., policy for access to sport, funding, Barker-Ruchti et al., 2018). This breadth of research has informed stakeholders (i.e., sport organizations, coaches, athletes, families) of key factors that can impact the identification and development of an athlete. While, to a degree, there have been some improvements in our understanding of talent (Tetlock, 2016), this work has predominantly been done in able-bodied (AB) settings with very limited information on the processes in Paralympic (or other disability sport) contexts.

On the one hand, there may be some crossovers between AB and Paralympic contexts, such as the importance of family support and the quality of coach-athlete relationships. On the other hand, however, disability-related factors (impairment[1] type, timing and nature of the impairment, potential classification) introduce levels of complexity that impact the range of factors that may be considered during athlete identification and development. For example, classification systems in Paralympic sports are designed to minimize the impact of impairment on the outcome (e.g., athlete's performance) (International Paralympic Committee, (n.d.)). In the limited research in this context, researchers have shown athletes' impairment and their potential classification to be a key indicator to the identification and potential success in their sport (Radtke and Doll-Tepper, 2014; Patatas et al., 2020).

Athletes in Paralympic sport enter sports at different ages based on the timing of impairment, thereby influencing how coaches consider athletes' readiness based on both their training and chronological ages (Radtke and Doll-Tepper, 2014).

Work by Dehghansai et al. (2017a, 2020b,c,d,f), Dehghansai and Baker (2020), and Lemez et al. (2020) highlighted the variability of development amongst Paralympic sport athletes and the need to consider the dynamic and complex interaction of factors influencing athletes' development from a holistic lens.

It is difficult to inform policy and structure optimal developmental environments with limited empirical evidence (Dehghansai et al., 2017b). Existing literature in this area has highlighted a need for organizations to optimize limited funding and support through the upskilling of (typically volunteer) development coaches with limited knowledge of disability, enhance cooperation between rehabilitation centers and school systems as these environments are entry points for athletes with impairments, and emphasize the importance of personal, financial, and infrastructural resources to support the identification and development process (Radtke and Doll-Tepper, 2014; Mann et al., 2017; Patatas et al., 2020).

In order to better understand the key components associated with talent identification and development, it is imperative to recognize the experience of the key stakeholders involved directly in the identification[2] of athletes (i.e., coaches, high-performance managers, talent specialists). The purpose of this study was to extend this limited research base through a focused examination of the Australian Paralympic system's approach to talent identification and development. More specifically, we aimed to better understand current approaches, challenges, and strategies utilized by coaches, high-performance managers, and pathway specialists.

METHOD

Participants

Recruitment

High-performance (HP) staff from Paralympics Australia and Australian Paralympic sports were contacted by the lead author. Eight coaches and three performance directors from six different Paralympic sports (boccia, Para athletics, Para cycling, Para table-tennis, wheelchair tennis, wheelchair rugby), along with two pathway specialists from Paralympics Australia agreed to participate in this study. Interviews were held in person and based on the responses, the authors felt data saturation was reached and no further recruitment was required. Interviews ranged between 52 and 114 min in duration. Participants were assigned pseudonyms to protect their identity.

Background

Twelve out of 13 participants were ex-athletes (AB or Paralympic) and athletic successes ranged from the national level to Paralympic medalist. All reported being in their current role for longer than a full Paralympic cycle (i.e., were involved at the previous Rio 2016 Paralympic Games), and they either attended a Paralympic Games as a coach or coached an athlete who competed at the Games (i.e., they were the private coach that trained the athlete, but did not attend with the athlete due to limited accreditations). Ten out of 13 reported having an athlete medal at the Paralympic Games directly under their guidance. Three participants reported having an impairment themselves, while another two were trained classifiers.

Methodology

Semi-structured interviews were used to capture participants' experiences, challenges, and perspectives of talent identification and development in the Paralympic context. The open-ended interviews strengthened the quality of data by eliciting

[1]In this paper, disability is used to refer to the biopsychosocial interaction of persons' biological impairment with their environment which creates the "dis" abled context. Impairment is used to refer to persons' biological conditions (International Paralympic Committee, 2014).

[2]Identification encapsulates the process of recognizing, selecting, and recruiting athletes into the system. In the event that one aspect of the process is more prominent to the content, the appropriate term is used.

meaningful conversations allowing participants to express their experiences.

Philosophical Assumption

This study was grounded ontologically and epistemologically in critical realism (CR, i.e., a reality exists which is experienced by individuals through a world that is constructed by social discourse, Fletcher, 2017). The CR approach allowed the search for underlying causal relationships in a world that is subjective and often unmeasurable. Thus, understanding multiple perspectives, the tendencies and meanings were drawn from participants' experiences (Creswell, 2014; Smith, 2015; Cooper and Ewing, 2019), and discerning key elements across different Paralympic environments in various roles allowed depiction of the larger structure of the "talent" narrative (Wiggins and Potter, 2008; Smith et al., 2016). Therefore, recognizing these narratives helped understand the larger system and can guide strategic directives to improve talent identification and development across Paralympic sport in Australia.

Methodological Rigor

A guiding list of criteria was set out to establish the rigor of this study design (Tracy, 2010; Sparkes and Smith, 2014; Smith and McGannon, 2017). While talent identification and development has been studied in the AB context, there remains a void in the Paralympic context which leaves stakeholders with very limited empirical evidence to inform their decisions, demonstrating the *worthiness of topic*, *significant contribution,* and *practicality*. Our methods align with previous literature (Cooper and Ewing, 2019; Dehghansai et al., 2019), using theoretical constructs, data collection, and analysis processes that have been accepted and regularly employed in sports research, highlighting the *rich rigor. Credibility* was achieved through the multivocality of participants, across numerous sports in a wide range of roles, enabling the view of talent in the Paralympic context from multiple lenses. *Ethical* considerations were taken to retain participant anonymity in this small community. We also considered the working relationship between a member of the research team (affiliated with Paralympics Australia) and the participants (i.e., *relational ethics,* Bergum and Dossetor, 2005). The lead author, with no previous working relationship, led the interviews and reiterated to participants that their contributions would be kept anonymous and their non-committal to this project would not impact their existing relationship with the authors or Paralympics Australia in any shape or form (Evans et al., 2004; Pollard, 2015; Upasen, 2017). The *meaningful coherence* of this study was captured through the achievements of stated goals as we discerned the perspectives of participants on talent identification and development in the Paralympic context. The technique of *critical friend* was also utilized as authors engaged in discussions to ensure personal bias and perspectives did not compromise or dilute the relevant meanings generated through the themes (Smith and Sparkes, 2012; Burke, 2016).

Procedure and Interview Guide

The interview guide consisted of a series of topics along with probe questions to elicit and navigate discussion (Patton, 2002). This guide was organized into three sections. The first captured coaches' development in Paralympic sport, observing their experiences as they progressed in their careers. The second section gathered information on what coaches deemed as indicators of talent during the identification process, a list of factors that can be developed to support athletes' career progression, and challenges pertaining to the identification and development of athletes. The final section was an open question that asked participants to design an ideal program without resource constraints (financial, staff, etc.). Closing questions allowed coaches to ask any specific questions or expand on items previously discussed.

Data Analysis

Using the NVivo (NVivo qualitative analysis software; Version 12), the interview recordings were transcribed verbatim and reflexive thematic analysis guided the data exploration process (Braun and Clarke, 2019). Using the interview questions, significant thoughts and patterns were noted through the re-reading of transcripts. A set of codes were developed to formulate the data domain that guided authors in identifying and generating shared meanings across the participants' responses. Through collaborative and reflexive discussions, the authors continued to refine, organize, and merge meanings that generated six themes of "familial involvement," "the role of impairment in talent identification and development," "biopsychosocial: interaction of constraints," "individualized approach," "searching for athletes," "funding the system" (refer to **Table 1** for the theme breakdown).

RESULTS AND DISCUSSION

Familial Involvement

Parental overprotectiveness was seen as a detriment to the athlete's ability to adapt and cope with sporting demands (e.g., commute to training, travel to camps and competition, the pressure to perform, and expectations of consistency). This sheltering by caregivers was seen by some as inhibiting their drive to take risks, which were identified as a fundamental component to success in Paralympic sport. As Alexandra noted:

Wrapped in cotton wool mentality from parents. I see the over-protective parents and what that creates. I've grown up in the community with those kids. One of them is practically blind and he can negotiate his way through the town through the school without any need for any help. And just his parents from day one said, "You're going to have to be on your own at some stage in your life, so let's start it now." Whereas the other one's getting nowhere because parent is right there all the time. You have to be able to be independent.

Coaches have highlighted the importance of athletes' level of independence for successful development in the Paralympic context (Tawse et al., 2012). Parent/caregiver overprotectiveness can diminish opportunities for athletes to become independent (Johnson et al., (n.d.), p. 37), increase pressure on athletes, and contribute to athletes' loss of feelings of ownership in decision making which contributes to sports dropout (Witt and Dangi, 2018). However, there are scenarios (e.g., athletes with more

TABLE 1 | Theme breakdown.

Theme	Examples
Familial Involvement	Overprotectiveness leading to athlete dependency
	Family sporting background fostering an environment for the growth mindset and unstructured play at home
	Resources to support athletes' early careers (equipment, travel, transportation)
The Role of Impairment in Talent Identification and Development	Previous sporting experiences (key for athletes with later-onset impairment)
	Potential for athletes to be classified in unfavorable classifications
	Competitive pool domestically and internationally for each classification
Biopsychosocial: Interaction of Constraints	Stable constraints (anthropometrics, hand-eye coordination)
	Malleable constraints (current residency, occupation/education commitments)
	Interaction between constraints influences development across athletes' career span
Individualized Approach	Different impairments, abilities, and personalities
	Due to the wide range of differences, each athlete is coached differently (coaching method, training structure, travel needs, psychological support, etc.)
Searching for Athletes	Wide range of programs utilized to try to recruit athletes: talent search days, school programs, supporting rehabilitation and hospital staffs, and talent transfer
Funding the System	Limited funding impacts sustainability of recruitment programs, high turnover of staff, loss of intellectual property, a small pool of pathway athletes including the lack of female participants

severe impairments) where parental involvement was a necessity, as illustrated by James:

Some of our guys, their health needs are so complicated, you need the parents. So, you have these competing theories of how it should be [limit parental involvement], but there is the reality of the health needs. Because if we do not have that parent then we are going to be in danger of seriously hurting that person if we take them away.

On the one hand, participants did not appreciate overprotective parents; however, they were cognizant that support especially in the form of resources was vital, especially during the early years of athletes' careers and this has been well-documented in the Paralympic context (Johnson et al., (n.d.); Radtke and Doll-Tepper, 2014; Patatas et al., 2018; p. 43).

Therefore, during talent search days[3] (see Dehghansai and Baker, 2020 for a detailed overview of a talent search day process), HP staff were conscious to observe family and caregivers' level of involvement, and therefore athletes' amount of independence (e.g., preparation for testing, maneuvering around the venue and between testing stations), as highlighted by James:

Whether the athlete comes in and they are pushing themselves in a chair, whether they have handles on the back of their chair or not because then they are relying on someone to push them. The level of independence is probably what we are looking at.

HP staff also preferred families (parents and siblings) with sporting backgrounds because the competitive and nurturing home environment fostered independence and a growth mindset, allowed for unstructured and informal sport experiences, and created a more effective line of communication between coaches and parents. Research findings in AB and Paralympic context suggests children with parents and siblings involved in sport are more likely to participate in sport (Hopwood et al., 2015; Papadopoulos et al., 2020) and parental support plays a key role in a person with an impairment's interest to participate and maintain long-term participation in physical activity and sports (Mactavish and Schleien, 2004; Dodd et al., 2009; Rowbotham et al., 2011; Buckley et al., 2020). Siblings have also been identified in AB literature as role models for work ethic and partners for unstructured play furthering athletes' development of technical and psychological skills (Côté, 1999; Weissensteiner et al., 2009; Phillips et al., 2010). While research in the Paralympic context is limited, coaches' perspectives of familial involvement here corroborate with the limited disability-specific literature and the conclusions drawn from AB literature.

The Role of Impairment in Talent Identification and Development

HP staff were confident in their ability to create an environment for athletes to acquire a high-performance mindset and habits while refining their sport-specific technical and tactical skills, but only *if* athletes entered their sport at the early stages of their careers. Therefore, previous sporting experience was perceived as a vital component for athletes with late-onset impairments. This perception is also starting to be supported with empirical data, with recent studies examining the sporting experience of Paralympic sport athletes reporting a high incident of experience in AB sports prior to impairment-onset for those athletes with late-onset impairments (i.e., impairments acquired in early-adulthood or adulthood; Dehghansai et al., 2017b, 2020d,f; Dehghansai and Baker, 2020). Considering the quantitative nature of past work, authors were limited in drawing conclusions. They proposed the need for qualitative work to better understand the underlying reasons for a disproportionate number of athletes with later-onset impairments currently in the system with AB sporting experiences relative to those of the same cohort without experiences in AB sports. Findings from the current study suggest HP staff are actively looking for athletes with prior sporting experience, especially for athletes with later-acquired impairments.

Participants highlighted not only the perceived impact of early sport participation on achievements later in athletes' careers (i.e., acquiring fundamental movement skills, exposure to training and competition), but also, the positive by-products athletes acquire that are transferrable to other aspects of their lives such as

[3]While it is more common in the able-bodied context to have participants of younger age attending these events, in the Paralympic context, participants of all ages attend the search days.

independence, confidence, active involvement in the community, social skills, and sense of belonging. Sporting experiences play an integral role in shaping individuals' physical, psychological, and social well-being (Macdougall et al., 2015) and more importantly, it helps individuals strengthen their self-identity through sport (Allan et al., 2018). For some, early sport participation could be integral to ensure they are embedded into the sporting system while learning to master the abilities and limitations set by their impairments, as alluded to by Alexandra:

Once they hit 13, puberty, self-conscious issues, that is bad enough when you are just an [able-bodied athlete]. Throw in a disability aspect of it and they are not likely to engage in sport because they are already worried about being different and now, they have got that added difference because of their disability.

While athletes' impairments can play a major role in their involvement in sports, it is also integral to athlete identification, where HP staff consider (a) athletes' potential classifications, (b) current classification depth domestically and internationally, (c) their functionality/performance capacity based on their impairment, and (d) athlete needs and support due to their impairment. The role of "disability" was prominent in talent identification and development conversations, with Sandra echoing sentiments similar to the rest of the HP staff:

So, the first thing is their disability[4]. There tends to be a big range within the class, so someone like [athlete 1] in class [x], as compared to [athlete 2], in class [x]. [athlete 1] might be super, hardest trainer ever, committed, does everything, but his disability affects his chances to actually ever win a medal in that class. He would be more at the mid-to lower range of that class. That first and foremost is an inhibitor.

While HP staff preferred inclusivity and opportunities for all the athletes entering their system, they had to be methodical in how they distributed the very limited resources (i.e., lack of funding, limited time due to filling multiple roles, and having limited staff), which is an implication of the systemic issues discussed later. The importance of international success and limited resources to reach these expectations illustrates the strategic approach HP staff adopted to recruiting athletes based on impairment-related factors, as highlighted by Andrew:

We have tried to target the lower functioning athletes which is where the pools are smaller. Whereas [higher classes], it is very difficult just because of the numbers [i.e., more competitive]. If we found athletes in lower classes, we can make quick gains.

Thus, most athletes identified at the beginning stages of their careers were more likely to receive information pertaining to local clubs along with a list of expectations to work toward to demonstrate their potential. These expectations varied between sports with some focusing on performance benchmarks (e.g., Para cycling) and others on sport-specific skills (e.g., Para table-tennis, wheelchair rugby) which were most often assessed during regional and national tournaments.

[4]The use of the term "disability" and "impairment" by interviewees were, at times, not reflective of our theoretical framework that is aligned to the International Paralympic Committee's mandate. However, we have kept the terminologies used in quotes directly as stated by the participants.

Biopsychosocial: Interaction of Constraints

HP staff highlighted key biopsychosocial constraints that can facilitate or inhibit athletes' development as they worked toward these expectations. First, participants identified psycho-behavioral factors as important for successful development including (a) resilience, (b) high work ethic, (c) response to pressure, (d) independence, (e) commitment to a high-performance lifestyle, and (f) a positive attitude toward previous challenges and anticipated upcoming barriers. Similar traits have been reported in the AB literature as indicators of high-performance success (Roberts et al., 2019). However, no specific testing tools were used, rather, HP staff relied on observation ("coach's eye") during physical testing (for a–d), and informal discussions with athletes and their families post-testing during talent search days (e and f). As indicated by James:

Taking the time to talk to the families and the athletes during the day, getting a bit of an understanding about if they are spending their time complaining about not being able to get anywhere, nobody is helping them, nobody understands, [etc.]... You know, if they have already got a negative mentality about the system or whether they have got a mentality that [indicates resilience]. I think attitude is a huge factor.

During talent search days, HP staff objectively captured some limited physical attributes, including targeted anthropometric measures and hand-eye coordination tests. HP staff perceived these attributes to be stable and/or difficult to change over time and would not be worth the expansive resources (time and energy) required by the athlete and coaches to try to position the athlete for success in a specific sport. In their proposed model, Dehghansai et al. (2020a) refer to these factors as *stable structural* (e.g., anthropometric) and *stable functional* (e.g., hand-eye coordination) individual constraints which interact with other factors within athletes' environment across their development. Parallel with recommendations in this model, HP staff considered the interaction of these factors with other constraints in athletes' development and evaluated the disadvantaged position athletes may be in later in their careers competing among a more homogeneous group of athletes at the high-performance level. As Tom highlighted:

We got a guy, loves [the sport], he will even ask me questions, but he is not in the high-performance category. But he is always asking me stuff. How can I do this? Can I change something in my chair? Because he is so short, the poor guy sitting in the chair looks like a 10-year-old kid. He is never going to be a high-performance athlete, unfortunately.

Contrastingly, situational factors such as *interpersonal* environmental constraints also impact athlete development (see Dehghansai et al., 2020a), but are considered malleable and can evolve; HP staff highlighted that they considered these factors during the initial selection process. For instance, coaches considered the location of athletes' residences and whether the targeted sport can support the athlete in their current circumstances (i.e., access to training centers, equipment, and/or local coaches/clubs) in order to facilitate their development. Lack of resources (i.e., coaches, trained staff, programs) and inaccessible facilities is a longstanding issue pertaining to Paralympic (and other disability) sport

(Radtke and Doll-Tepper, 2014; Martin Ginis et al., 2016; Patatas et al., 2018), and here, HP staff emphasized its direct impact on any further consideration and progression from the talent identification stage. A second barrier was athletes' ability to invest the appropriate time to become a high-performance athlete (e.g., extensive training, attending training camps, competitions abroad), which may require sacrifice in other areas of life (e.g., pausing or withdrawing from other educational/vocational developments, Schaal et al., 2011; Foskett and Longstaff, 2018). Dehghansai et al. (2020e) reported Paralympic sport athletes in their study often terminated their careers and education, with some moving cities and countries to focus on preparations for the Tokyo 2020 Games. As such, HP staff considered athletes' commitment to these other domains and potential interference with their sporting commitments. However, HP staff recognized the importance of approaching each situation individually with considerations to the interaction of constraints for both the immediate and long-term opportunities.

Individualized Approach

HP staff outlined a wide range of factors that are considered for optimal development. First, impairment knowledge was a key component for coaches. Unfortunately, due to a lack of available impairment-related resources, coaches often lamented that they had to learn on their own, through trial and error and in-depth communication with parents and athletes (Radtke and Doll-Tepper, 2014; Lepage et al., 2020). Literature has previously highlighted that Paralympic coaches utilize different methods of learning (i.e., non-formal, informal) to combat the lack of resources and support available, particularly early in their careers (McMaster et al., 2012; Tawse et al., 2012; Turnnidge et al., 2012; Taylor et al., 2014; Lepage et al., 2020). Aligned with this, HP staff in this study specifically reported self-educating on classifications and impairment to better prepare for talent identification and development. There was also a notable reflection on the evolution of the classes and anticipating how classes may evolve in the future. Classification systems are a unique and evolving aspect of Paralympic sport that can facilitate or inhibit athletes' progression; coaches see it as an integral part of their role to understand the placement of an athlete within the system for athletes to succeed long-term (Radtke and Doll-Tepper, 2014; Patatas et al., 2020).

Dehghansai et al. (2020a) proposed a framework that considers a wide range of interconnected factors that contribute to the dynamic developmental environment. Highlighting the potential impact of this framework, insights from HP staff demonstrated the nuances associated with athletes' impairment, classifications, as well as secondary impairments and/or psychological disorders; thus, a truly individualized approach was considered for each athlete (Dehghansai et al., 2020a; Patatas et al., 2020). Impairment-related factors influence how athletes respond physiologically and whether they can execute a task based on their physical abilities. In addition, understanding athletes' prior experiences in and outside of sport helped coaches design more effective environments to reduce negative feedback and maximize engagement and positive experiences to ensure athletes approach training with the appropriate mindset. Louis summarized the complexity and the need for empathy to approach each athlete individually to fulfill their needs:

You get someone with a spinal cord injury, obviously they cannot take the heat as well so you just got to be very careful when you ask them to try something, and MS, you have got to be aware that they cannot do [certain tasks] because of their balance issues.

Impairment knowledge was not only important for sport-specific (e.g., classification, training response) purposes, but for other significant factors such as how athletes responded to travel. For example, Andrew shared a negative experience for them and their athlete which became a learning opportunity to prevent future mishaps:

The worst one was going to Fiji with the plane that did not have an aisle chair for one of the athletes. Having to carry her to the toilet was difficult for her, really difficult for her, to the point of her incurring an injury. That affected performance and her results at the event.

It was also important to understand the psychological impacts (e.g., anxiety and/or depression related to incident trauma) to better prepare for stressful environments that athletes are exposed to, and to develop contingency plans on how to deal with these circumstances. The high-performance environment can be very demanding, and the culmination of stressors, internal and external pressure can create an environment that is physically and psychologically draining (Fletcher and Scott, 2010; Lara-Bercial and Mallett, 2016). Frank explained the importance of understanding the unique psychological support needs for each athlete and the variability between athletes:

Knowing how to deal with athletes when they are uptight, and how to deal with nerves, [etc.]. It is not a one size fits all. Each athlete, you got to treat differently. Some you got to be really firm with. Others, if you are really firm with them, they will crack.

Therefore, there is not only a striking need to support coaches in better understanding impairment and providing sufficient resources on key physical indicators to optimize training environments, but the individuality of athletes' experiences also emphasizes the importance of supporting coaches on how to respond and support athletes' psychological needs.

Searching for Athletes

HP staff shared a wide range of strategies utilized for athlete recruitment, whether it was working independently or partnering with state and national bodies (e.g., Paralympics Australia), These included talent search days, school programs, supporting rehabilitation and hospital staffs, and talent transfer from other high-performance Paralympic programs. During talent search days, it was seen as important to have experts with sport-specific knowledge. However, it was equally, if not more, important to have support from staff with an in-depth understanding of impairments and classification systems (Radtke and Doll-Tepper, 2014; Patatas et al., 2020), as highlighted by Alexandra:

Number one, we have got a sport who have coaches looking at athletes, but not understanding the impairment. We have also got sports who, work on a membership base so anybody who comes to that door, "We want them all to do [our sport]" Not so much, "This guy has the potential based on where he fits in the classification." Or, "Maybe you should look at another sport."

As such, HP staff with classifying experiences were able to help with the efficiency of selection during talent search days and appropriately set athlete expectations as alluded to by Alexandra:

Knowledge of classification is really helpful for [talent search days]. So [my colleague] and [my] classification knowledge is good, [so] we were able to say, "Look, I know you have written down here that you are interested in athletics, but the reality is you are on the low end of your class. Do it for fun, obviously. If you enjoy it, do it. But if you want to go through the pathway, here is what we recommend your best options are.

And HP staff not only took into consideration athletes' impairment and their abilities but also the depth of competition within that classification domestically and internationally.

Some sports have attempted to use coach development programs (aligned with their AB program) to educate local coaches on impairment-related factors and designing inclusive training programs that can be delivered at any club. As Kenny noted:

The coach development through the able-bodied pathway is very important for that. Developing all the coaches in Australia to know the basic of the sport. If someone [with an impairment] comes [to the club], they are not lost. They might not be full-on, but at least they are not lost, and they know who to contact if they want further information. They have got also a rough idea of the disability. If you have got a kid, a 7 year old in a chair, just put him with the other kids. That is okay. Another chair for her. Same. You do not do the ladder [exercise], you zigzag, whatever. That is inclusion.

Other attempts to support local clubs included additional equipment and resources to take on athletes with impairments.

Considering one of the common methods of "recruitment" as indicated by HP staff was "drop-in" (i.e., athletes initiating contact with a local club), supporting local clubs was a strategy to ensure stakeholders with the first point of contact were equipped with the necessary skills to support athletes' initial experiences (Radtke and Doll-Tepper, 2014; Patatas et al., 2018). Previously, sports also aimed to design programs to "upskill" and educate staff in industries that work with individuals with impairments including rehabilitation centers and school teachers. Research has shown rehabilitation centers play a key role in the introduction and integration of persons into sports post-injury (Wu and Williams, 2001; van der Ploeg et al., 2006; Radtke and Doll-Tepper, 2014; Patatas et al., 2018). Educating those in positions of "first contact" (e.g., medical staff in rehabilitation centers) was critical for ensuring patients with acquired impairment had knowledge of available resources to continue sporting activities upon leaving rehabilitation programs.

There were also approaches to recruiting athletes through informal "talent transfer" between sports, where an athlete may have the opportunity to advance further in a different sport. While informal and formal transfer programs have been investigated in the AB setting (e.g., Halson et al., 2006; Collins et al., 2014; MacNamara and Collins, 2015), there is limited research on the effectiveness of talent transfer programs in Paralympic contexts. In particular, it is unknown whether this type of approach can be formalized to maximize talent retention while ensuring athletes are supported through the transfer process. In summary, while HP staff attempted to utilize a range of strategies to identify potential athletes, the main challenge was finding sufficient funding to maintain the program and hire skilled staff.

Funding the System

Participant insights suggested that limited funding was an overarching factor impacting athlete identification and development. Policy and limited funding have restricted sport organizations' capacity to maintain an effective pathway system with sufficient staff training (Radtke and Doll-Tepper, 2014; Patatas et al., 2020). In this study, participants shared similar experiences with funding limiting opportunities to support on-going recruitment initiatives (e.g., school and rehabilitation educational programs) or hiring of specific roles to increase initiatives which in turn reduced sport exposure within the community. HP staff also shared particular frustrations about the limited capacity to support pathway programs and to provide local coaches/venues with key resources (i.e., equipment, venue time) to ensure opportunities for athletes at the recreational level. Limited resources increased the demands of HP staff, forcing them to wear multiple hats and subsequently, increase their workload (Tawse et al., 2012). There were also concerns regarding how to support athletes once they entered the system, including the provision of equipment (i.e., lack of generic equipment to sample sports, costly equipment), coaching (i.e., lack of local coaches with impairment knowledge), and training (i.e., available facilities, training programs, cost of transportation to training camps).

Some of the participants alluded to a historically disjointed funding structure that supports both high-performance and recreational level sports as a particular challenge. HP staff understood the importance of the focus of the Australian Government to increase participation across the recreational level due to its benefits to the overall health of the individual and society at large.

From the sporting systems' perspective, most of the focus is on medal attainment with the majority of funding structured around the high-performance hubs and athletes. Therefore, the developmental pathway is lacking the necessary support from both streams to sustain the capacity to support athletes from recreational to high-performance, as Sandra further explained:

That is all about getting kids in schools playing sport more often. Then, for us, the challenge is then to transition them into clubs, then they've got the state, then you've got your national. It's always a vicious cycle. They want you to win medals, but to win medals you need a lot of money. A gold medal can be up to a million dollars investment in one athlete. We did some figures around how much for the Australian Winning Edge's model, the base amount of funding that a sport should be receiving, just to meet all those requirements, is half a million dollars. Most of us get a lot less than that. We have achieved a medal at the Paralympic level, at that time, with $290,000.

Many of the HP staff shared their concerns regarding the lack of depth at the lower levels and how this can be of concern looking ahead to the Paris 2024 Games and beyond. Edgar explained how the current structure and lack of funding for the pathway have put the pool of potential athletes for the Paris 2024 Games at risk:

I think that mainstreaming in terms of the national federations being responsible for the pathway has had challenges. I think the challenge is they have been provided funding to deliver a high-performance program for the Para perspective, but they have not really been provided the resources to deliver the pathway for Para athletes. So, I think there are plenty of gaps, there is a lot of work that needs to be done by the sports commission and national federations to really close some of those gaps. Because I think not only are we in jeopardy of not getting a great result in maybe not... Tokyo might be okay but 2024, I think we have got some real issues if our goal is to finish high on the medal tally at the Paralympic Games.

There are concerns regarding the impact of limited funding on recruiting, retaining, and developing athletes (e.g., quality coaching, opportunities for competition). With the weak pathway system, HP staff suggested an unhealthy consequence for athletes at a high-performance level, who potentially may have felt less pressure and had fewer concerns for internal competition for their spot leading to a culture of complacency. The limited pool of athletes among a small cohort of the population who have an impairment, coupled with budgetary constraints to expand resources and recruit more athletes puts HP staff at a clear disadvantage in trying to identify and develop athletes. James illustrated metaphorically how hard finding talent in the current system is:

We see a lot of kids over a whole year, a lot of kids. In some respects, [our sport] is an easy sport to deliver because it is so simple. There is that come and try level where it works really, really well, but to find the classifiable athletes and the ones who are going to take it seriously and can actually go from being a hit and giggle player, to a serious athlete, that seems to be so hard. You know the concept you are looking for a needle in the haystack? The problem is you are looking for a *golden* needle in the haystack.

This type of targeted approach to recruitment is even more difficult when looking for female athletes. Some sports see an obvious advantage of having a female on their roster as they receive additional classification points in international competitions, and many others acknowledged that female classes often do not have the same depth as their male counterparts; that said, many still have trouble recruiting female athletes. Recent studies have demonstrated the lower number of female participants in Paralympic sports including attendance in talent search days (Dehghansai and Baker, 2020; Dehghansai et al., 2020b). Even at the highest stage, there has been a consistent imbalance of numbers of female participants in comparison to male athletes at the Paralympic Games. While the recent Rio 2016 Summer Paralympic Games had a record high of 1,671 female participants, this was significantly lower than the male counterpart (n = 2,657) (Rio 2016 Paralympic Games, (n.d.)). HP staff in this study suggested puberty-related factors (e.g., self-consciousness of appearance) may play a role in female athletes' lower participation rates, especially if not introduced to sports prior to adolescence, as Edgar explained:

If someone has got a congenital impairment and they have not been captured in some way when they are at school age, then it is a bit of a challenge beyond that. And particularly for females with a disability if they have not been introduced to sport in some way, by the time they are about 13 when they care about their appearance a bit more, a bit more self-conscious, if they have not been captured at that age or around that age then it is pretty hard to get them back at 16 or 17 and beyond.

Recent work by Buckley et al. (2020) highlighted the family's role (i.e., being supportive and encouraging) in facilitating female athletes with visual impairments to participate in sports and develop an athletic identity. Here, Alexandra expressed how parents' overprotectiveness may play a role in a predominantly male environment:

A definite issue here is the lack of females in the system. I know it is an issue at 13–15. But I wonder if it is the over-protective nature of parents. You know, guys are going to be a little bit more out there. I do not know what the cultural reason is for that, but it could have an impact.

Literature examining the interaction of gender roles, puberty, and sport participation has highlighted the conflicting status between being an athlete and negotiating the role of femininity, and this crossroad is further complicated by the intersection of disability (Shakib, 2003). These environments position parents to be more "hands-on" in the decision-making process, and at times, minimizing unwelcoming environments to protect their children (Cirdland et al., 2014). On the other hand, there is literature suggesting sport participation for females prior to adolescence can address issues pertaining to self-consciousness and discontent that occurs during adolescence (Davison et al., 2007). Therefore, there is a need to develop initiatives to educate families on sport benefits and provide optimal environments for sport participation for young females with impairments.

In addition to systemic factors impacting the number and quality of athletes, limited funding also impacts the quality of staff and their experiences in Paralympic contexts. Due to budgetary constraints, most staff in the pathway are either volunteers or underpaid, with local clubs not having sufficient resources to educate staff on impairment-specific knowledge (Radtke and Doll-Tepper, 2014). These underpaid and unappreciated roles are usually met with high turnaround rates resulting in loss of intellectual property and reoccurring of the cycle with Edgar highlighting his frustration on these circumstances:

The big challenge for us is the turnover of staff and most people that work within [the organizations] do not grow up working in the disability industry. Some might work in sport but particularly when things like classification can be relatively complex in some sports and then to have staff that you work really closely with and they understand the network and the system and they are able to join lots of dots.

The limited funding is exacerbated in sports where equipment is an additional cost on top of already over-exceeding expenses (i.e., travel, accommodation, etc.). With technological advances, equipment is always evolving, and many are tailor-fit to the athletes, with limited opportunity to retrofit for someone else, therefore, each equipment is individualized and can play an integral role in how the athlete performs giving an advantage to athletes that can afford technological innovations. As alluded to by Wong (2008) and subsequent studies (i.e., Kean et al., 2017; Patatas et al., 2018), the rising cost of equipment can limit the growth potential for some athletes. On the other hand, technological innovations maximize the performance output for athletes who can afford these advances (Hambrick et al., 2015). James expressed their frustration on the competitiveness of equipment and the role technology plays:

Equipment is constantly evolving. If you are not innovating everyone else is. And to help, even if you have got the best coach in the world, your equipment has to be up to scratch. It is a bit like there is a bulls race going on. It is all about the bulls. And not just accepting that something half thought through is okay, that you got to be as fussy as maybe Niki Lauda is on his Formula One car. That you do not just accept what people are willing to do, you got to tell them actually what you need and make sure it is delivered.

In sum, systemic issues (policy, funding distribution, organizational communication) have resulted in limited funding opportunities across the pathway but have a marked impact on athlete identification and retainment. These funding limitations impact the quantity and quality of athletes, coaches, staff available in the system, but also limit opportunities to develop resources (coach education programs, relationships with community members, and organizations).

Practical Implications

There is a range of practical implications emerging from the current study and what it means in the context of prior research. First, athletes' impairment and potential classifications are critical in the identification process. While, there has been criticisms of the medical approach to understanding athletes' impairments (i.e., focusing on the biological component of impairment rather than the disability construct), it is common for coaches to take this approach to frame their coaching strategies (Townsend et al., 2015). Therefore, ensuring coaches have an in-depth knowledge of impairment functionality and classification systems can contribute to more informed selection decisions (Radtke and Doll-Tepper, 2014; Patatas et al., 2020). However, coach education programs should consider the influence of social relationships that attribute to the impairment-related factors under evaluation (Townsend et al., 2015). As such, it is also important to consider the evolution of the Games and the classification system to ensure athletes selected today are positioned to benefit from changes to the classification system in the future. Second, knowledge of athletes and parents' sporting background, athletes' level of independence, and their behavior during search days was relevant in the identification process. This assessment occurs informally, alluding to the importance of conceptualizing, and formalizing this process to reduce biases in athlete identification. Research from the AB literature has demonstrated talent identifiers' implicit biases that influence their selection decision (Johnston and Baker, 2020). Systematizing and tracking selections based on objective measures may reduce chances of biases, but more importantly, will allow opportunities for reflection and correction to improve the identification process.

Within the Paralympic context, the impairment-related factors (i.e., classification, onset of impairment, experiences before acquiring impairment) suggest a need for reconceptualization of talent identification and development. In an ideal world, athlete development precedes identification, aiming to provide a rich environment for athletes to flourish and display their potential excellence. However, the classification component in the Paralympic contexts appear to impact this process by forcing HP staff to select athletes with impairments that align with functional specifications of their sports prior to developmental opportunities. This approach can have debilitative affects for persons that do not fit the classification criteria and/or are looking to sample sports recreationally; however, it does inform athletes of their potential in a given sport before they invest extensive training hours.

While it is difficult to make recommendations regarding how to increase funding for Paralympic sports, it is important to note the impact of limited pathway funding on the entire pathway, including the lack of qualified staff to recruit and retain athletes and loss of intellectual property due to unsustainable support models (Radtke and Doll-Tepper, 2014). This contributed to the limited athletes to develop for subsequent Paralympic Games, but then impacted through a lack of competition for national spots changing athlete behaviors (i.e., complacency).

HP staff highlighted the importance of sport opportunities at younger ages (i.e., pre-adolescence) to allow athletes to feel comfortable with their abilities and the sporting environment while developing fundamental skills. The current assumption on overprotectiveness of parents and especially the lack of opportunities for female athletes early on in their lives, appeared to be a contributing factor to the low number of females in Paralympic sport, highlighting the importance of creating female-specific initiatives to support their early entry and to create resources for educating parents on the benefits of sport participation for their children. Last, there was a complex interaction of factors that could impact athletes' development (Dehghansai et al., 2020a), and when identifying and developing athletes, HP staff considered these stable constraints in combination with more malleable constraints that evolve across athletes' careers. Some of these malleable constraints were directly tied to opportunity-cost (i.e., athletes' current residency, available resource to support remote athletes), therefore, there is a need to identify cost-effective initiatives (e.g., partnership with local venues for accessible resources) and maximize coaching opportunities (e.g., educational resources on impairment and sport-specific nuances for development coaches and volunteers, remote-coaching) to create a more sustainable environment to support athletes in remote areas with limited resources.

Future Directions

For many of the participants, learning about the nuances of impairment (i.e., impairment type, classification) and associated implications (physiological response to training, psychological impacts of injury) was done informally due to limited available resources (McMaster et al., 2012; Lepage et al., 2020). While research in this area has increased recently, developing resources to support coaches can help ensure a safe and optimal environment is created for athletes, as well as inclusive coaching education programs for all mainstream (AB) sports to address a clear lack in recruitment and retention of athletes with impairments. As noted above, examining current sporting environments to better understand the lack of females in Paralympic sport remains a key area of further work. HP staff suggested the combination of puberty, disability identity, sporting environment, and familial role impacting females' interests in Paralympic sport. Focusing on extracting the factors that contribute to the disproportionate number of females in sport could be key to designing appropriate programs and initiatives to support female athletes' sport participation.

Two informal methods in the identification process, namely, the "coach's eye" and talent transfer initiatives, could be improved with formalization and empirical evidence is necessary to identify elements of their structure (Christensen, 2015; Jokuschies et al., 2017; Lund and Söderström, 2017; Romann et al., 2017; Roberts et al., 2019; Sieghartsleitner et al., 2019). Conceptualizing and systemizing coaches' approaches to assessment and selection could help track the identification process, refine and improve selection methods, and, more importantly, design programs to educate new coaches on strategies that experienced coaches use to select athletes. Similarly, formalizing talent transfer initiatives could help optimize sports' limited resources and ensure athletes are supported accordingly during and post-transition process.

Limitations

While findings from this project contribute to a limited work in Paralympic talent identification and development, there are a couple of limitations for consideration. First, the reality explored here are specific to the Australian Paralympic system. While findings do align with the limited work from other nations (Radtke and Doll-Tepper, 2014; Patatas et al., 2018, 2020; Dehghansai and Baker, 2020; Dehghansai et al., 2020b,c,d), generalizations outside of this context should be done with caution. Second, it would be important to obtain the experiences of athletes within the system to identify developmental gaps from athletes' lens.

CONCLUSIONS

There is very limited information on talent identification and development in Paralympic contexts. This study aimed to develop a better understanding of the Australia Paralympic talent identification and development through conversation with domain experts across a range of sports. It is clear that impairment and classification are pertinent factors to (initial) selection and therefore successful development (Radtke and Doll-Tepper, 2014; Patatas et al., 2020). However, there were other factors including familial involvement, biopsychosocial factors, and stable and malleable constraints that HP staff considered during the identification process. There were also long-standing issues (i.e., pathway funding, limited resources, and skilled staff) that appear to be consistent with literature from other nations (Radtke and Doll-Tepper, 2014; Patatas et al., 2020). Future research should examine how the current system can be designed to better track talent identification in a formalized method while creating resources to support coaches in the development of athletes and designing initiatives to introduce a more welcoming space for female athletes.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because providing transcriptions of the interviews will put participants' anonymity at risk. Requests to access the datasets should be directed to nimadehghan@gmail.com.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Research Ethics - Research & Innovation, York University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

RP and ND were involved in the recruitment process, ND conducted the interviews and led the transcription and thematic analysis, all authors participated in the reflexive discussions to formulate the themes. ND structured the manuscript sections and RP and JB reviewed the manuscript and provided feedback. ND was responsible to prepare the manuscript for submission and ensured manuscript formatting aligned with the journal's guidelines. All authors contributed to the article and approved the submitted version.

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The Influence of Parents, Coaches, and Peers in the Long-Term Development of Highly Skilled and Less Skilled Volleyball Players

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The purpose of this study was to understand the perceptions of highly skilled and less skilled volleyball players about the influences that parents, coaches, and peers had on their sport development and performance achievement. Highly skilled ($n = 30$) and less skilled ($n = 30$) volleyball players participated in semi-structured retrospective interviews to explain how parents, coaches and peers may have influenced their sport participation. Data was analyzed through a process of content analysis. Results indicated that parents, coaches, and peers had an important influence in player's sport development but differing according to players' expertise level. Concerning to parental influences, tangible support during the early years of development was mentioned by all players. However, parents' level of involvement and parenting styles revealed interesting differences between highly skilled and less skilled players. Highly skilled players perceived a moderate parental involvement and an autonomy-supportive parenting style, while less skilled players referred a excessive parental involvement in players' sport participation. Coaches influences showed to have some similarities in the early years with all players mentioning coaches as caring and recognizing their value as an athlete. However, highly skilled players described a different training environment characterized by a demanding coach, individualized instruction, and specific goal setting. Regarding peers' influence, all players recognized that friends were not only one of the main reasons to start playing volleyball, but also an important source of support to remain engaged and staying motivated to do sport. Highly skilled players, however, mentioned the importance of teammates' positive push and critiques during practice for enhancing their motivation, team cohesion and friendship. They also highlighted the importance of friends outside of sport in the later years of their career by acting as an escape from all the pressure that emerged from volleyball training and competition demands. Overall, these findings highlight different social influences according to the players' expertise level suggesting the need to examine more extensively the nature of significant others' support on athlete and talent development.

Keywords: social influences, talent development, athlete development, expertise level, volleyball

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INTRODUCTION

Sport is a privileged social context that provides rich opportunities for interpersonal interaction. The social network established throughout athlete's sport participation, in combination with the fairly intensive nature of this involvement, plays an important role in how they experience sport. Particularly, the social agents that directly interact in those experiences such as parents, peers and coaches, may have significant implications in athletes' sport participation, personal development, and performance (Côté, 2002; Côté and Hay, 2002; Côté et al., 2007, 2012).

Parents play a particularly important role during the early years of athlete development (sampling years) by giving the opportunity for their child to experience several sports and providing the resources needed to nurture their sport development (Côté et al., 2007; Harwood et al., 2012; Knight and Holt, 2014; Knight, 2016). As the athlete progresses in sport, the parents' role changes from a leadership role during the sampling years to a follower and supporter role during the specializing and investment years, where the facilitation of an optimal environment for athletes' development is the major concern (Côté and Hay, 2002; Côté et al., 2007; Harwood et al., 2012; Knight, 2016; Knight et al., 2016). Here, autonomy-supportive parents (i.e., parents who support their child's sport involvement and allow them to have an active role on their decisions) have been associated as a positive influence on children's sport development (Lauer et al., 2010b; Knight et al., 2011; Barreiros et al., 2013; Fraser-Thomas et al., 2013; Keegan et al., 2014; Knight and Holt, 2014). On the contrary, parents' over involvement in children's sport participation as well as the supply of an excessive sport-related feedback can act as sources of pressure, which may consequently decrease motivation and enjoyment in sport (Gould et al., 2008; Lauer et al., 2010a,b; Harwood et al., 2012).

Besides parental influences, the coach has a critical role in optimizing athletes' development through sport (Côté et al., 2010; Chan et al., 2012; Cushion et al., 2012; Atkins et al., 2015; Mesquita et al., 2015). Literature has suggested that during the sampling years the role of the coach is supportive, caring and encouraging (coach as a sport-helper and child-centered), while in the specializing and investment years coaches are described as more qualified, knowledgeable (sport specialist), and performance oriented (Potrac et al., 2002; Côté et al., 2007; Fraser-Thomas et al., 2008b; Barreiros et al., 2013; Jones et al., 2013). Coaches are also responsible for designing practices, encouraging their athletes to train on a long-term basis, and giving instruction (Barreiros et al., 2013). For example, time devoted for individual instructions with athletes usually differentiates not only those who prolong their engagement in sport from those who drop out (Fraser-Thomas et al., 2008a,b; Fraser-Thomas and Côté, 2009), but also experts from non-experts (Baker et al., 2003; Barreiros et al., 2013). Studies have also shown that coach behaviors have a significant impact on athletes' affective responses. For example, coach reinforcement, encouragement, individualized instruction, guided goal setting, and a belief in athletes' capabilities are associated with athletes' positive experiences in sport such as increased motivation and enjoyment in sport (Fraser-Thomas and Côté, 2009; Cushion et al., 2012; Barreiros et al., 2013; Mesquita et al., 2015).

Finally, peers can also play an important role throughout athlete development. During the sampling years, peers are one of the main reasons why children participate in organized and unorganized sports, as well as remain involved and motivated to practice sports later in their development (Côté et al., 2007; Keegan et al., 2010; Chan et al., 2012; Barreiros et al., 2013). As the athlete progresses in sport (up to the investment years), friends outside of sport are considered an important source of support since they tend to fulfill athletes' motivational and emotional needs (Côté et al., 2007; Fraser-Thomas et al., 2008a,b; Barreiros et al., 2013; Bruner et al., 2013). Studies that examined the association between peer relationships and athletes' affective outcomes have suggested that positive reinforcement and the motivational atmosphere provided by peers during practice are positively linked to athletes' motivation toward sport (Vazou et al., 2005; Keegan et al., 2010, 2014; Smith et al., 2010). Despite the importance of these social agents in athlete's sport participation, comparatively little attention has been given to the specific role of peers on athlete and talent development.

This body of research has been supported in the literature as contributing to a better understanding of the role of social influences in athlete and talent development. Notwithstanding, most studies have provided an isolated perspective of those influences, examining the influence of parents, coach and peers in an independent way. Future studies would therefore benefit from an ecological rational that examine all these social influences in an integrated viewpoint. Here, a more contextual approach will provide a better understanding of the interrelatedness between the athlete and the context contributing with richer evidence about the influence of the social environment on athlete and talent development. Moreover, this research topic is in a clear need of sport-specific studies to better understand the idiosyncratic behaviors of parents, coaches, and peers based on the sport itself and the developmental stage of the athlete (Lauer et al., 2010a,b; Atkins et al., 2015; Harwood et al., 2019). For instance, the unequal developmental pathways taken by athletes from sports where peak performance occurs before or after an athlete has full matured may imply different patterns of parents, coaches, and peers support throughout athlete development. Particularly in volleyball (where peak performance is achieved during adulthood) (Balyi and Hamilton, 2004; Coutinho et al., 2016), no studies have attempted to specifically understand the influences of parents, coaches and peers throughout the players' development.

Therefore, the purpose of this study was to understand the perceptions of highly skilled and less skilled volleyball players about the influences that parents, coaches, and peers had on their long-term sport development and performance achievement.

MATERIALS AND METHODS

Philosophical Perspectives and Design

A qualitative descriptive approach was considered in this study. Qualitative descriptive studies are particularly useful when exploring applied topics and used to understand the "who, what, and where of events or experiences" (Sandelowski, 2000, p.338). Considering that this study was interested in understanding the behaviors and influences of parents, coaches, and peers throughout the volleyball players' long-term development, a qualitative descriptive approach was deemed appropriate. This study was positioned within the interpretivism paradigm, underpinned by ontological relativism and epistemological constructionism. That is, within this study, it was assumed that reality is multiple and subjective and that knowledge is socially constructed (Weed, 2009). The rational for this approach was to understand the players' experiences with parents, coaches, and peers in sport, whilst acknowledging that their views are reflective of their own sporting contexts. This study focused on understanding the influences of social agents (parents, coaches, and peers) in the development of volleyball players from different expertise level and gender. The focus on different players (i.e., highly skilled/less skilled, male/female) was driven by a recognition that the participants' lived experiences may differ according to their cultural, social, and personal context. As such, the players analyzed in this study was selected based on two main criteria: (1) expertise level (considering their competitive level and previous sporting experiences; defined as highly skilled and less skilled players), and (2) gender (male and female players). The aim of such criteria was to achieve maximal variance between participants. The heterogeneity of participants, the diversity of contexts and the variety of lived experiences are factors of particular importance to understand the phenomena under study.

Participants

Sport Coaching staff members of 18 volleyball clubs in Portugal were recruited to help select participants for the study. Participants included 30 highly skilled and 30 less skilled volleyball players (15 male and 15 female for each group). Taking into account the philosophical perspective and design of this study, a panoply of factors is related with the topic of this study (i.e., social influences in sport). For that reason, only with a diversified sample characterized by its interindividual variety (15 highly skilled male, 15 highly skilled female, 15 less skilled male, 15 less skilled female), we were able to capture a complete picture of the influence of parents, coaches, and peers in the development of volleyball players. The average age of highly skilled players was 29.6 years ($SD = 3.4$) and the average age of less skilled players was 28.9 years ($SD = 3.1$). Participants were selected based on two main criteria: (a) being no younger than 23 years old (peak performance in volleyball is achieved in the mid to late twenties) (Balyi and Hamilton, 2004), and (b), having a minimum of 10-years of sport-specific experience in volleyball, but with no prior limitations on the number of reported hours spent in sport participation. Additional criteria that we used to characterize the sample of highly skilled participants included: belonging to a senior national team (Memmert et al., 2010; Hayman et al., 2011) and being ranked amongst the best volleyball players by national team coaches (Berry et al., 2008). The less skilled players were regularly involved in organized competitive volleyball but competing in a lower level (third league) and had never been part of a senior national team.

All procedures followed the guidelines stated in the Declaration of Helsinki and were approved by the ethics committee of the first author's institution. Players were contacted personally or by telephone and were provided with an overview of the study–100% of the players contacted agreed to participate in the study. Prior to the beginning of the study, all players were given information sheets that informed them about the purpose of the study and signed consent forms.

Procedure and Data Collection

Semi-structured interviews were deemed the most appropriate method of data collection for this study because they allow in-depth information to be gained from participants discussing their interpretation of the influence of significant others (i.e., parents, coaches, and peers) in their sport development (Cohen et al., 2001; Denzin and Lincoln, 2005). This was particularly important in the study considering the subjective and individual nature of the topics under study.

A semi-structured interview guide was developed based on the retrospective interview procedure suggested by Côté et al. (2005). The interview design sought to gain an in-depth understanding of the influence of significant others (i.e., parents, coaches, and peers) in players' sport development.

The interview began with a statement of what was being studied and a brief explanation of the concepts under study (i.e., types of parents, coaches and peers behaviors, influences and support within the sport context). Following this, participants provided their names and ages for the tape and briefly explained their pathway in volleyball. This process facilitated subsequent questions and transcription—it also acted to "break the ice." After this initial phase, the interview continued with questions intended to assess the influences (positive and negative) of parents, coaches and peers on player's sport development. These included: parents' tangible support, parents' emotional support, coaches behaviors and leadership style, coaches' emotional support, peers behaviors, and peers' emotional support. Probing and follow-up questions were used to encourage athletes to expand their answers and also to allow the participant to think in a different manner, such as "Can you give me a specific example of your parents behaviors during that time?"

All interviews were conducted by a female interviewer, who, apart from having experience in qualitative research methods, was also a qualified coach with a high level of volleyball playing experience. This served to facilitate the development of rapport with the participants and a closeness to the phenomena under investigation. Prior to carrying out the interviews, two pilot interviews were completed with participants. These lasted ~60 min and were taped and reviewed with the co-authors. Pilot interviews highly contributed to increase the research quality of this study since allowed the identification of the need to modify questions or other procedures that do not elicit appropriate responses or enable the researcher to obtain rich data (Malmqvist et al., 2019). This allowed the interviewer to rehearse and refine the interview procedure, including the intelligibility of the questions, an improvement in the clarity of the questions, the use of more accessible language for the participants, and the efficient use of elaboration and clarification probes (Miles and Huberman, 1994; Johnson, 1997).

Before each interview the participants were provided with a written and verbal introduction. The introduction outlined the research, reassured confidentiality and included definitions of the main research concepts. Participants were reminded that they were free to discuss any issues they felt were relevant to the topic. Informed consent was obtained and any questions were answered. Interviews were conducted in a quiet and free of distraction location by the primary researcher. The interview was conducted in a one-on-one format and took ∼1–2 h to complete. All interviews were audio recorded and transcribed verbatim.

Data Analysis

All interviews were digitally recorded, transcribed verbatim and checked for accuracy by the research team. Pseudonyms were assigned to each participant to ensure confidentiality throughout the analysis process. Content analysis (Sparkes and Smith, 2014) was used to analyzed the data. The initial stage involved immersion and familiarization with the transcribed data. Specifically, this involved reading the interviews texts several times and identifying segments of data containing meaningful information. The second phase involved the production of initial codes from the data, and basic segments deemed meaningful, were attached labels. This process developed with pre-existing research aims in mind (deductive), alongside openness to new segments (inductive), and was completed manually by-hand. The third phase involved the creation of themes by addressing concepts, and sorting codes into themes. Constant comparison (Weed, 2009) was employed, leading to the amendment of themes for the initial phase four grouping of overarching themes, themes and subthemes. Once themes were reviewed and defined, the last phase involved going back through the data to name the identified themes in a more representative demise.

Methodological Rigor

A number of steps were introduced to enhance the trustworthiness of the findings as well as their credibility and dependability (Johnson, 1997). Firstly, engaging in pilot interviews (and maintaining the same interviewer throughout) helped to maximize interview consistency. The experience of the interviewer as a player and coach also encouraged an affinity with participants. The interviewer previously reflected on the themes under study considering her experiences as a player and coach and awareness was taken before starting the interviews in order to guarantee an impartial position. Secondly, all interview transcripts and a summary of the results were returned to participants for member checking and participant feedback (Johnson, 1997; Cohen et al., 2001). Participants were asked to review their transcripts for verification, which allow them the opportunity to add, delete, or rework any data that they felt did not accurately reflect their intended communications (Miles and Huberman, 1994). After that, participants were contacted by the lead researcher via telephone to undertake a short discussion about the nature of the findings. This process enabled the lead researcher to pose questions to verify that the participants had indeed discussed the topic appropriately. All participants confirmed their transcripts. Finally, two members of the research team were involved in a collaborative approach within the interpretational analysis, with regular meetings to discuss the emerging categorical organization system. These meetings and reflections challenged the lead researcher's decisions and constructions of knowledge, developed interpretations, and offered alternative explanations for the findings. Following an in-depth discussion, the themes that remain doubts or disagreement were re-analyzed and reworded to more accurately portray the data. Through this discussion and questioning the final coding scheme was agreed upon. This important process contributed to the trustworthiness of the data, ensuring the interpretative validity while minimizing the risk of individual research bias (Silverman and Marvasti, 2008).

RESULTS

Through the analyses of the data, it became apparent that parents, coaches and peers had an important influence in player's sport development but differing according to players' expertise level. In the following sections, types of parent, coach and peer involvement and behaviors that influence the players' development are presented. Results are organized showing the commonalities and differences in these behaviors considering the player's expertise level. Corresponding quotes are provided to illustrate and clarify each theme.

Parental Influences

Highly Skilled and Less Skilled Players: Parents as Providers of Sport Experience

Both highly skilled and less skilled players described and explained how their parents provide a variety of opportunities to practice different sports throughout childhood and how this was important for them as an athlete to choose the right sport. They also referred the importance of parents provided them the resources, equipment, and all the financial and logistic support needed for their sport participation.

> *"My parents were tireless during my sport involvement. They provide me the opportunity to try different sports and gave me all the equipment I needed. They were always concerned that I had enough food and sleep… Now I recognize they provided me with the best conditions possible so I was calm and able to practice and compete…" (Highly skilled male #13).*

Less Skilled Players: Parents' Excessive Involvement in Players' Competitive Sport

The most commonly reported description of less skilled players' parents was how they were overly involved in their competitive sport participation, being present in every event of their sport experience, such as competitions, informal tournaments, friendly matches, and training sessions. They mentioned this involvement became a way of pressure for them. They also acknowledged this excessive involvement was a negative influence for their sport development and performance.

"My mom was always there... not only in my official games, but also in the majority of my training sessions. Sometimes was tough to see her always there because it seemed like she was judging me..." (Less skilled female #3).

Highly Skilled Players: Parents With a Moderate Level of Involvement in Player's Competitive Sport and Autonomy-Supportive Parenting Styles

Highly skilled players outlined their parents had a moderate involvement in their competitive sport participation (volleyball). This was characterized by being present in important moments for the player such as official competition like finals, but not present, for example, in trainings or informal competitive events. Highly skilled players explained how this behavior has benefitted their sport development. They also mentioned how their parents provided supportive feedback and how this was important for their motivation and commitment. Highly skilled players also highlighted that parents always gave them autonomy to decide which is the best path in their sport participation. They explained that when it comes to decide which club they will play in the next year or to negotiate their contract, for example, parents were there to listen to them and provide their opinion but did not meddle in their decisions.

"My parents have never been too much involved... they only came to watch my games when I asked them. However, they were always very careful and sought to know how I was doing... It seems like they were not physically there, but they were always in the background..." (Highly skilled male #6).

"My parents have never opposed to anything about volleyball. All they want is to see me happy playing volleyball. They always encouraged me to do my best and always supported through good and bad times..." (Highly skilled female #14).

"When I had to decide something about my career, they never intruded and always let me decide. For example, when I had to move to a different club I always asked them their opinion. They were always there for me and to listen to me. They provided their opinion but never said something that interfere in my decision. In the end, the decision was mine and I decided what was the best for me..." (Highly skilled female #14).

Coach Influences

Highly Skilled and Less Skilled Players: Coach as Caring in the Early Years

Both highly skilled and less skilled players explained how their coaches in the early years of development were friendly, affectionate, and passionate about volleyball. These coaches' characteristics were very important to motivate them to start practicing volleyball and to stay involved and committed to the sport. They highlighted the importance of their first coach for their sport development and learning about the sport.

"I liked my first volleyball coach so much! She was so sweet and managed to motivate me a lot in that time. She loved volleyball and I think that's why I started to love volleyball too. She was always worried about us, about our school... she was like a second mother for me..." (highly skilled female #5).

Highly Skilled and Less Skilled Players: Coach Recognition of Player's Value

Both highly skilled and less skilled players described the importance of having their value acknowledged by coaches throughout their development. They reinforced the importance of coaches belief in their potential as an athlete and always helping them to evolve in volleyball by providing feedback, reinforcement, attention, and specific exercises. They also stated that coaches gave them the opportunity to exhibit their skills and encouraged them to be better than they were.

It was important for me to feel that they (coaches) were interested in me and I was not only one more player... they believe in me and in my development... they never ignore me and always believe that I would achieve some degree of success (Less skilled male #10).

Highly Skilled Players: Demanding Coach

Highly skilled players mentioned how their coaches were tough, rigorous, and demanding during adolescence and how this was important for their expertise achievement. These behaviors, and specially coaches' demand, were represented in the way they want the things to be done. The exercises, the technical actions, the tactical positions, the understanding of the game, the overall commitment, they always tried to get the best out of the player. Their coaches were very committed in providing high level training practices, attention to technical and tactical development and push them to the limit so as they were able to achieve a high level of performance whenever possible. This demanding training environment was perceived by highly skilled players as beneficial for their development and they never considered it as excessive, negative or prejudicial for them.

"The majority of my coaches always gave me a lot of attention and push me to the limit during adolescence ...they were very tough with me, providing lots of attention to technical and tactical details and I knew that's because they wanted me to do my best and achieve a high-level standard." (highly skilled female #15).

"Trainings were very demanding. We were there to do our best. Or even more, if possible! However, I never felt it was too much. I never felt my coaches passed the limit. I knew that they needed to be like that to get the best out of us. Actually, I always like that type of training environment because I knew I will improve my performance..." (highly skilled male #8).

Highly Skilled Players: Individualized Coaching and Goal Setting

Highly skilled players referred to having coaches with a very specialized knowledge and experience in volleyball, which was determinant for having high quality training practices. They also mentioned their coaches provided them one-on-one instruction and established specific targets particularly in later stages of development. They considered this individual consideration was especially important for their development because it guided them to know what they need to work and focus on. They also acknowledged that all these behaviors were determinant for achieving high levels of performance later in their careers.

"They knew very well what they were doing. The targets of the team were well-established and common to everyone, but they also set very specific goals for each player… This was important because we knew what we had to do and what we needed to improve. Because of this, they spent a lot of hours with me after the training session, working on my difficulties… their feedback used to be highly specific and I improved my performance because of that." (Highly skilled male #5)

Peers Influences

Highly Skilled and Less Skilled Players: Friends as a Reason to Play Volleyball

Both highly skilled and less skilled players referred that friends were the reason to start playing volleyball and remain involved in this sport. Friends were already practicing volleyball when they started and were important for their integration in the sport and the team/group. This positive first experience helped them to enjoy practicing volleyball at that time and stay involved in this sport throughout the time.

"I start playing volleyball because all my friends played at that time… Then it was easy to start enjoying that sport…" (Less skilled male #3).

"I remained involved in volleyball in the first years definitely because of my friends/teammates…" (Highly skilled female #8).

Highly Skilled and Less Skilled Players: Friends Outside of Sport as a Positive Influence

Both highly skilled and less skilled players described friends outside of sport (i.e., friends that were not involved in volleyball) as an important source of support and encouragement to play volleyball. They mentioned the importance of their friendship and invitation to social events despite their busy agenda related to volleyball (training sessions and competitions). They highlighted how positive is this understanding about their sport career and recognized the contribution of these behaviors to a stable psychological state and well-being, which was favorable for their development as an athlete.

"It was very important to have their friendship. Although I was very busy with volleyball, they still invited me to parties and social programs and never forgot me! This was very important for me and all this was then reflected in training and competition, because I was feeling good with myself and feeling that everyone supported me…" (Highly skilled male #13).

Highly Skilled Players: Teammates Positive Push

Highly skilled players indicated that teammates provided a stimulating motivational climate during training practices. They explained that teammates' push and critiques during practice were important for training with higher quality. Teammates' push and critiques are represented in behaviors such as asked the player to do more and better when he/she were not doing, providing corrective feedback concerning technical and tactical actions, establishing rivalry and a competitive environment when they are playing. They also mentioned this motivational climate promoted by teammates was positive since enhanced team cohesion, friendship and players' motivation to achieve better results. They never felt this motivational climate was negative for them. On the contrary, they believed this training environment contributed to potentiate their development and the achievement of high levels of performance.

"The competitiveness between us was an important ingredient for our success…this was an important factor in enhancing our motivation and making us work more and more… At the end of the training we were all friends again, but in the practice we were like warriors!" (Highly skilled female #4).

"They [teammates] were very important for me. They were always there to push me when I am not totally committed to do my best. They helped me to know what I was doing wrong technically or tactically and corrected me. Also, when we were doing six vs. six [playing/preparing the game] they were very competitive and the rivalry present in the game was amazing! I never felt that was a bad thing… I know that only with that kind of thing I would achieved my best! (Highly skilled male #12).

Highly Skilled Players: Friends Outside of Sport as an Escape in the Later Years

Highly skilled players described how their friends outside of sport acted as an escape from all the pressure and stress of volleyball in the later years of their career. They mentioned they were important to think and talk about other issues than volleyball and therefore relax from all the pressure and negative things related to their sport career.

"I really try to have other things besides volleyball… There is a lot of pressure to win so my friends are very important because when I go out with them I know that I will talk and think about other things rather than volleyball…" (highly skilled male #7).

DISCUSSION

The present study sought to understand the perceptions of highly skilled and less skilled volleyball players about the influences that parents, coaches, and peers had on their sport development and performance achievement. Consistent with previous research on this topic (Côté et al., 2007; Barreiros et al., 2013; Keegan et al., 2014; Atkins et al., 2015), this study suggests that parents, coaches and peers played an important role throughout volleyball players' development and affected players' experiences in sport as well as their expertise achievement.

The tangible support provided by parents of both highly skilled and less skilled players during the early years of development was perceived to facilitate their overall development. Here, parents provided the best conditions possible for their children's sport involvement, particularly the opportunity to engage in sport and all resources required for practice (i.e., financial support, equipment, transportation to and from training sessions and competitions, flexibility in rearranging family schedules). This type of support is considered a precondition for a sustainable and committed early sport involvement, building therefore a solid foundation for a prolonged engagement in sport and talent development (Côté et al., 2007; Lauer et al., 2010a; Harwood et al., 2012; Fraser-Thomas et al., 2013; Knight, 2016). While tangible support was to be expected for all players, parents' level of involvement and parenting styles revealed interesting differences between highly skilled and less skilled players. Highly skilled players emphasized the importance of parents' moderate level of involvement, explaining that they were present in important competitive moments for the player (example: official competitions, finals), but not present in trainings or informal competitive events (less significant for players). Highly skilled players also mentioned the importance of the autonomy provided by parents throughout development. Here, they explained that parents did not meddle in their decisions when it comes to the choice of a club or the negotiation of their contract. On the contrary, less skilled players reported an excessive parental involvement in their sport experience, represented by parents being always present in everything (formal or informal competitive moments, training sessions, etc.). They acknowledged this excessive involvement was a negative influence for their sport development and performance. Research examining parents' level of involvement in sport have shown that when parents adopt a moderate level of involvement in sport combined with autonomy-supportive behaviors (continuing attempts to encourage and allow their children to take responsibility for their own achievement performance and behavior), athletes tend to have positive experiences in sport such as higher levels of intrinsic motivation (Fraser-Thomas et al., 2008a,b; Lauer et al., 2010b; Barreiros et al., 2013; Preston and Fraser-Thomas, 2018). On the other hand, an excessive parental involvement is linked to athletes' negative sport experiences such as pressure, stress, negative emotional outcomes and burnout (Fraser-Thomas et al., 2008a,b; Fraser-Thomas and Côté, 2009; Harwood and Knight, 2009a,b). While these findings shed light on important insights regarding the positive and negative parental behaviors that influence volleyball players talent development, more research is needed to examine the specific behaviors that facilitate healthy sport experiences in highly skilled and less skilled players.

Coach behaviors also had a significant impact throughout players' development. Both highly skilled and less skilled players identified caring as an important characteristic of their coaches in the early years of development. This finding is corroborated by past research describing coaches' role in the early years as being kind, cheerful and caring, providing a playful introduction to sport (Côté, 2002; Côté et al., 2007; Fraser-Thomas et al., 2008b; Jones, 2009). The entrance in organized sport is a stressful moment for a child, so this motivational and cheerful environment offered by the coach may provide positive initial experiences captivating therefore children for a prolonged engagement in sport. Coach recognition of player's value was also a positive influence perceived by all players. This recognition was demonstrated in coaches' belief of players' potential to play volleyball, combined with a positive style of communication (Rollnick et al., 2020) and the opportunities provided for players to exhibit and develop their skills. This finding corroborates the results found by Fraser-Thomas and Côté (2009) showing that coaches' belief positively influenced adolescent swimmers' experiences in sport. Despite the importance of such findings, this body of research has been deeply overlooked in sport sciences. Therefore, additional research would benefit further understanding concerning the relationship between coach's recognition of player's value (or coach's belief) and athletes' outcomes in sport.

Of particular interest is the differences found between highly skilled and less skilled players concerning specific coach behaviors. Highly skilled players recognized that a rigorous and perceived demanding training environment combined with a very structured training plan and one-on-one instruction during adolescence were beneficial for their expertise development. These behaviors, and specially coaches' demand, were represented in the way they want the things to be done (exercises, the technical actions, the tactical positions, the understanding of the game, the overall commitment). Highly skilled players characterized their coaches as very committed in providing high level training practices, providing attention to technical and tactical development and pushing them to the limit so as they were able to achieve a high level of performance whenever possible. Highly skilled players interpreted this type of coach behaviors as beneficial for their development and they never considered it as excessive, negative or prejudicial for them. These findings are consistent with past studies showing that demanding coaching, individualized instruction and goal setting are important requisites to enhance athlete development and expertise achievement during the specializing years (Côté et al., 2007; Fraser-Thomas et al., 2008a,b; Cushion et al., 2012; Barreiros et al., 2013).

Finally, the findings of this study also highlight the important role of peers (within and outside sport) throughout athlete development (Côté et al., 2007; Keegan et al., 2010; Barreiros et al., 2013; Bruner et al., 2013). Specifically, both highly skilled and less skilled players recognized that friends were not only one of the main reasons to start playing volleyball, but also an important source of support for continued engagement and staying motivated for practicing sport. These findings are aligned with previous research clearly indicating affiliation with others and the development of positive social relations as major motives underlying children's interest in sport involvement (Weiss and Stuntz, 2004; Fraser-Thomas et al., 2008a; Fraser-Thomas and Côté, 2009). Nevertheless, clear differences relating to specific peers or teammates behaviors were found between highly skilled and less skilled players. Highly skilled players perceived teammates' criticisms and positive push (during practice) as an important factor for enhancing their motivation, team cohesion and friendship. These behaviors were perceived as positive rather than negative for the player and they believed this training environment contributed to potentiate their development and the achievement of high levels of performance. Within the study of peer interactions in sport (Keegan et al., 2009, 2010, 2014), researchers have suggested that a wide range of behaviors such as competitive behaviors, evaluative communication and social relationships may create an appropriate motivational atmosphere that strongly contributes to consolidate and strengthened friendship and team cohesion, enhancing athletes' motivation and facilitating therefore the athletes' healthy development in sport. Thus, the way athletes perceive such behaviors is of utmost importance to know how to deal with them. Furthermore, highly skilled players also described the importance of having friends outside of sport because they understand their demanding sporting life and agenda, while simultaneously act like an escape from all the pressure of volleyball during the later stages of their development. Consistent with literature (Côté et al., 2007; Fitzgerald et al., 2012; Bruner et al., 2013; Atkins et al., 2015), friends are an appropriate source of support during the later stages of development by fulfilling athletes' motivational and emotional needs. Notwithstanding, further studies examining peer support in sport should explore the athletes' and peers' backgrounds and contexts since this may have a great influence in the manner peers understand the sport involvement and its requirements.

Despite the important findings of this study, there are some limitations that should be addressed. Although widely used in literature, reliable and valid, retrospective methodologies only reflect interpretation of records and participants' reports/perceptions of their previous sport experiences, which need to be triangulated with other data (Sosniak, 2006). Future studies, though, may benefit from further exploring the use of qualitative research methods (such as focus groups, participant observation, action research, ethnographic studies) so as to provide a more consistent and enhanced understanding regarding the role of parents, coaches, and peers throughout players' development and expertise achievement. The use of such qualitative research methods could be specifically important to explore an integrated understanding of the inter-relationships that may exist between them and their influences on players' development. Here, longitudinal mixed methods approaches may also contribute to better understand these issues since may combine intervention, observation and practical reflection with multiple stakeholders (parents, coaches, athletes, other parents, peers) providing a more ecological and integrated perspective of these social influences throughout time. These studies could offer a more concrete understanding about the changes that the influence of parents, coaches, and peers may have throughout time according to the athletes' developmental stage. Future studies may also profit from the triangulation of different perspectives of distinct social agents rather than solely the athletes' perception (Pankhurst et al., 2012). Thus, examining the perception of parents, coaches and peers (within and outside sport) may provide a better, global, and solid picture of social influences in sport. In line with this perspective, further investigations should therefore explore in more detail what specific behaviors, attitudes and influences parents, coaches and peers exert that positively or negatively influence the development of an athlete and their expertise enhancement (e.g., supportive behaviors, how autonomy was provided by parents, types of leadership behaviors by coaches, types of behaviors provided by peers during training sessions and competitions that may interfere in the motivational climate, etc.). Here, more sport-specific studies are necessary to understand if the behavioral patterns showed by parents, coaches and peers change according to the idiosyncrasies of each sport as well as its cultural context. Finally, it is also important that future studies take into consideration the socioeconomic background of the social agents under study since this factor could interfere in the way they interpret sport and the interrelationships within this context.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of Faculty of Sport of University of Porto. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Nationwide Subjective and Objective Assessments of Potential Talent Predictors in Elite Youth Soccer: An Investigation of Prognostic Validity in a Prospective Study

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Recent studies have provided empirical evidence on the prognostic relevance of objective performance diagnostics in the soccer talent identification and development process. However, little is known about the prognostic validity of coaches' subjective evaluations of performance. This study evaluated objective and subjective assessments within a nationwide talent development program and addressed motor, perceptual skill, and personality-related performance factors. Male players ($N = 13{,}869$; $M_{age} = 12.59 \pm 1.07$ years) from the age groups U12 to U15 of the German soccer talent development program participated in this study. Participants completed an objective motor diagnostic (sprint, agility, dribbling, ball control, juggling) and were subjectively rated by their coaches (kicking skills, endurance, individual tactical skills, psychosocial skills). All nine predictors were assessed with sufficient psychometric properties ($\alpha \geq 0.72$; except dribbling and ball control: $\alpha \geq 0.53$). Players' success three seasons later was operationalized by achieving professional youth academy level or not (success rate, 9%). Independent-samples *t*-tests analyzed univariate mean group comparisons between future selected and non-selected players. Logistic regression models examined the multivariate prognostic validity of all assessments by predicting success with subjective (model 1), objective (model 2), and both groups of predictors (model 3). Confirming the univariate prognostic validity, future selected outperformed non-selected players regarding all predictors (each $p < 0.001$, except for agility in U15: $p < 0.01$). Tactical skills, kicking skills, and sprint were of highest predictive value ($d \geq 0.61$ in each age group). Multivariate results provided empirical evidence for the subjective (7% $\leq$ Nagelkerke's $R^2 \leq$ 11%; each $p < 0.001$) and objective (8% $\leq$ Nagelkerke's $R^2 \leq$ 13%; each $p < 0.001$) assessments' prognostic validity. However, model 3 revealed the best statistical explanatory power in each age group ($0.15 \leq$ Nagelkerke's $R^2 \leq 0.20$; $p < 0.001$). In this combined assessment model, sprint, tactical skills, and dribbling were found to be the most predictive variables. In conclusion, this study reinforces the call for multidimensional diagnostics integrating objective and subjective assessments. Future research is needed to address the demands for longitudinal analyses of subjective ratings, the integration of biological maturation, and empirical evidence for female soccer.

Keywords: football, coach's eye, talent identification and development, tactical skills, technical skills, physiological abilities, psychosocial skills, multidimensional diagnostic

INTRODUCTION

Talent identification and development in soccer have been "vibrant research areas" for sport scientists in the last two decades (Williams et al., 2020, p. 1). Several prospective studies with multidimensional approaches have provided empirical evidence on the significant, yet also partly limited prognostic relevance of objective diagnostics that assess youth players' characteristics, abilities, and skills in soccer (Murr et al., 2018a,b; Sarmento et al., 2018; Ivarsson et al., 2020). However, little is known about the prognostic validity of subjective evaluations of such performance factors by coaches or scouts, and recent studies highlight the need to integrate both subjective and objective evaluations of potential talent predictors (Dugdale et al., 2020; Ford et al., 2020).

The identification of talent in soccer has been studied from a variety of theoretical and methodological approaches (Williams et al., 2020). Since soccer is a complex team sport, a number of performance factors must be considered when determining which youth athletes have the highest potential to develop into elite players (Lund and Söderström, 2017). For example, researchers have highlighted different qualities associated with performance, including physiological, technical, tactical, and psychological attributes (Hoare and Warr, 2000; Unnithan et al., 2012; Suppiah et al., 2015). With respect to physiological performance measurements, researchers indicate that selected youth soccer players are faster than non-selected players (Gil et al., 2014; Höner and Votteler, 2016). Furthermore, researchers found players who progressed to an elite level were more technically competent for skills such as juggling, dribbling, and passing accuracy (Höner et al., 2017; Bergkamp et al., 2019). In addition, skilled players have been found to possess superior perceptual–cognitive skills when compared to less skilled counterparts (Ward et al., 2013; O'Connor et al., 2016). Finally, psychological attributes such as self-confidence, motivation, mental toughness, commitment, and seeking social support have also been found to predict elite level soccer career success (Williams and Reilly, 2000; Toering et al., 2009; Van Yperen, 2009; Baláková et al., 2015; Höner and Feichtinger, 2016). Most of these findings were based on objective measurements and provide an indication of the factors that may predict future high performance. However, due to the considerable variation in study designs, findings across individual talent identification studies are inconsistent and difficult to compare. Therefore, there is no clear set of variables that uniformly predicts skill level (Breitbach et al., 2014; Höner and Feichtinger, 2016; Bergkamp et al., 2018; Johnston et al., 2018; Murr et al., 2018b).

Given the challenges associated with talent identification, standard talent identification procedures often rely on the evaluation of athletes' current performance by coaches and scouts (Williams et al., 2020). Within this process, coaches' experience and expertise in identifying potential talent comprise an important tool (Larkin et al., 2020). To this end, researchers have used interview techniques to determine what experienced soccer coaches look for when identifying potential talent. Christensen (2009) found Danish national team coaches valued game intelligence (i.e., ability to read and predict game play) and soccer-specific physiological and technical skills as the most important factors when assessing talent. Coaches also considered personal qualities (e.g., character, attitude, drive to succeed, and willingness to learn) as important. This finding is further supported by Larkin and O'Connor (2017), who identified a hierarchy of attributes perceived as important by coaches when identifying youth soccer players: technical (i.e., first touch, kicking skills, one-vs.-one ability, technical ability under pressure), tactical (i.e., decision-making skills), and psychological attributes (i.e., coachability, positive attitude).

Specifically related to the process of talent selection, Lund and Söderström (2017) found that Swedish soccer coaches made decisions based on previous experience, current elite players' qualities, and the values and belief system of the club. This suggests the decision to select or not to select an athlete is based on intuition and deliberation, grounded on an "overall impression," factoring in subjective evaluations of technical skills, game understanding, and a variety of psychological characteristics (Meylan et al., 2010; MacMahon et al., 2018; Williams et al., 2020). However, based on knowledge from selection psychology, it is argued that individuals should be cautious when using such "clinical judgments" (Dawes et al., 1989), as various pieces of information have to be combined to make a decision, and as such, there is potential for different errors and biases. As a result, this may lead to less accurate decisions and inconsistencies between individual decision-makers (Den Hartigh et al., 2018). This issue has been identified with evidence to suggest the accuracy of subjective talent decisions by coaches and scouts is relatively low. Koz et al. (2011) found the accuracy of selection decisions for professional sports "entry drafts" suggests that even when these decisions are made late in development (i.e., early adulthood), the level of predictive accuracy is comparatively low.

Therefore, Ford et al. (2020) suggested researchers consider the integration of both subjective and objective evaluations of performance factors. However, according to the review of Williams et al. (2020), only two studies have explored the relationship between subjective evaluations and objective tests in this context. In a prospective design, Sieghartsleitner et al. (2019a) examined the isolated and combined prognostic relevance of several characteristics for the identification of future playing status, including the subjective evaluation of players' in-game performance in addition to objective diagnostics of technical and general motor performance factors. Results indicated that the use of subjective coach assessments and objective performance data was significantly better at predicting under 19 (U19) player status than objective performance data alone. More recently, Dugdale et al. (2020) compared levels of agreement between subjective and objective assessment of youth elite Scottish soccer players' (U11–U17 age group) physical performance. Athletes completed different physical performance assessments (e.g., endurance, acceleration, speed), with coaches providing a subjective evaluation of the physical variables. The findings indicated the coaches' subjective evaluation only corresponded with high and low performance on the objective physical assessments, suggesting that coaches' subjective evaluations may not be sensitive enough to discriminate between players whose performance level is rather similar. In conclusion, the two studies highlight the importance of combining both subjective evaluations and objective test results within the talent identification process. It should be noted, however, that Sieghartsleitner et al. (2019a) did not examine subjective performance factors, but general in-game performance, and Dugdale et al. (2020) did not address the prognostic validity of subjective rated performance factors with regards to players' future performance level. Thus, given the lack of data on coaches' and scouts' efficacy regarding selection decisions, there is a need to examine the prognostic validity of subjective and objective evaluations of youth players' performance factors in regard to their validity for talent selections over an extended period.

THE PRESENT STUDY

With an applied focus on the key process of talent selection, the present study was conducted within the talent development program of the German Soccer Association (Deutscher Fußball-Bund, DFB). In this program, two nationwide assessments of potential talent predictors are implemented to monitor the development of players' performance factors. First, a motor test battery was implemented as an objective diagnostic in 2004 and is conducted semiannually. Second, starting with the 2015/2016 season, coaches involved in the program rate players on subjective evaluation criteria in the spring of each season. This subjective evaluation supplements the objective motor diagnostic that currently addresses technical skills (i.e., ball control, dribbling, juggling) as well as linear and change of direction speed abilities (i.e., sprinting, agility[1]).

Given these two existing nationwide assessments in the German talent development program, the aim of this prospective study was to investigate the objective diagnostic and subjective evaluation in the age groups U12–U15 in relation to their prognostic validity for future success. First, within a *univariate perspective*, we examined the prognostic validity of each single performance factor that was measured with an objective or subjective assessment. Second, within a *multivariate perspective*, we evaluated whether the (objective, subjective, and combined) assessments as a whole provide a meaningful prognostic model for players' future success and compared the contributions of each performance factor within these assessments.

METHODS

Sample and Design

Within the German talent development program, nearly 1,300 part-time DFB coaches select about 14,000 early-adolescent players (i.e., age groups U12–U15) from amateur clubs all over the country to participate in one additional practice session per week at one of the 366 regional competence centers (CC). This quite homogeneous group of high-performing youth players belong to the top 4% of all German male youth players in their age group (Deutscher Fußball Bund, 2009). A central purpose of this program is the development of these CC players with the aim that they will be selected for one of the professional German soccer clubs' youth academies in middle-to-late adolescence (YA, top 1%).

The sample of this *prospective cohort study* comprised $N = 13{,}869$ male CC players ($M_{age} = 12.59 \pm 1.07$ years; age groups U12–U15; birth cohorts: 2001–2005) who participated in the nationwide motor diagnostic (Höner et al., 2015). Furthermore, players were subjectively rated by their coaches regarding several performance factors either in spring of the 2015/2016 season (birth cohorts 2001–2004) or in spring of the 2016/2017 season (birth cohorts 2002–2005). The objectively and subjectively evaluated performance factors served as predictors for *players' future success* three seasons later.

Before entering the talent development program, players' legal guardian provided written informed consent for the recording and scientific use of the data. The CC coaches together with DFB staff members conducted the motor diagnostic and performed the subjective evaluations of the present study. The DFB

[1]There are inconsistent definitions of agility in sport science literature (Sheppard et al., 2014). In the present study, the term "agility" is used for tests that assess a speed-related motor ability enabling preplanned changes of movement direction that does not include cognitive aspects such as anticipation or decision-making. Thus, this study investigated the physical dimension (or movement component) of agility. This perspective categorizes agility as a physical performance factor in accordance with the majority of prospective studies referred to in the present article (e.g., Hohmann et al., 2018; Sieghartsleitner et al., 2019b; Saward et al., 2020) as well as with the recent reviews on talent identification research in soccer (e.g., Bergkamp et al., 2019; Williams et al., 2020). However, following the work by Sheppard and Young (2006), agility is often used in a broader sense whereby agility is considered an open skill based on two factors, "change of direction speed" (CODS) and perceptual–cognitive facets such as anticipation and decision-making. To address the inconsistency in the literature, we use both terms in the figures and tables of the present study [i.e., "Agility (CODS)"] to indicate that we refer to the physical dimension of agility but not to the more complex reactive agility.

In a recent position paper, Young et al. (2021) encourage researchers to study (reactive) agility in more ecologically valid settings that include a sport-specific stimulus (e.g., video simulations, 1 vs. 1 situations, small-sided games). This call is also true for the other objective motor diagnostics investigated in the present study because they do not represent the contextual constraints of soccer games (for a discussion of the representativeness and fidelity of predictors in talent identification research in soccer, see also Bergkamp et al., 2019).

TABLE 1 | Subjectively assessed youth players' performance factors serving as potential predictors for future success.

Domain	Performance factor (# items)	Items for subjective evaluation of youth players' performance factors
Motor	Kicking skills (3)	– Kicking the ball with ○ dominant leg ○ non-dominant leg – Heading
	Endurance ability (1)	– Endurance
Perceptual–cognitive	Individual tactical skills (7)	– Behavior in offensive situations ○ before ball-related actions ○ during ball-related actions ○ after ball-related actions – Behavior in defensive situations ○ before ball-related actions ○ during ball-related actions ○ after ball-related actions – Game intelligence
Personality related	Psychosocial skills (3)	– Motivational skills – Volitional skills – Social skills

TABLE 2 | Key points and their explanations for rating players' individual tactical skills in offensive situations (before, during, and after ball-related actions).

Behavior in offensive situations…	Key points	Explanation of the key points
Before ball-related actions	➢ Preorientation ➢ Offering/creating space	Competence center players can… • Orientate themselves in such a way that they make an appropriate decision: e.g., open, look over their shoulders. • Make themselves available in such a way that they are playable or create space in which another player becomes playable: e.g., separate themselves from a defender.
During ball-related actions	➢ First touch ➢ Orientation on the ball ➢ Situation-appropriate decision-making	Competence center players can… • Play the ball with the first touch according to the situation: e.g., in the new direction of play, in the open space/away from the opponent, secure the ball. • Orient themselves while they are on the ball: e.g., glance away from the ball, view the next situation. • Decide appropriately: e.g., pass the ball to a teammate, dribble with the ball, shoot the ball toward the goal.
After ball-related actions	➢ Re-orientation ➢ Follow-up action	Competence center players can… • Act according to a new situation after a play: e.g., pass the ball and immediately find an opening again, be offset to back up teammates, be open again, create space for teammates.

provided the authors with players' data of the five birth cohorts (2001–2005). The university's ethics department approved the implementation of this study.

Measures

Predictors

The *subjective performance evaluation* was conducted by the 1,300 coaches of the German talent development program who possess at least the UEFA B-License. Coaches' subjective evaluations of motor (i.e., kicking skills, endurance), perceptual–cognitive (i.e., individual tactical skills), and personality-related domain (i.e., psychosocial skills) were assessed using a questionnaire consisting of 14 items (see **Table 1**). With respect to the motor domain, three items assessed kicking skills (i.e., kicking the ball with the dominant and non-dominant leg, heading the ball), and one item addressed endurance as a physiological performance factor. Regarding the perceptual–cognitive domain, individual tactical skills were subjectively assessed by the quality of individual tactical behavior in offensive and defensive situations (i.e., before, during, and after ball-related actions) as well as overall game intelligence (i.e., seven items in total). Finally, within the personality-related domain, the assessment of psychosocial skills comprised three items including motivational, volitional, and social skills (one item each). To enhance a nationwide common understanding of the items, the CC coaches were educated by DFB staff members, and a 16-page manual was distributed to the coaches before implementing the subjective evaluation. For each item, the manual included key points as well as detailed explanations and examples. Both the key points and examples guided the CC coaches what to look for in their subjective ratings.

Table 2 provides an extract of the manual in regard to the three items addressing individual tactical behavior in offensive situations. For the item "individual tactical behavior in offensive situations *before* ball-related actions," the CC coaches were directed by the manual to focus their subjective evaluation on the key points "preorientation" and "offering/creating space." To get a more vivid and concrete understanding, the two key points were explained by typical examples: (1) CC players can orientate themselves in such a way that they make an appropriate decision (e.g., find an open position, look over their shoulders), and (2) CC players can make themselves available (e.g., separate themselves from a defender) in such a way that they can receive a pass or create space in which another players can receive a pass. The individual tactical behavior in offensive situations *during* ball-related actions was concretized by the key points "first touch", "orientation on the ball", and "situation-appropriate decision-making", and regarding the behavior in offensive situations *after* ball-related actions, coaches should pay attention to the "reorientation" and "follow-up action" (these key points were also illustrated by typical examples, see **Table 2**;

for corresponding information regarding the other performance factors, see **Supplementary Table 1**).

Coaches were asked to judge each item from a holistic perspective (i.e., for their "overall impression" about the player in the respective season). For the motor and perceptual–cognitive performance factors, coaches rated their CC players' performance in comparison to the general CC player level and to the level of regional association team players (i.e., the next highest level within the talent development program). These reference levels were familiar to all CC coaches and thus implemented for the subjective assessment to ensure that CC coaches not only had a similar idea of the items (see **Table 2**) but also a reference norm that was as consistent as possible regarding the performance level. Thus, for each item, coaches evaluated their players on a 4-point rating scale as "below-average DFB competence center level" (0); "average DFB competence center level" (1); "level of the extended squad for regional association team" (2); or "level of core team for the regional association team" (3). As it was difficult for CC coaches to judge the psychosocial skills on these levels, no direct relation to the general CC or regional association team level was established. Thus, for the evaluation of the psychosocial skills items, the coaches rated their players as "below average level" (0), "average level" (1), "high level" (2), or "very high level" (3). Based on these ratings, a value for each respective performance factor was calculated by the average of the corresponding individual items (e.g., the mean of the three judgements for the kicking skills items represented the indicator for the subjective evaluation of the player's kicking skills).

The *objective motor diagnostic* included five individual tests to assess players' speed abilities and technical skills (for details, see Höner et al., 2015): sprint (i.e., time in a 20 m linear sprint); agility (i.e., time in a slalom course without a ball); dribbling (time in a slalom course with a ball); ball control (i.e., time needed to play six passes alternately against two opposing impact walls with at least two ball contacts); and ball juggling (i.e., juggle the ball alternately with the left and right foot through as many subsections of a figure eight-course without ground contact). Light barrier systems (Brower TC Timing, Draper, USA) were utilized to measure execution times for sprint, agility, and dribbling. Times for ball control were assessed by hand-stopped chronographs. Each test was performed twice with the best result recorded for analysis purposes. Between the attempts, the athletes were given enough time to recover. Whereas the time-based individual tests (i.e., sprint, agility, dribbling, and ball control) were negatively coded (i.e., a lower value indicated a better performance), a higher value in the juggling test represented higher performance.

As the nationwide assessments were more relevant for comparisons of players within age groups than over several age groups, the *psychometric properties* for the predictors in this study were investigated for each age group separately. The subjective performance scales were characterized by excellent reliability values in terms of internal consistency for tactical skills ($0.89 \leq \alpha \leq 0.91$ for U12, U13, U14, and U15) and psychosocial skills ($0.84 \leq \alpha \leq 0.87$), whereas kicking skills ($0.73 \leq \alpha \leq 0.77$) showed at least satisfying values. Moreover, Höner et al. (2015) analyzed the age-specific motor test battery's psychometric properties for a sample of nearly 70,000 male CC players and found excellent internal consistency for sprint ($0.92 \leq \alpha \leq 0.93$ for U12, U13, U14, and U15) and agility ($0.90 \leq \alpha \leq 0.90$). Juggling revealed satisfying values ($0.72 \leq \alpha \leq 0.75$), whereas those for dribbling ($0.53 \leq \alpha \leq 0.57$) and ball control ($0.61 \leq \alpha \leq 0.64$) were slightly lower.

Criterion

Three seasons after participating at the nationwide assessment in the competence centers (i.e., time of predictor data collection), players' future success was operationalized by achieving the German YA level or not (i.e., *selected* vs. *non-selected*). In general, the CC coaches who conducted the objective and subjective assessments were not involved in the future selection process for the YAs. Moreover, the approach ensured the same prognostic period (i.e., three seasons) for all players. The selected group comprised players who participated at the assessments in spring 2015 and were enrolled in a YA for the 2018/2019 season and those who completed the tests in spring 2016 and were enrolled in a YA for the 2019/2020 season. To identify the enrolled YA players, the squad lists for the respective age groups of all German YA were examined regarding the players' names and birth dates. Players who were—according to the squad lists in the respective seasons—identified as YA players were defined as *selected* and the others as *non-selected* players. Overall, $n = 1{,}198$ players were categorized as selected and $n = 12{,}671$ players as non-selected players (i.e., the success rate for achieving the youth academy level in this study was about 9%).

Statistical Analysis

Data were analyzed utilizing IBM SPSS version 26. To provide robust results regarding the predictors' prognostic relevance, the data from the two measurement points (i.e., season 2015/2016 and 2016/2017) was accumulated for each age groups (U12–U15). If a player participated in the assessment in both seasons, only the data from the first assessment was taken. However, the two seasons and the corresponding birth cohorts in the sample (2001–2004 and 2002–2005, respectively) may confound the analysis of performances' differences between selection levels (Elferink-Gemser et al., 2012). To control for this assumption, two-way ANOVAs for each performance factor were conducted testing whether there was an interaction effect between future success and the respective birth cohorts tested at the first and second season. As non-significant interactions [$F_{(1,13865)} \leq 3.36$, $p \geq 0.07$] were found for all variables, the cohort variable was not considered as a confounder in the following analysis. Similarly, the influence of relative age as a potential confounder within the analysis was investigated, and non-significant interactions [$F_{(1,13865)} \leq 3.12$, $p \geq 0.08$] between future success and relative age (player born in first or second half of the year) were found.

As coaches' subjective evaluations were ratings in relation to the respective age group (i.e., U12, U13, U14, and U15), the following statistical analyses were conducted for each age group separately. The variance of the investigated variables within each age group of the preselected samples and, accordingly, the expected statistical effect sizes may be limited in talent research studies (restriction of range of talent; Ackerman, 2014).

Moreover, single predictors may represent only a small part of complex soccer performance. Thus, test power or sensitivity in prospective talent studies is a critical issue (Bergkamp et al., 2019). To determine the size of a possibly detected population effect for differences between two groups, sensitivity was calculated by *post-hoc* power analyses using G*Power version 3.1.9.7 and predetermined parameters ($\alpha = 0.05$, $1 - \beta = 0.85$, two-tailed). For the age groups U12, U13, U14, and U15 and their corresponding sample sizes (see **Table 3**), the analyses were sensitive enough to detect small to medium effect sizes $d \geq 0.13$, $d \geq 0.17$, $d \geq 0.22$, and $d \geq 0.40$, respectively.

With respect to the *univariate prognostic validity* of the subjective evaluations as well as motor diagnostics of players' performance factors, mean group comparisons between future selected and non-selected players were computed for all assessed predictors. To identify significant differences between future successful and less-successful players, two independent samples *t*-tests were computed. Cohen's d (computed as the mean difference divided by the pooled standard deviation) served as effect size (including the respective 95% confidence intervals) and was classified into the categories small ($0.2 \leq d < 0.5$), medium ($0.5 \leq d < 0.8$), and large ($d \geq 0.8$) in accordance with Cohen (1992). Regardless of whether the considered variable was negatively or positively coded, the provided d values were set positive when the selected players achieved better test results[2].

Second, a logistic regression approach was chosen to investigate the *multivariate prognostic validity* of the assessed performance factors. Within three different logistic regression models, the binary criterion variable (selected vs. non-selected for YA) was predicted by the subjectively (*model 1*), objectively (*model 2*), and the combination of subjectively and objectively (*model 3*) assessed performance factors. Independent variables for *model 1* comprised the four subjectively judged performance factors (see **Table 1**), whereas *model 2* consisted of the five single motor tests. Model 3 included both the four subjective and five objective performance factors. To evaluate the whole (subjective, objective, and combined) nationwide conducted assessments, the enter method was used for each regression analysis, and each overall model fit was analyzed with the likelihood ratio chi-squared test and Nagelkerke's R^2. Regression coefficients and the odds ratio coefficients e^b (including their 95% confidence intervals) were calculated to provide a clearer view of a player's relative chances to get selected, depending on the considered predictors. To facilitate comparisons for effect sizes of individual predictors, the odds ratio coefficients e^b were additionally adjusted to the standard deviations of the respective age group (Höner and Votteler, 2016). Thus, the resulting $(e^b)^{SD}$ represents the relative change of the likelihood for being selected for a YA by a one standard deviation increase within the considered predictor. Thereby, the adjusted odds ratios were inverted and displayed as $(e^b)^{-SD}$ for negatively coded predictors (i.e., the time-based tests sprint, agility, dribbling, and ball control) where lower values in time represent higher performance.

Regarding the chosen predictors within the models, considerable bivariate correlations were detected. Correlations among the four subjective performance factors in the respective age groups ranged from $r = 0.51$ (kicking skills with endurance in U15) to $r = 0.79$ (kicking skills with tactical skills in U12), while those for the five objective motor diagnostics ranged from $r = 0.02$ (sprint with juggling in U14) to $r = 0.51$ (agility with dribbling in U15). For the bivariate comparisons between subjective and objective performance factors, the highest relationship was found for endurance with sprint in U12 and U15 (i.e., each $r = 0.22$). Consequently, in order to control for a potential bias due to multicollinearity, the variance inflation factor (*VIF*) for the predictors within each logistic regression model was investigated. The *VIF* values for the predictors within the three models were all $VIF \leq 3.81$, and because *VIFs* exceeding 10 are considered as an indicator for serious multicollinearity (Akinwande et al., 2015), no meaningful multicollinearity bias was expected for this study.

RESULTS

Univariate Prognostic Validity of Subjective and Objective Performance Factors

Table 3 provides the results for the assessed predictors in the considered age groups separated by level of future success. Overall, the results for all predictors correspond to the later achieved performance level. That is, players who were selected for a YA after three seasons showed significantly superior performance factors compared to non-selected players (each $p < 0.001$, except for agility in the age group U15: $p < 0.01$).

Figure 1 illustrates the superior performances of the selected compared to the non-selected players in terms of Cohen's d. The results indicated no clear trend for a decline or incline of the effect sizes over the age groups, that is from U12 to U15. According to the median of the effect sizes, tactical skills [$Mdn\ (d) = 0.75$; $0.61 \leq d \leq 0.85$ for U12, U13, U14, and U15]; kicking skills [$Mdn\ (d) = 0.71$; $0.61 \leq d \leq 0.82$]; and sprint [$Mdn\ (d) = 0.69$; $0.40 \leq d \leq 0.73$] proved the highest discriminative power between selected and non-selected players. Dribbling [$Mdn\ (d) = 0.47$; $0.41 \leq d \leq 0.54$]; endurance [$Mdn\ (d) = 0.43$; $0.37 \leq d \leq 0.48$]; psychosocial skills [$Mdn\ (d) = 0.43$; $0.38 \leq d \leq 0.50$]; and juggling [$Mdn\ (d) = 0.42$; $0.35 \leq d \leq 0.52$] revealed nearly medium effect sizes, whereas small effect sizes were found for ball control [$Mdn\ (d) = 0.34$; $0.22 \leq d \leq 0.41$] and agility [$Mdn\ (d) = 0.30$; $0.25 \leq d \leq 0.36$].

Overall, the predictive power of the four subjectively rated performance factors [$Mdn\ (d) = 0.56$; $0.38 \leq d \leq 0.85$ for all subjective predictors over all age groups] were detected to be higher than those of the objectively assessed motor performance factors [$Mdn\ (d) = 0.41$; $0.22 \leq d \leq 0.73$]. Except for sprinting, effect sizes for the objective diagnostics revealed slightly lower values ranging from $d = 0.22$ for ball control in U14 to $d = 0.54$ for dribbling in U15.

[2]In addition, to have a pragmatic measure for the chance of players' future success, groups of low [percentile rank (PR) ≤ 33.33], medium ($33.33 < PR \leq 66.67$), and high ($PR > 66.67$) performers were built for each considered predictor. Based on these categorizations, odds ratios being selected for a YA for players with high vs. medium and high vs. low performance outcomes were calculated (results for these analyses are presented in the **Supplementary Table 2**).

TABLE 3 | Test results for subjectively (printed in italics) and objectively evaluated performance factors of selected and non-selected players separated by age class (U12–U15, $N = 13{,}869$).

Performance factor	Future performance level (after 3 seasons)	*M* ± *SD*				*t (df)* Cohen's d^+ (95% CI)			
		U12	U13	U14	U15	U12	U13	U14	U15
	Selected (*N*)	582	356	202	58				
	Non-selected (*N*)	6,077	3,324	2,083	1,187				
Kicking skills	Selected Non-selected	1.71 ± 0.53 1.33 ± 0.56	1.76 ± 0.55 1.37 ± 0.54	1.70 ± 0.51 1.38 ± 0.56	1.88 ± 0.42 1.48 ± 0.54	15.72 (6,657) 0.70*** (0.60; 0.77)	15.12 (5,703) 0.72*** (0.61; 0.83)	10.17 (3,454) 0.61*** (0.43; 0.72)	6.80 (1,963) 0.82*** (0.48; 1.01)
Endurance	Selected Non-selected	2.05 ± 0.72 1.70 ± 0.75	2.03 ± 0.74 1.75 ± 0.75	2.03 ± 0.67 1.77 ± 0.73	2.19 ± 0.61 1.90 ± 0.73	10.27 (704.86) 0.48*** (0.38; 0.55)	8.13 (699.57) 0.37*** (0.26; 0.48)	7.59 (392.07) 0.43*** (0.21; 0.50)	3.99 (1,963) 0.43*** (0.14; 0.66)
Tactical skills	Selected Non-selected	1.89 ± 0.57 1.46 ± 0.58	1.90 ± 0.57 1.48 ± 0.57	1.84 ± 0.55 1.49 ± 0.57	2.05 ± 0.51 1.59 ± 0.56	17.26 (6,657) 0.76*** (0.66; 0.83)	14.45 (5,703) 0.73*** (0.63; 0.85)	11.32 (3,454) 0.61*** (0.47; 0.76)	7.36 (1,963) 0.85*** (0.56; 1.09)
Psychosocial skills	Selected Non-selected	2.01 ± 0.67 1.71 ± 0.66	2.04 ± 0.64 1.72 ± 0.66	1.99 ± 0.65 1.78 ± 0.68	2.02 ± 0.54 1.79 ± 0.65	10.53 (695.75) 0.46*** (0.40; 0.54)	10.51 (693.16) 0.50*** (0.38; 0.60)	6.71 (391.13) 0.38*** (0.17; 0.46)	4.40 (110.19) 0.39*** (0.09; 0.62)
Sprint (20 m)#	Selected Non-selected	3.54 ± 0.15 3.64 ± 0.16	3.43 ± 0.15 3.55 ± 0.16	3.29 ± 0.15 3.42 ± 0.17	3.23 ± 0.14 3.29 ± 0.16	14.79 (6,657) 0.65*** (0.54; 0.71)	17.64 (719.59) 0.73*** (0.64; 0.87)	12.07 (3,454) 0.73*** (0.63; 0.92)	4.98 (110.75) 0.40*** (0.11; 0.64)
Agility (CODS)#	Selected Non-selected	8.23 ± 0.42 8.38 ± 0.40	8.14 ± 0.39 8.24 ± 0.39	8.02 ± 0.37 8.13 ± 0.40	7.94 ± 0.43 8.06 ± 0.39	8.41 (6,657) 0.36*** (0.29; 0.46)	5.78 (5,703) 0.25*** (0.15; 0.37)	5.41 (3,454) 0.29*** (0.13; 0.42)	3.05 (1,963) 0.30** (0.04; 0.57)
Dribbling	Selected Non-selected	10.69 ± 0.69 11.06 ± 0.74	10.49 ± 0.65 10.77 ± 0.68	10.30 ± 0.57 10.56 ± 0.64	10.10 ± 0.65 10.47 ± 0.72	11.55 (6,657) 0.52*** (0.42; 0.59)	8.78 (5,703) 0.41*** (0.30; 0.52)	8.51 (406.06) 0.42*** (0.27; 0.56)	4.63 (1,963) 0.54*** (0.52; 0.64)
Ball control#	Selected Non-selected	9.74 ± 1.25 10.27 ± 1.33	9.37 ± 1.20 9.73 ± 1.26	8.98 ± 1.04 9.28 ± 1.14	8.61 ± 1.21 9.06 ± 1.17	9.10 (6,657) 0.41*** (0.32; 0.49)	6.89 (5,703) 0.29*** (0.18; 0.40)	4.79 (3,454) 0.22*** (0.12; 0.41)	3.41 (1,963) 0.38** (0.12; 0.65)
Juggling	Selected Non-selected	4.12 ± 4.24 2.50 ± 3.01	6.13 ± 5.29 4.06 ± 4.31	7.90 ± 5.48 6.15 ± 5.32	9.76 ± 6.40 7.29 ± 5.74	9.05 (638.52) 0.52*** (0.43; 0.60)	7.90 (656.82) 0.43*** (0.36; 0.58)	5.78 (372.97) 0.35*** (0.18; 0.47)	3.91 (1,963) 0.41*** (0.16; 0.69)

These variables are negatively coded, i.e., a lower value represents a higher performance.
+ *A positive d value displays a better test result for the selected players regardless whether the considered variable was negatively or positively coded.*
* *$p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.*

Multivariate Prognostic Validity of Nationwide Subjective and Objective Assessments

In each age group, the overall fits for the subjective [Model 1: $40.87 \leq \chi^2_{(4)} \leq 305.20$, $p < 0.001$; $0.07 \leq$ Nagelkerke's $R^2 \leq 0.11$] and objective [Model 2: $40.87 \leq \chi^2_{(5)} \leq 388.02$, $p < 0.001$; $0.08 \leq$ Nagelkerke's $R^2 \leq 0.13$] assessment models were significantly better compared to the null model. That is, both the subjective, as well as the objective assessment, significantly predicted the binary outcome (selected vs. non-selected player) in each age group (each $p < 0.001$). Except for the age group U15, where the explained variance by subjective evaluations (i.e., 10%) exceeded those by the objective assessment (i.e., 8%), model 2 comprising the objective diagnostics showed higher values of explained variance compared to model 1 (13, 14, and 13% vs. 10, 11, and 7% for the age groups U12, U13, and U14; for further details, see **Supplementary Tables 3a,b**).

Moreover, hierarchical regressions revealed that adding the subjective predictors of model 1 to the objective predictors of model 2 [for the age group U12–U14, $42.67 \leq \Delta\chi^2_{(4)} \leq 137.29$, each $p < 0.001$; $0.04 \leq \Delta$ Nagelkerke's $R^2 \leq 0.06$] or adding the objective predictors of model 2 to the subjective predictors of model 1 [U15; $\Delta\chi^2_{(5)} = 20.42$, $p < 0.01$; Δ Nagelkerke's $R^2 = 0.05$] led to a significant increase in the explained variance. Thus, the combination of the subjective and objective assessments (model 3) showed the best statistical explanatory power in every age group [Model 3: $61.29 \leq \chi^2_{(9)} \leq 525.31$, $p < 0.001$; $0.15 \leq$ Nagelkerke's $R^2 \leq 0.20$].

The results of the logistic regressions for model 3 separated by age group are displayed in **Table 4**. Regarding the significance of the predictors, the subjectively evaluated tactical skills as well as the motor test results for sprinting and dribbling significantly contributed to the explanation of players' future success in each

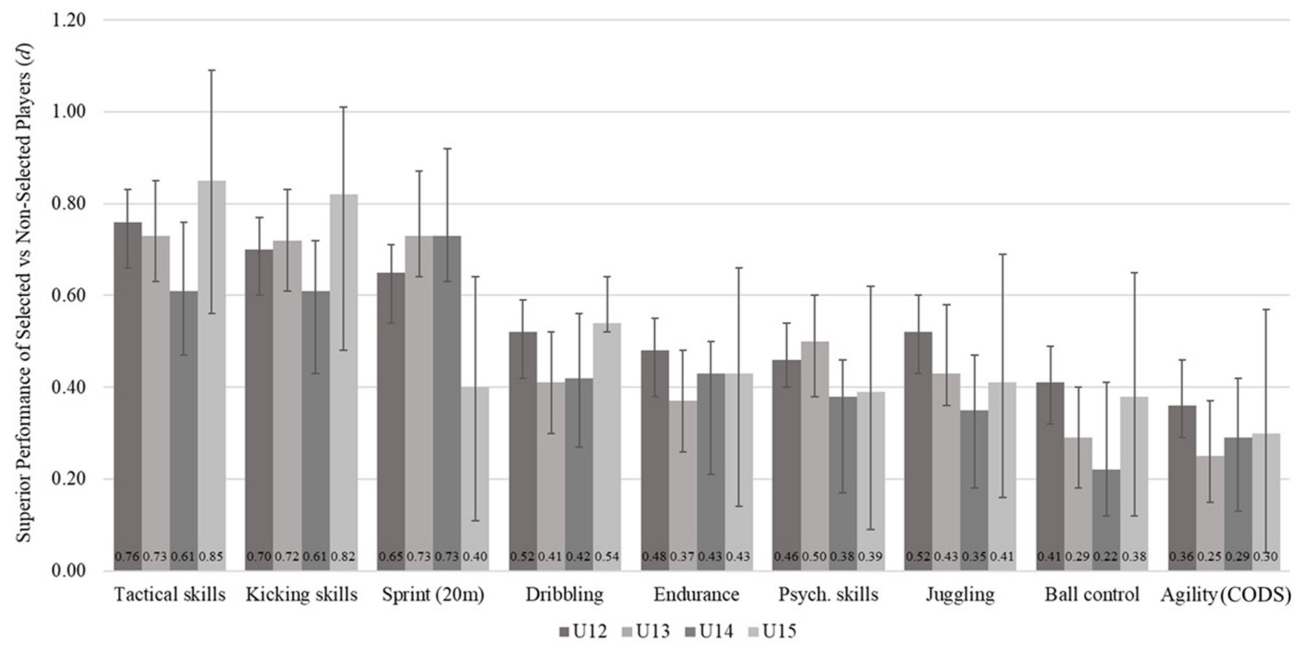

FIGURE 1 | Superior performance of selected vs. non-selected players in terms of Cohen's *d* and respective 95% CI (the variables are ordered regarding the median of the effect sizes for the four age groups).

age group (each $p < 0.05$). Moreover, kicking skills was a significant predictor for all age groups except for U15 (each $p < 0.05$) and juggling for the younger age groups U12 and U13 (each $p < 0.01$), whereas ball control only showed a significance for the youngest age group U12 ($p < 0.01$). In contrast, the predictors endurance, psychosocial skills, and agility did not show any significant positive contribution to the models in three of the four investigated age groups. In 9 out of 12 cases, the regression coefficients for these three predictors in the four age groups were not significant (each $p > 0.09$). Interestingly, and presumably caused by the noticeable correlations to other explaining variables in the model, in the three remaining cases, psychosocial skills (U12, $p = 0.02$), endurance (U13, $p < 0.01$), and agility (U13, $p = 0.01$) contributed in the opposite, non-expected direction to the explanation of the criterion within the multivariate model.

With regard to the adjusted odds ratios $(e^b)^{SD}$ for significant predictors in the logistic regressions, it can generally be seen that sprint (except for U15) and tactical skills were characterized by the highest scores. For instance, a one standard deviation better result in the sprint would approximately double the chance of being selected for a YA three seasons later in the age groups U12 [$(e^b)^{SD} = 1.75$], U13 [$(e^b)^{SD} = 2.05$], and U14 [$(e^b)^{SD} = 2.13$]. The regression results revealed a similar importance for tactical skills in U15 [$(e^b)^{SD} = 2.09$], and this performance factor was still a relevant predictor in the younger age groups [$1.52 \leq (e^b)^{SD} \leq 1.68$]. Moreover, dribbling in all age groups [$1.35 \leq (e^b)^{SD} \leq 1.53$] and kicking skills in U13 [$(e^b)^{SD} = 1.40$] and U14 [$(e^b)^{SD} = 1.36$] proved their relevance in this regard, whereas all further significant predictors provided limited predictive relevance [$(e^b)^{SD} \leq 1.24$].

DISCUSSION

For a discussion of the study results, it is important first to identify the stage of talent development at which the study took place and second the parameters of the study design used to investigate the talent predictor's prognostic relevance. Regarding the first aspect, Williams et al. (2020) provided a conceptual framework for the talent identification and development process. They identified three key processes for players who are not involved in a structured talent program: detection (i.e., screening for players from outside soccer); participation (i.e., playing soccer but not in a structured development program); and identification (i.e., recognizing soccer players who have the potential to progress in a structured development program). Studies in this field are characterized by a heterogeneous sample (e.g., Hohmann et al., 2018). In contrast, the present study was conducted within the German soccer talent development program, where participants had already been selected as competence center (CC) players leading to a more homogeneous sample. Therefore, according to the conceptual framework, the present results refer to the stages of "development" (i.e., providing the players with a suitable learning environment), "selection" (i.e., on-going process of selecting players within the development program; e.g., for the next highest level or age group) and "deselection" (i.e., removing players from the program) of youth players (Williams et al., 2020).

The present study provides comprehensive insights into empirical evidence for the prognostic validity of nationwide assessments and thus of subjectively and objectively assessed performance factors in youth elite soccer. First, within a

TABLE 4 | Logistic regression results for the prediction of players future success (selected for a YA three seasons later) in dependence of the subjective (printed in italics) and objective assessments (model 3, separated by age group).

Age group	Omnibus tests			Predictor	Logistic regression coefficients				$(e^b)^{SD}$ (#)
	χ^2 (*df*)	*p*	Nagelkerke R^2		*b*	*Wald*	*p*	e^b (95% CI)	
U12	525.31 (9)	<0.001	0.17	Constant	12.53	–	–	–	–
				Sprint	−3.49	107.71	< 0.01	0.03 (0.02; 0.06)	1.75
				Tactical skills	0.87	33.75	< 0.01	2.39 (1.78; 3.20)	1.68
				Dribbling	−0.40	23.63	< 0.01	0.67 (0.57; 0.79)	1.35
				Juggling	0.05	15.44	< 0.01	1.05 (1.02; 1.07)	1.16
				Ball control	−0.13	10.06	< 0.01	0.88 (0.81; 0.95)	1.19
				Kicking skills	0.39	9.03	< 0.01	1.47 (1.14; 1.89)	1.24
				Psychosocial skills	−0.25	5.21	0.02	0.78 (0.63; 0.97)	0.85
				Agility (CODS)	0.22	2.29	0.13	1.24 (0.94; 1.64)	–
				Endurance	−0.08	0.72	0.40	0.93 (0.78; 1.10)	–
U13	354.65 (9)	<0.001	0.20	Constant	11.97	–	–	–	–
				Sprint	−4.37	111.22	< 0.01	0.01 (0.01; 0.03)	2.05
				Tactical skills	0.84	20.67	< 0.01	2.32 (1.61; 3.34)	1.63
				Juggling	0.05	15.87	< 0.01	1.05 (1.03; 1.07)	1.24
				Dribbling	−0.44	14.74	< 0.01	0.65 (0.52; 0.81)	1.35
				Kicking skills	0.61	13.13	< 0.01	1.83 (1.32; 2.54)	1.40
				Endurance	−0.39	12.19	< 0.01	0.67 (0.54; 0.84)	0.74
				Agility (CODS)	0.52	7.85	0.01	1.68 (1.17; 2.41)	0.82
				Ball control	−0.05	0.76	0.38	0.95 (0.86; 1.06)	–
				Psychosocial skills	0.04	0.08	0.78	1.04 (0.79; 1.36)	–
U14	176.87 (9)	<0.001	0.17	Constant	16.13	–	–	–	–
				Sprint	−4.41	69.83	< 0.01	0.01 (0.00; 0.03)	2.13
				Dribbling	−0.52	9.98	< 0.01	0.59 (0.43; 0.82)	1.40
				Tactical skills	0.72	8.06	< 0.01	2.05 (1.25; 3.36)	1.52
				Kicking skills	0.54	6.17	0.01	1.72 (1.12; 2.64)	1.36
				Ball control	−0.13	3.09	0.08	0.87 (0.75; 1.02)	–
				Juggling	0.02	1.57	0.21	1.02 (0.99; 1.05)	–
				Psychosocial skills	−0.20	1.43	0.23	0.82 (0.58; 1.14)	–
				Endurance	−0.18	1.35	0.24	0.83 (0.61; 1.13)	–
				Agility (CODS)	0.19	0.64	0.42	1.21 (0.75; 1.96)	–
U15	61.29 (9)	<0.001	0.15	Constant	8.31	–	–	–	–
				Tactical skills	1.31	7.75	0.01	3.70 (1.47; 9.29)	2.09
				Dribbling	−0.59	4.21	0.04	0.56 (0.32; 0.97)	1.53
				Sprint	−1.98	3.85	0.05	0.14 (0.02; 1.00)	1.36
				Psychosocial skills	−0.52	2.81	0.09	0.60 (0.33; 1.09)	–
				Ball control	−0.23	2.50	0.11	0.79 (0.59; 1.06)	–
				Juggling	0.03	1.99	0.16	1.03 (0.99; 1.08)	–
				Kicking skills	0.56	1.98	0.16	1.76 (0.80; 3.85)	–
				Endurance	−0.17	0.36	0.55	0.85 (0.49; 1.46)	–
				Agility (CODS)	0.12	0.07	0.80	1.12 (0.46; 2.77)	–

Predictors were ordered by increasing values with regard to the Wald statistic. (#) In order to facilitate comparisons for effect sizes of individual predictors, the odds ratio coefficients e^b were additionally adjusted to the standard deviations of the respective age group (Höner and Votteler, 2016). The resulting $(e^b)^{SD}$ represent the relative change of the likelihood for being selected for a YA by a one standard deviation increase within the considered predictor. For negatively coded predictors, the adjusted odds ratios were inverted and displayed as $(e^b)^{-SD}$.

univariate perspective, the results confirmed the prognostic validity for all considered predictors addressing the motor, perceptual–cognitive, and personality-related domain. Thereby, the variables with the highest predictive value (i.e., tactical skills, kicking skills, and sprint) represent both assessment methods (subjective and objective) and depict different domains. However, effect sizes were limited, and thus, the sensitivity was not high enough to justify case-by-case selection decisions on the stand-alone basis of these assessments (Carling and Collins, 2014; Höner and Votteler, 2016). Second, within a *multivariate perspective*, the results provided empirical evidence for the subjective and objective assessments' prognostic validity. Overall, the objective assessment showed higher explanatory power when comparing both assessments. Most important, the combined model, integrating both assessments, revealed explained variances of 15% $\leq$ Nagelkerke's R^2 $\leq$ 20% over the four investigated age groups and proved superior to the models comprising either the subjective or objective assessment. Consequently, this addresses current gaps within the literature by linking subjective coach evaluations with objective measures (Williams et al., 2020). Within these multidisciplinary models, sprint, tactical skills, and dribbling were found to be the most predictive variables, although the order of the most significant predictors varied in parts among the age groups.

Prognostic Validity of the Performance Factors

The present study analyzed large-scale nationwide assessments based on a powerful sample size and assessed data from U12, U13, U14, and U15 players belonging to the top 4% of their age group in Germany. The prospective criterion was the achievement of youth academy status (i.e., top 1% of all players) three seasons later, with a success rate of 9%. For a more detailed interpretation, one must take into consideration the variety of *study design features* in prospective studies that influence the expectable amount of significant effects and their sizes (Hohmann et al., 2018; Bergkamp et al., 2019). For instance, players' age and soccer development stage (e.g., foundation, talent, or elite stage), the level and type of the criterion variable, and the applied assessments must be considered as moderator variables regarding the prognostic relevance of talent predictors (Murr et al., 2018b). Moreover, due to the sports-specific performance requirements, important information with respect to prognostic validity such as effect sizes are only comparable within a specific sport.

Therefore, the following discussion about the effect sizes presented in this study is focused on recent systematic reviews exploring prospective studies in youth soccer (such as Murr et al., 2018a,b; Sarmento et al., 2018; Williams et al., 2020) because reviews provide "overarching approaches" and are not dependent on each single study design feature. Moreover, individual studies with similar design features were considered for comparing effect sizes to the present study (and if these studies provided effect sizes other than Cohen's *d*, *d* was reanalyzed from the presented descriptive statistics). Studies from three nationwide talent development programs were considered. First, studies investigating male players from the German program at these age groups (Höner and Feichtinger, 2016; Höner and Votteler, 2016) seem to be most comparable to the present results (e.g., because of similar success rate). Second, two prospective studies conducted within the Swiss talent development program (Sieghartsleitner et al., 2019a,b) used similar diagnostic tools to assess motor performance factors (i.e., the same tests for agility, dribbling, juggling, and a modified version for ball control) and were characterized by further similar designs parameters. For example, the Swiss program selects the top 6% of the registered U12 players in their early selections for talent bases and about 1% for their elite youth development program in U15 (Romann and Fuchslocher, 2013). Grounding on this, the success rate in the prospective studies for a U13/U14 sample was 12%, and for a U14 sample, 17% (Sieghartsleitner et al., 2019a). However, these studies were characterized by less statistical power due to a smaller sample size ($N \leq 133$), leading to a lower sensitivity to detect small effect sizes. Third, Saward et al. (2020) published a longitudinal study with data from male soccer players between 8 and 19 years from the English talent development system program. The data for the age groups U12–U15 was also considered suitable for a comparison with the present study results. In each age group, Saward et al. (2020) investigated about 1,000 players from 16 professional academies in England. As the prospective success rate of these players was between 17 and 30% for the age groups U12–U15, this might indicate a more elite sample compared to the present study.

Physiological Abilities (Motor Domain)

Regarding potential physiological talent predictors, this study investigated linear and change in direction speed abilities (i.e., sprint, agility) and endurance. According to the systematic review conducted by Murr et al. (2018b), mid-term prospective studies in early adolescence provided mixed results regarding the prognostic validity of *agility* [change of direction speed (CODS)] tests. For age groups U12–U15, there is a noticeable variation in the effect sizes across age groups ranging from non-significant effects (Deprez et al., 2015) to significant and large effect sizes of more than one standard deviation (Figueiredo et al., 2009). Presumably, due to its large sample size, the present study provided more robust results regarding the effect sizes. Here, agility varied only to a small extent around the median $d = 0.30$. This effect size is in line with the general conclusion in the review conducted by Williams et al. (2020, p. 3) that future successful players are "slightly more agile." Similarly, a prospective study conducted by Höner and Votteler (2016) found not only significant but also small effect sizes for agility with CC players from earlier birth cohorts (i.e., 1993–1997). Saward et al. (2020) revealed significantly better agility performance in future professional players; however, the effect sizes were trivial to small in adolescence ($d < 0.20$ by the age 12.0) and got larger with further development ($d = 0.50$ by the age 18.0). In contrast, Sieghartsleitner et al. (2019a) descriptively presented agility test results of Swiss U14 players that did not indicate any differences ($d < 0.10$) between players who achieved a professional level 5 years later or those who did not.

In relation to *sprint* performance, Saward et al. (2020) found that future professional players in England were faster in a 20-m sprint than non-professional players but only reported a small effect size ($d = 0.20$ over all age groups, U9–U20). In the present study, the 20-m sprint was one of the most relevant tests and revealed the highest effect size of $d = 0.73$ for the age group U14, whereas Sieghartsleitner et al. (2019a) did not find prognostic relevance for a 40-m sprint test for the same age group. This inconsistency may be caused by the diverse sprinting distances in the study, although in the review by Murr et al. (2018b), sprinting tests with a distance of >20 m were more relevant than the tests with shorter distances (≤20 m). Going beyond, further inconsistencies related to study design, such as performance level of players and length of prognostic periods, may also impact the generalizability of the study results. For example, Sieghartsleitner et al. (2019a) as well as Saward et al. (2020) utilized longer prognostic periods (≥5 years). This, together with partly different performance levels of players at the time of predictors' assessment (i.e., a higher level of selection, Saward et al., 2020), might have led to lower effect sizes detected in these studies compared to the present study. Although recent reviews (Murr et al., 2018b; Williams et al., 2020) and the present study provide insight into the predictive power of sprint performance, future research is needed to clarify whether sprint results may be less relevant regarding predictive validity in older aged or higher selected groups. At least, there seems to be a trend in this direction since, in the present study, the effect size for U15 ($d = 0.40$; $p < 0.001$) was remarkably smaller than for the younger age groups (although still significant). Moreover, Murr et al. (2018b) found less significant empirical evidence for sprinting tests in the elite stage (U16–U19) compared to the talent stage (U12–U15).

With regard to the assessment of *endurance*, it should be noted that this performance factor was evaluated subjectively by coaches. Dugdale et al. (2020) indicate that coaches reach their limits in subjective evaluations when players show similar performances regarding endurance. Nevertheless, in the present study, the mean univariate effect size of $d = 0.43$ is within the range of the significant effect sizes presented in the review by Murr et al. (2018b) for objective endurance diagnostics ($0.28 \leq d \leq 1.56$). However, that review also revealed that nearly one-third of the effect sizes identified for endurance in the talent stage phase (U12–U15) were non-significant, and in a more recent study, Sieghartsleitner et al. (2019a) found the (objective) Yo-Yo intermittent recovery test in U14 age group not to be of predictive relevance for future success. Moreover, besides the different approaches of assessing endurance (i.e., subjective vs. objective), different statistical approaches may lead to a further inconsistency regarding the prognostic validity. For example, when utilizing a multivariate approach, Sieghartsleitner et al. (2019a) found a negative relationship with professional player status (i.e., Swiss U19 junior national players) for their comprehensive general motor performance variable (i.e., Yo-Yo intermittent recovery test, counter movement jump, 40 m linear sprint, and agility test). In a similar way, the multivariate analysis in the present study revealed in each of the considered age groups negative effects (i.e., $e^b < 1$; in one case significant: $p < 0.01$ for U13) for the subjectively rated endurance item when considered in combination with the other performance factors. Although multicollinearity between the predictors of the logistic regression models was acceptable in terms of *VIF*, the different results for endurance in the univariate and multivariate perspective are likely due to noticeable correlations with other (mainly subjective) predictors. Therefore, more research regarding the prognostic validity of this factor, predominantly in multidimensional approaches, is needed.

Technical Skills (Motor Domain)

In addition to the reviews for sport (Sarmento et al., 2018; Koopmann et al., 2020) or soccer skills (Murr et al., 2018a; Williams et al., 2020), the present study underlines the importance of technical skills. The median effect size for *dribbling* ($d = 0.47$) in this study was at the lower end of the range of effect sizes that Murr et al. (2018a) identified in 10 prospective soccer studies ($0.47 \leq d \leq 1.24$). Interestingly, *ball control* ($d = 0.34$) was below the range ($0.57 \leq d \leq 1.28$) detected by Murr et al. (2018a). Moreover, *juggling*, a skill not investigated as much as other technical skills, proved to be a significant predictor with a median effect size of $d = 0.42$ and was also found to be a relevant predictor in the younger age groups (i.e., $d = 0.52$ in U12 compared to $d = 0.35$ in U14). In both studies within the Swiss program, even higher effect sizes were detected regarding juggling compared to the present study. While Sieghartsleitner et al. (2019a) found a medium effect size ($d = 0.62$) for the U14 age group, in a second study with a comparable sample of U14 soccer players, a large effect size ($d = 1.07$) was found (Sieghartsleitner et al., 2019b). However, these inconsistencies regarding the detected effects in these studies could have been affected by the rather low sample size of players in the professional groups ($17 \leq n \leq 20$).

Of particular interest, especially when considering a direct comparison of objective and subjective assessments, are the results for *kicking skills*, as these results can be compared to the prognostic validity of a shooting test investigated by Höner and Votteler (2016). Although practitioners consider shooting skills to be very important for soccer performance, only small effect sizes were found in that study. However, a challenge for researchers is the ability to create a reliable and valid shooting skill test, and many tests have poor psychometric properties (Ali, 2011; Höner et al., 2015). Therefore, within the German talent development program, the shooting test was substituted by the subjective rating presented in this study. Indicated by an effect size of $d = 0.71$, the newly established subjective evaluation of kicking skills proved to have superior prognostic validity compared to the former shooting test. One reason for this may be that the subjective assessment of kicking skills was based on a broader concept compared to the objective shooting skill tests where only the precision and speed of the shots were registered. For example, coaches evaluate the ability of the CC players to use different kicking techniques, to pass or shoot at the goal with a high degree of variability, at a speed appropriate to the game situation or under pressure from the opponent (see **Supplementary Table 1a**).

Individual Tactical Skills (Perceptual–Cognitive Domain)

Tactical skills such as behavior in one vs. one offensive/defensive situations, anticipation, decision-making, or game intelligence have been found to be crucial for achieving top-level performance in football (e.g., Roca et al., 2012). In accordance to the current results, Murr et al. (2018a) identified in their systematic review medium to large effect sizes for the prognostic relevance of these skills. However, the effects sizes are based on only four prospective studies, indicating a lack of such studies and limiting the empirical evidence for perceptual–cognitive skills compared to other domains. Moreover, the review identified only one study in soccer to assess these skills based on an objective assessment. O'Connor et al. (2016) used video-based tests including different soccer-specific tasks of tactical skills (e.g., decision-making), which prompt a written response. Such video-based diagnostic instruments are established in the (cross-sectional) expertise research; however, they are considered to have limitations regarding the representativeness of the stimuli presentation as well as the limited motor response of the participants (e.g., Travassos et al., 2013). Besides critical arguments regarding the representativeness of video-based diagnostics, test economic reasons might cause the lack of prospective studies examining the predictive value of perceptual–cognitive factors. For example, three studies (i.e., Kannekens et al., 2011; Huijgen et al., 2014; Forsman et al., 2016) providing empirical evidence in the systematic review used the tactical skill inventory in which players rate their soccer performance in comparison to the top players in the same age category (TACSIS; Elferink-Gemser et al., 2004). However, besides general criticisms concerning the lack of soccer-specific performance response (Nortje et al., 2014), self-reported tactical skills might be biased by socially desired answers or unrealistic self-concept.

To avoid such biased assessments, Williams et al. (2020) suggested that researchers should consider measuring individual performance factors, *via* coach ratings, in matches or small-sided games. However, the authors acknowledged the challenge of developing rating tools with satisfactory psychometric properties. The present study revealed excellent reliabilities for the subjective evaluation tool. Going beyond, tactical skills were the strongest predictor in the univariate ($0.61 \leq d \leq 0.85$) and one of the strongest in the multivariate analyses. Therefore, the tactical skills evaluation tool (**Table 1**) proved to be an appropriate assessment method within a nationwide talent development program. While a positive outcome, future research is needed to explore the correlations between the coaches' ratings to other perceptual–cognitive diagnostics such as in-game performance assessments (e.g., small-sided games; Bergkamp et al., 2020), video-based decision-making skills tests with a soccer-specific response (Murr et al., 2021), or assessments of general cognitive functions (e.g., Beavan et al., 2020).

Psychosocial Skills (Personality-Related Domain)

Comprehensive models for talent development (e.g., DMGT; Gagné, 2010) provide a theoretical basis for examining the predictive value of psychosocial dispositions and skills from the personality-related domain, such as motivation or volitional self-regulation (e.g., Mills et al., 2012) that are mainly investigated with subjective self-report questionnaires. Several systematic reviews (e.g., Gledhill et al., 2017; Murr et al., 2018a; Ivarsson et al., 2020; Williams et al., 2020) highlight the importance of psychological predictors for (successful) talent development in soccer. Nevertheless, similar to the other investigated domains in this study, the effect sizes in these reviews do not support the use of sport psychological diagnostics as a selection tool in talent development programs.

This is also in line with the present results regarding the psychosocial skills, although the median effect size ($d = 0.43$) represents a recognizable prognostic relevance that was, to some extent, larger than the effects found in a comparable study within the German talent development program (Höner and Feichtinger, 2016). In that 4-year prospective study, U12 players ($N = 2,677$) completed 17 psychological scales of established sport psychological self-report questionnaires addressing motivational, volitional, self-referential cognitions and emotional characteristics. Whereas the majority of the psychological scales (10 out of 17) proved to be significant in predicting success (i.e., achieving the youth academy level at U16), the effect sizes were smaller ($0.19 \leq d \leq 0.30$) than in the present study. This indicates that coaches' subjective assessment of psychological characteristics may add explanatory power to self-report questionnaires (Musculus and Lobinger, 2018) because coaches can base their judgements on observations of a player's behavior in several "representative" situations and in reference to the other talented players. However, further research is needed to bridge the gap between the (scientifically sound) sport psychological self-report questionnaires and the (often unevaluated) scouting sheets occasionally used in youth soccer. Thereby, recommendations on how to improve the subjective assessments of personality-related factors and how to educate the youth soccer coaches in this regard should be considered (Musculus and Lobinger, 2018).

Limitations and Perspectives

Although the present study is characterized by several strong design features (i.e., homogeneous sample with talented players, high test power, midterm prognostic period, and multidimensional subjective and objective assessment), several limitations need to be considered. First, in accordance with the vast majority of studies in this research area, the current study focused on assessing performance at a *single time point*. However, based on the multidimensional and dynamic conceptualization of talent (Buekers et al., 2015) and, in some parts, the inconsistent results in longitudinal studies (e.g., Leyhr et al., 2018; Saward et al., 2020), further empirical studies are needed to examine the progress of players' performance factors longitudinally. However, it should be noted that the present study focused on the simultaneous examination of the validity of subjective and objective assessments in an attempt to address the gap in this field of research. Moreover, from a methodological perspective, there are some non-trivial difficulties when combining subjective and objective assessments in one longitudinal analysis. For example, in this study, the coaches were asked to evaluate the players' performance factors in regards to the corresponding reference groups (Ivarsson et al., 2020). Thus, in contrast to the motor tests, no absolute values were available from the implemented subjective assessment and an investigation of players' developmental process would have been restricted to the exploration of development only relative to other players.

Second, the *operationalization of the criterion variable* is a methodological issue critically debated in soccer talent identification research (Bergkamp et al., 2019). The prognostic period in this study ranged from early to middle adolescence, whereas the criterion was operationalized as performance level in age groups U15, U16, U17, and U18 respectively. As juvenile success as an appropriate predictor for success in adulthood might be questioned in sport (Güllich and Emrich, 2014), this prediction period may be regarded as a limitation. However, being selected for the youth academies (that is, the present study's criterion variable) seems to be strongly associated with success in adulthood in German soccer, as nearly 90% of German adult professional players played at least one season for a youth academy (Güllich, 2014). Furthermore, the criterion for the prediction was operationalized as performance level. Bergkamp et al. (2019, p. 1319), highlighted "an explicit measure of soccer performance is rarely used as a criterion," and this may imply some problems. For instance, binary-coded performance levels, as utilized in this study, provide only limited information on the individual differences between players' soccer performance. However, such information is helpful as decisions on selecting or deselecting players frequently occur in sport talent pathways (Ford et al., 2020), and especially in the present study over a prolonged prognostic period of three seasons, different coaches and institutions (competence centers, regional associations, youth academies, youth national teams) were involved in these decisions concerning the players. Moreover, valid and test economic assessments for measuring individual soccer performance in large-scale studies are challenging. Consequently, an operationalization of soccer performance by players' performance level seems appropriate from a practical perspective (Bergkamp et al., 2019).

Third, the players' development and their performance factors are not only dynamic but also interactive with additional factors. Thereby, not only personal but also *environmental factors*, such as family support or training history, play a decisive role. However, one of the few studies investigating the combination of motor performance diagnostics and coaches' subjective evaluations with additional information about family support and training history led to the conclusion that including these environmental factors in existing data on motor performance tests and coach assessments did not provide significant additional explanatory power (Sieghartsleitner et al., 2019a). Therefore, the integration of environmental factors in prognostic models may be a demanding task for future studies (e.g., when considering the operationalization of the variables and the underlying assumptions about the association between constructs such as family support and successful player development). That is, probably an optimal but not maximal family support may be most supportive for a player, and going beyond, this optimum might be individualized and thus different for each player.

Moreover, further *potential moderating or confounding variables* were not in the scope of this study. For example, Sarmento et al. (2018) highlighted a complex relationship between youth players' performance factors according to relative age, maturity status, or specific playing positions. In particular, maturational status might have enabled interesting insights for the present study, as indicated by a recent study from Hill et al. (2020b), who observed positive associations between coaches' subjective match performance ratings and maturation in U14 and U15 academy soccer players. However, data on maturity status was not assessed in this large-scale study, and assessments such as the Mirwald method (Mirwald et al., 2002) or the Khamis–Roche method (Khamis and Roche, 1994) still need further investigation concerning their reliability and validity (Myburgh et al., 2019; Leyhr et al., 2020a). Regarding information about relative age, interactions between future success and relative age for each investigated predictor were found non-significant, and therefore, this was not considered as confounder for the present examination of prognostic validity. Nevertheless, future research should investigate relative age-related biases regarding objective (e.g., Votteler and Höner, 2017; Hill et al., 2020a) and subjective assessments (e.g., Furley and Memmert, 2016). In addition, talent predictors' prognostic relevance with respect to specific playing positions seems to be a promising perspective. As specific playing positions within players' talent development in the investigated age groups (U12–U15) may frequently change (e.g., especially considering their future playing position in professional soccer), data about specific playing positions were not assessed and considered in the present study. However, future research should address this when investigating predictors assessed in later stages of talent development and their predictive value for reaching a professional level in soccer.

A further limitation is that this study only investigated male players. With a few exceptions (Datson et al., 2020; Leyhr et al., 2020b), this is typical of talent research in sport, with an overrepresentation of male studies in general (Johnston et al., 2018; Koopmann et al., 2020) and in soccer (Murr et al., 2018b; Sarmento et al., 2018). However, *gender* must be considered as a potential moderator variable regarding the prognostic relevance of talent predictors, and thus, future studies should extend their focus to female athletes (Williams et al., 2020), in particular due to the increasing popularity of female soccer (Manson et al., 2014).

Conclusion and Implications for Practice

In conclusion, this study provides empirical evidence for the prognostic validity of performance factors from different domains and thus reinforces the call for multidimensional assessments and the use of objective as well as subjective assessments in talent development programs (Sieghartsleitner et al., 2019a; Williams et al., 2020). All nine investigated predictors proved to be significant, but integrating the univariate and the multivariate perspective, tactical skills, and sprint, and thereafter kicking skills and dribbling, were the most important predictors in this study.

Interestingly, the univariate predictive power of the four subjectively rated performance factors were detected to be slightly higher than those of the five objectively assessed motor performance factors. However, multivariate results indicated a higher explanatory power of the objective assessment compared to the subjective assessment. As a consequence, predictors such as kicking skills and psychosocial skills proved more relevant in the univariate than in the multivariate perspective. This may be due to the breadth and dominance of the tactical skills in the subjective assessments and also suggests that coaches' subjective ratings differentiate less between theoretical distinct constructs than objective assessments. At least, it is remarkable that the subjective assessments in this study addressed a broader spectrum of performance factors compared to the objective assessments but lost more explanatory power in the multivariate analyses. This may be interpreted as a weakness of the subjective assessment, and coaches should be educated regarding their analytic skills of performance factors. On the other hand, the subjective assessment also proved strengths in assessing more complex skills like tactical, kicking, or psychosocial skills that are difficult to assess *via* objective (and test economic) measures in nationwide programs. Thus, a challenge for future research is to explore strengths and weaknesses of both assessment approaches and the optimal method to integrate them.

In regard to practical implications, it is important to note that both subjective and objective assessments in the German talent development program mainly support the monitoring of players' development and are therefore not used as a "tool" for selection or deselection. Accordingly, CC coaches are advised to base their selection decisions on their personal experiential knowledge. Nevertheless, the assessments may provide an additional piece of information for making these decisions. More importantly, to know which factors are relevant for the development of successful players, the presented empirical evidence for the prognostic relevance of the investigated factors is crucial.

Moreover, from an organizational perspective, the study results may also inspire youth academies or soccer associations coach education programs to develop about the coaches "eye" for relevant talent predictors. First, by describing performance factors such as kicking skills, endurance ability, tactical skills, and psychosocial skills in a detailed manual provides a "common" understanding of these factors, and coaches can evaluate their players as uniformly as possible in the nationwide program. Second, by implementing the subjective assessments, CC coaches were consciously encouraged to deal with the described talent predictors and to discuss them with their peers or with the associations staff members responsible for CC coach education programs. Furthermore, CC coaches are able to evaluate and reflect on their diagnostic ratings and discuss this with peers or association staff members. Thereby, their documented views may be strengthened if the CC coaches' evaluations are confirmed by players' future success; however, if there is a difference, specific education may be offered. For this purpose, the manual may also provide the foundation and the described key points, and their explanations can be used to create instructional videos that allow CC coaches to convey a uniform idea of the individual talent characteristics.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of the Faculty of Social Sciences and Economics, University of Tübingen. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

OH, DL, and DM: conceptualization and methodology. OH: data curation, supervision, funding acquisition, project administration, validation, visualization, and writing original draft. DL: formal analysis. OH, DL, DM, and RS: investigation. OH, DL, DM, RS, and PL: writing review and editing. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2021.638227/full#supplementary-material

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ORIGINAL RESEARCH
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Talent Identification in Youth Soccer: Prognosis of U17 Soccer Performance on the Basis of General Athleticism and Talent Promotion Interventions in Second-Grade Children

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Several talent identification programs in elementary school have implemented motor diagnostics to introduce children to groups of sports, like game sports, or even to particular sports like soccer. However, as in most other sports, in youth soccer, the predictive value of such early testing is still unclear. This prospective study evaluated the midterm prognostic validity of generic motor performance tests. The sample consisted of male second-grade children, which had received a recommendation to participate in soccer. The talent screening campaign was a basic check comprising two anthropometric parameters, five physical fitness, and three motor competence diagnostics of the German Motor Test 6–18. The test data were collected from the participating elementary school classes of the years 2010 to 2014. The soccer competition performance of those children having completed the age of at least 15 years ($n = 502$) up to the end of the season 2019/2020 (2020, September 30) was recorded. This group of U17 players was then assigned individually to five different competition levels. The prognostic validity of the physical and physiological tests was determined using ANOVAs, odds ratios, and a regression path analysis. All diagnostic methods exhibited medium-to-high prognostic validity over the 8 year time span from the talent screening to the later soccer competitions in the adolescent age groups. For later success in soccer on the province level, the 6-min run (OR = 4.28), dynamic balance (OR = 4.04), and 20-m sprint (OR = 2.46), as well as the participation in the training center of the German Soccer Federation (OR = 5.67) and the diversity of club sport activities (OR = 3.56), were of particular importance.

Keywords: talent identification, talent promotion, youth soccer, child athlete, prospective study, longitudinal design, path analysis, odds ratio

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INTRODUCTION

Long-term talent development programs combine a diagnostic talent identification process with a sustainable talent promotion strategy (see **Figure 1**). On the diagnostic side of such a talent development model, early *talent orientation* includes early talent testing measures as well as recommendations for specific sports that match best with the individual ability profile.

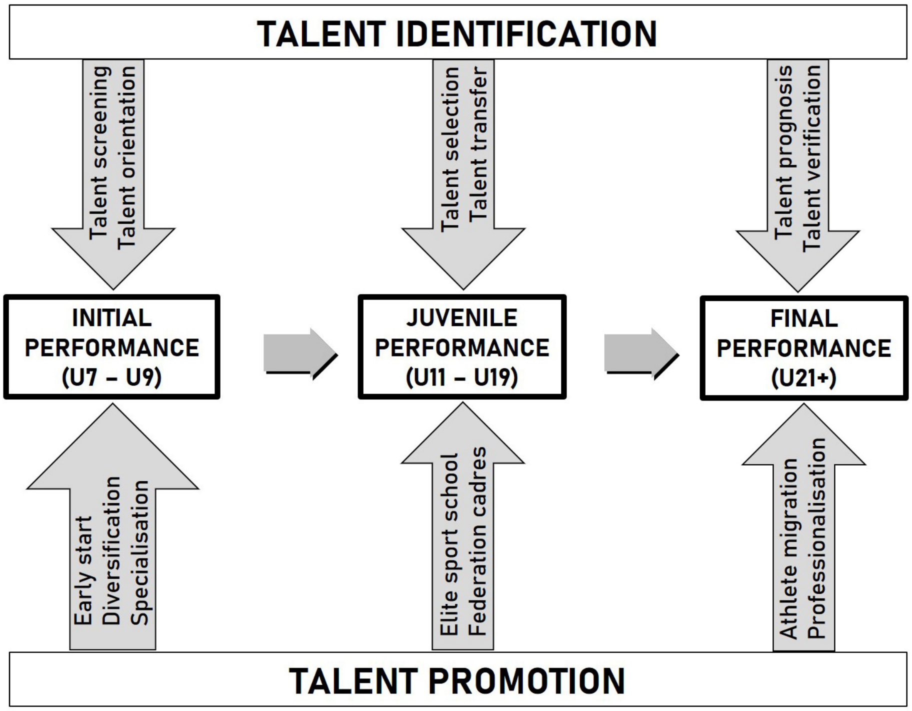

FIGURE 1 | Talent identification and talent promotion as the two intertwined strategies in the long-term talent development model (mod. from Hohmann and Seidel, 2003).

The term talent orientation is related to early talent detection in preferably untrained and thus still heterogeneous samples and "aims at motivating youngsters to choose a sport that matches the individual talent characteristics" (Pion, 2015, p. 22). Following this idea, several talent screening programs in elementary school have implemented motor diagnostics (e.g., Fuchslocher et al., 2011; Golle et al., 2015; Pion, 2015) to orientate the best movers according to the strengths of their individual profile of the general motor giftedness into specific sports where they can transform their physical, physiological, and psychological gifts through a long-term process of diligent learning, deliberate practice, and an extended amount of high-quality training into ultimate achievement (Davids and Baker, 2007; Pion, 2015). The better the individual talent characteristic profile fits to the (future) soccer demands, the higher the chances that the soccer beginners will achieve success and satisfaction in this complex team sport. This assumption is underlined by Suppiah et al. (2015), who state that a wrong choice can never be compensated by training. Engaging in an unsuitable sport might not only be detrimental to fun but also lead to dropout ahead of time. Furthermore, soccer is one of the sports that require early talent orientation (Papic et al., 2009), as on the one hand, a high amount of learning time is needed for the specific technical skills, and on the other hand, the athletes competing on the highest level got younger over the last decade. Thus, besides a systematic long-term athletic development, early talent orientation is of great relevance. In addition to that, an early talent orientation and soccer education starting at the elementary-school age gives the coaches a longer observation period and in this way reduces selection errors during early adolescence. Although most of the soccer federations administer their talent selection campaigns at a later point of time, when youth athletes have already trained for some years and developed into more homogeneous samples (Pion, 2015), early talent orientation at elementary-school age could contribute positively to the ongoing debate in talent research. In this debate, some academics warn against talent selection procedures that are conducted too early (Meylan et al., 2010), whereas others acknowledge that these selections are worthwhile to help the sport federations to focus their resources on the most talented young athletes (Unnithan et al., 2012; Zuber et al., 2015, 2016; Hoener and Votteler, 2016). The latter is especially important in soccer, as this very professional sport attracts the majority of children already at elementary-school age. Especially, if the final step of the scientific verification of the former talent prognosis was included in the talent development program of the federations, an early talent orientation could lead to a more successful talent development model in soccer.

In general, there is a lack of research investigating the prognostic value of different performance prerequisites over the full long-term period from child to adult training (Johnston et al., 2018; Sarmento et al., 2018; Williams et al., 2020). Most of the research concentrated on the middle stages of the juvenile performance development. Although previous studies questioned juvenile success even at the advanced stage of late adolescence as an appropriate indicator for soccer success in adulthood (Guellich, 2014), from recent studies on the early part of the juvenile training stage between early and late adolescence, there is compelling evidence that early talent orientation is a fruitful endeavor. So in the age group of under-15 (U15) soccer participants, various authors (Le Gall et al., 2010; Carling et al., 2012; Deprez et al., 2015; Hoener and Votteler, 2016; Hohmann et al., 2018; Sieghartsleitner et al., 2018) investigated prognostic periods of at least 3 years. Doing so, Hoener and Votteler (2016; see also Hoener et al., 2017) could show that even on the homogeneous level of the *German soccer competence centers*, a soccer-specific test battery (German Soccer Federation, 2009) provides prognostic valid and also practically worthwhile information about the 7.2 times better odds of the fastest and technically best third of the preselected players to reach the U15 junior national team. Including psychological characteristics, Zuber et al. (2016) showed that 12- to 15- year-old individuals having started early with soccer training had 2.5 times better chances to reach the Swiss U17 national team than players starting later in time with soccer-specific deliberate training.

Although reliable and valid information about the future potential of talented players on the basis of motor abilities and technical skills diagnostics is a valuable tool in talent development programs for sport clubs and federations, several studies question the long-term predictability of future success (Cote et al., 2009; Pankhurst and Collins, 2013; Carling and Collins, 2014). The main reasons for these scientific concerns arise from the often undifferentiated mixture of generic as well as sport-specific tests in talent identification campaigns, poor operationalization of the criterion variables, and the unsystematic timing of cross-sectional diagnostics at single points in time during the long-term athletic development process (Bergkamp et al., 2019). It thus comes as no surprise that the great variety of study design parameters have led to inconsistent research results, providing an ambiguous picture with regard to the prognostic validity of physical and physiological tests addressing generic motor abilities and sport-specific technical skills. Especially in the adolescent U15 age group, some studies verified a medium stability (Deprez et al., 2015) and prognostic validity of physical and physiological tests (Figueiredo et al., 2009; Hoener and Votteler, 2016; Sarmento et al., 2018), whereas others did not find significant associations between test results and later success in youth, junior, or adult soccer (Le Gall et al., 2010; Carling et al., 2012). Recent talent research in soccer by Hoener and Votteler (2016; see also Hoener et al., 2017) and Hohmann et al. (2018) has made clear that a longitudinal investigation of motor predictors' prognostic relevance for long-term success is not only a key topic in talent research (see also Gonaus and Mueller, 2012; Sarmento et al., 2018; Bergkamp et al., 2019) but also an indispensable prerequisite for a sophisticated understanding of the changing prognostic validity of the various diagnostics at the different stages of the non-linear and multifactorial long-term development of elite soccer players (Skorski et al., 2016).

As soccer is based on a complex, multidimensional performance profile (Williams and Franks, 1998; Reilly et al., 2000; Williams and Reilly, 2000; Huijgen et al., 2014; Buekers et al., 2015; Forsman et al., 2016b; Johnston et al., 2018, the early talent screening is by definition focused on a multifaceted variety of general physical, physiological, and psychological performance diagnostics in heterogeneous populations. With this in mind, our study focused on general anthropometric, physical fitness (PF), and motor competence (MC) characteristics. PF can be defined as the overall performance in various strength, speed, and endurance tasks in a specified physical, social, and psychological environment (Demetriou et al., 2019). MC summarizes the degree of proficiency in a wide range of motor tasks as well as the movement quality, coordination, and control leading to a particular motor performance (Bardid et al., 2019). The generality–specificity dilemma says that the testing of soccer-specific skills is not yet suitable for beginners like the second-grade elementary-school children at hand. The reason is that even the best movers do not yet possess the high-fidelity skills of dribbling, passing, or shooting (Hohmann et al., 2018). Notwithstanding this, Pion et al. (2020) assume that even on the basis of a generic test battery, it is possible not only to identify sporting potential in primary school but also, on the one hand, to orient children toward a sport that best suits their personal strengths or, on the other hand, to facilitate the transfer between similar sports. However, the authors concluded that more research is needed on how to assist children in choosing sports that match their own traits and preferences. Thus, the aim of this long-term study is to examine the prognostic validity of a more fundamental and general testing of early athleticism on the second-class age level, although this cohort included some older scholars who had to repeat the second class in the year 2010, with 93.1% of the vast majority of the test participants representing the U9 age group. So for the sake of easier communication in the following, we adhere to the age category U9 to refer to the soccer-specific age group framework.

The present study is a follow-up version of a previous study of Hohmann et al. (2018) to examine the prognostic validity of a broader performance testing at the same age of second grade of elementary school. In contrast to the former study, which investigated prognostic validity of 11 general performance characteristics and two soccer-specific skill tests (agility run and soccer dribbling) over a midterm follow-up period in regard to the U15 age group, in the current study, the follow-up period was extended to a long-term prognosis until the U17 age group. In this study, the test results of the investigated second-class children in two anthropometric, five PF tests, and three MC tests are compared with their successes as juvenile soccer athletes at age U13 and U17. By including the intermediate U13 stage of the participants' soccer performance, this study allows for a more complex picture of the soccer performance development. Athletes who later show better performances should also be able to be distinguished significantly from later weaker athletes already in the U9 age group. By means of this prospective cohort design, this study is aimed on the extension of the current knowledge on the prognostic validity of very early talent characteristics, as the majority of previous studies focused on the later stages of the U12 and U15 age groups.

MATERIALS AND METHODS

Study Design

According to our model of long-term talent development (see **Figure 1**), the relevance of the performance characteristics profile has to be investigated in a stepwise procedure for at least three

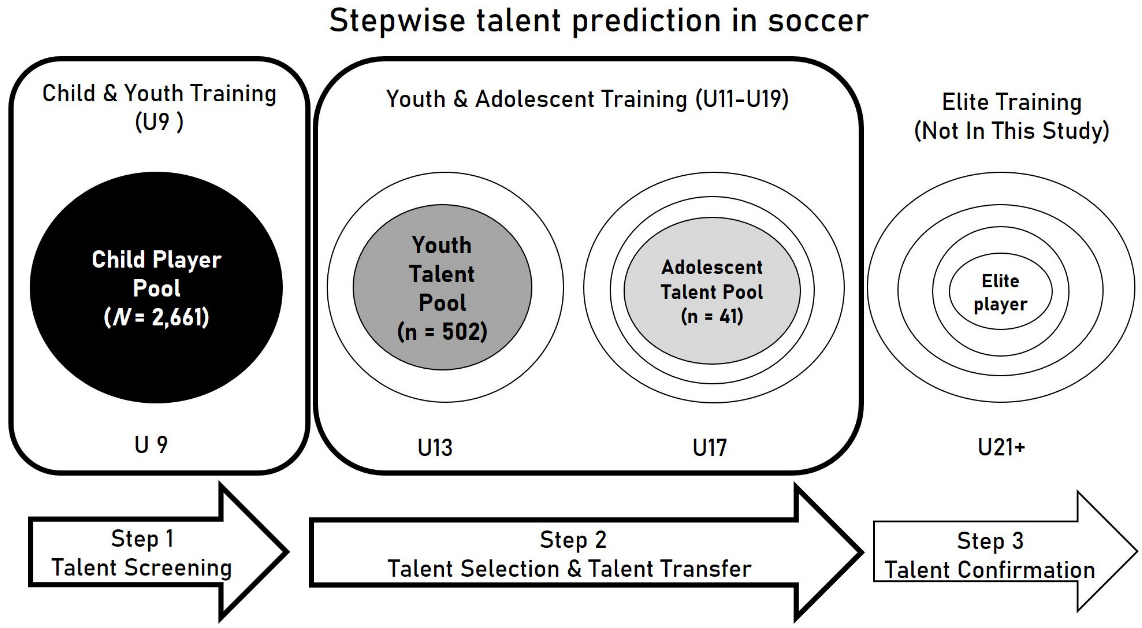

FIGURE 2 | Stepwise talent prediction during the three stages of the talent development process.

prognostic periods from the beginning of a talent development program until the full reach of the professional level as its final destination (**Figure 2**). Each prognosis should allow for midterm soccer performance predictions over a time span of about 5 years (Hoener et al., 2017). As talent development in soccer mostly starts in the U9 age group during elementary-school attendance, the youth training center of the federation starts at age 12 and promotes the talents until age 15. Besides the youth training centers of the soccer federation, the professional soccer clubs run certified soccer academies including players of the same age and also older ones of the age group U17. The final stage of elite adult expertise is reached earliest at about age 21; and in most cases around the age of 23 years, the long-term perspective should cover a development period of about 15 years. This also corresponds to the average time span of 15 years that is needed to reach international soccer excellence (Leite et al., 2009).

The second-grade scholars' physical and physiological test results served as predictors for the participants' later success in soccer at the intermediate point in time of age U13 and finally in late adolescence, which is the U17 age group. The total prognostic time span between the testing and the adolescent competition U17 success was $M = 7.94$ years ($SD = 0.87$).

University staff members and students conducted the testing in all five test campaigns (2010–2014). After the testing, the participation of the children in soccer competitions on any youth soccer division level was recorded from the beginning of the season 2010/2011 (2010, September 30) until the end of the season 2019/2020 (2020, September 30). The data were extracted from the regional print media (tournament and soccer match lists), the official DFB website (www.fussball.de; www.torgranate.de), and the official team lists provided by the soccer clubs.

Before entering the test campaign, all children's parents provided written informed consent for the recording and scientific use of the data collected in the anthropometric and motor tests. The university's ethics department approved the implementation of this study.

Participants

All soccer participants underwent the motor diagnostics at the average age of $M = 8.10$ years ($SD = 0.73$) together with their classmates who did not engage in youth soccer. For the prospective cohort study at hand, we investigated the data from $N = 2{,}661$ male second-grade children with no more than one test data missing. All 2,661 study members took part in the talent screening campaign in the years 2010–2014. Out of this total population, $n = 502$ were found to compete later on in official soccer games independent from the playing division and also reached the age of 15 years ($\geq$180 months) until the deadline of the sport season 2019/2020 (2020, September 30; **Figure 3**). Children who had chosen other competition sports other than soccer were not included in this study to allow for the comparison of the soccer participants with actually untrained children.

Measures

Performance Characteristics

Besides the two physical characteristics body height and body weight, the testing included five physiological fitness, and three MC tests, which were used as performance predictors. The test tasks aimed at the diagnosis of sprint, coordination, balance, flexibility, arm and upper body strength, leg power, ball throw, and endurance performance. The standardization of the test items was secured by protocols, which included a detailed description of test materials and setup, test demonstration,

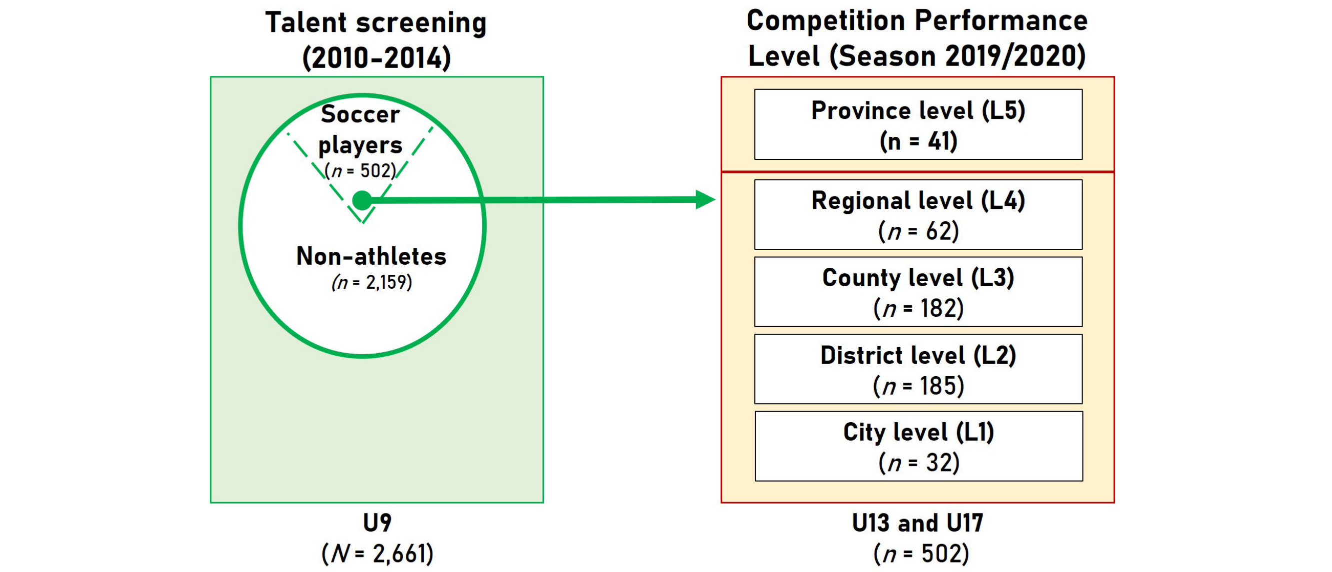

FIGURE 3 | Scheme of the participants' groups of the talent screening campaign (2010–2014) included in this study.

warm-up and training trials, assessment, and registering of the test scores (Boes and Schlenker, 2016). Besides the generic motor tests, each player's body height, body weight, and calendar age (measured by the month of birth within a calendar year) were registered.

20-m Sprint

Time for a 20-m linear running sprint (Boes et al., 2001). The run time was measured by means of light gates (Brower Timing Systems; Draper, USA). The starting position was 0.3 m behind the start line. Between the two possible attempts, a break of at least 2-min was kept. The reliability of this test is $r_{tt} = 0.90$ (Boes and Schlenker, 2016). For easier understanding, in the following, we changed the scale into positive direction for faster run times.

Sideward Jumping

The test contains of 15 s of sideward jumping within two adjacent 50 × 50 cm squares (Kiphardt and Schilling, 1970). The number of two-legged jumps from one square to the other without touching a boundary line was measured. Five trial jumps were allowed before the testing began. Between the two possible attempts, a break of at least 2-min was kept. The objectivity of this test is $r_{obj} = 0.99$, and the reliability is $r_{tt} = 0.89$ (Boes and Schlenker, 2016).

Balancing Backwards

Balance backwards on 6-, 4.5-, and 3-cm wide beams (Kiphardt and Schilling, 1970). For each bar, the number of steps backwards balanced (feet fully raised) until leaving the bar was counted. The maximum number of steps per attempt was limited to eight. For each of the three beams, two possible attempts were made. Thus, the result was the sum of all steps taken (maximum: 48 steps). There was a short practice period before the test was carried out. The objectivity of this test is $r_{obj} = 0.99$, and the reliability $r_{tt} = 0.73$ (Utesch et al., 2015).

Standing Torso Bend Forward

A standing torso bend forward test was performed as a flexibility test (Fetz and Kornexl, 1978). Here, the participants tried to reach as far as possible with their fingertips beyond their feet and to hold this position for at least 3 s. The distance of the fingers in cm to ground level was recorded, whereby a low range aboveground level was recorded as a negative distance. There were two attempts allowed. The objectivity of this test is $r_{obj} = 0.99$, and the reliability $r_{tt} = 0.94$ (Boes and Schlenker, 2016).

Push-Ups

The push-up test was carried out after a short trial period. Within 40 s, the number of fully completed repetitions is counted. Hands have to touch each other when the body is lying down on the floor and also when the arms are extended after the push-up. A complete repetition was only evaluated when the upper body was laid down on the mat and hands touched each other (Haag and Singer, 1981). Only one attempt was carried out here. The objectivity of this test is $r_{obj} = 0.98$, and the reliability $r_{tt} = 0.69$ (Boes and Schlenker, 2016).

Sit-Ups

Similar to the push-up test, the time available for the push-up test was limited to 40 s (Boes et al., 2001). After a short practice phase, only one test was granted, and the number of correctly executed sit-ups was counted. The objectivity of this test is $r_{obj} = 0.92$, and the reliability $r_{tt} = 0.74$ (Klein et al., 2012).

Standing Long Jump

The standing long jump was carried out without a previous tryout. The distance of the two-leg standing jump was measured in cm (measured from the heel; Fetz and Kornexl, 1978). A break of at least 2-min was observed between the two possible attempts. The objectivity of this test is $r_{\text{obj}} = 0.99$, and the reliability $r_{\text{tt}} = 0.89$ (Boes and Schlenker, 2016).

6-min Endurance Run

A 6-min endurance run around a volleyball pitch (9 × 18 m) was carried out (Fetz and Kornexl, 1978). There, the number of meters covered was measured. The test was conducted in groups of 15 persons at the same time. The reliability of this test is $r_{\text{tt}} = 0.92$ (Boes and Schlenker, 2016).

All players were assessed under similar conditions. The tests were carried out during regular school hours (8–12 pm) by qualified test personnel. The testing always began after a uniform warm-up phase with the 20-m sprint and ended with the 6-min endurance run. In all tests, except for sideward jumping (where the average of the two attempts was taken as test result), the better one of the attempts counted.

All eight tests were examined in a whole series of studies by various authors (Klein et al., 2012; Utesch et al., 2015; Boes and Schlenker, 2016) with regard to the test standards. Boes and Schlenker (2016) analyzed the test battery's psychometric properties for a sample consisting of nearly 50,000 school children and adolescents. The authors found an average test–retest correlation coefficient of $r_{\text{tt}} = 0.82$ at elementary-school age (7–11 years), even if there is considerable variation between the tests ranging from $r_{\text{tt}} = 0.52$ for balancing backward to $r_{\text{tt}} = 0.94$ for the bend forward.

Talent Promotion Interventions

On the side of the talent promotion variables, the club sport diversity of the 502 soccer participants was quantified by the number of different club sport activities with at least one official competition participation attended voluntarily before or in parallel to the talent screening, as well as during the following period of soccer practice during youth age.

Also very early, the sport administration of the government of the Hessen province offers a local talent promotion course, which is conducted by an expert sport teacher. Out of the 502 soccer participants, about 5% ($n = 26$) of the players took part in this talent promotion program. Such an additional 90-min school sport session takes place once a week and is open to about 10–15% of selected pupils with the aim to enhance the basic components of PF and MC. Thus, the generic training program aims primarily at the development of fundamental movement skills (Burrows et al., 2014; Barnett et al., 2016). The talent promotion courses start during the first grade of elementary school (normally at the age of 6–7 years) and end with finishing elementary school after the fourth grade.

As a third talent promotion strategy, two certified schools from the tested region offer sport-specific talent promotion classes, which were attended by about 10% ($n = 51$) of the soccer players. The sport classes consist of about 25 children who are selected and intensively guided by expert school sport officials. The membership in a sport class of one of the two local youth sport schools could comprise a maximum duration 6 years starting at the fifth grade (normally at the age of 11 years) and ending after the 10th grade (at the age of 16 years), which is 2–3 years before finishing high school education. The sport class members take part in two additional training sessions embedded in the official school timetable in the morning. Both training, sessions take place in sport-specific training centers and are guided by qualified expert coaches of the particular sport. The training focuses on general as well as sport-specific performance prerequisites.

As a fourth talent promotion campaign, the German Soccer Federation (DFB) offers between the age of 12 and 15 years 1 weekly soccer training session conducted by expert soccer coaches in one of the 366 soccer training centers distributed all over Germany. Building up on a basic soccer promotion stage (U11 groups and younger), the soccer training (or competence) centers form the second level of the pyramid of the successful talent promotion system of the German soccer system. The soccer training centers prepare about 14,000 promising youth athletes per year over 3 years in the age groups U12, U13, U14, and U15 (in some regions also U11), so the players can participate for 4 years in the program (Schott, 2010). In parallel, more than 50 professional soccer clubs run youth soccer academies, which include players from the same and also older age groups. The youth soccer academies are attached to the professional soccer clubs of the first, second, and third professional soccer divisions (Bundesliga). The youth soccer academies represent the second level of the talent promotion of the DFB and open the door to the third and final step to participate in the different DFB youth national teams. About 8% ($n = 40$) of the investigated soccer players were selected for a membership in one of the two regional talent promotion centers, with four players transferring to different youth soccer academies at age 15 after finishing with the training center.

Competition Performance

The soccer performance level (**Table 1**) reached by the soccer players until the end of the season 2019/2020 was utilized to quantify all athletes' success in early adolescence as criterion variable. All second-grade athletes who participated in the motor diagnostics and participated a minimum of one official soccer competition in a division or city level until the end of the season 2019/2020 or at least held an official club license without taking part in competitions (level 1) were recorded. Based on their success in the youth soccer competitions, the individual soccer performance was ranked from level 1 up to level 5, if the athlete was playing on the province "*Hessen level*." Although the participation in the Hessen soccer division (level 5) was the highest level registered in this study, from a nationwide perspective, such a soccer competition participation represents only a sub-elite soccer performance level. So it has to be stressed that there is still a gap between the soccer performance investigated in this study and the nation's best soccer performances within the U17 age group. To promote especially the elite youth soccer level, the German Soccer Federation not only organizes an U17 national championship by means of a first division competition (Bundesliga) but also promotes an U17 national team for Germany's best players.

TABLE 1 | Five-level scale for the recording of the soccer-specific competition results of the study participants taking part in official soccer competitions of the age groups U13 and U17 ($N = 502$).

5-level scale of U13 and U17 age group soccer performance		
Level 1	$N = 32$	Holder of an official soccer club license or competition participation on the city level (Kreisklasse) at the age of U13 and U17
Level 2	$N = 185$	Competition participation on the district level (Kreisliga) at the age of U13 and U17
Level 3	$N = 182$	Competition participation on the county level (Bezirksliga, Gruppenliga) at the age of U13 and U17
Level 4	$N = 62$	Competition participation on the regional level (Verbandsliga) at the age of U13 and U17
Level 5	$N = 41$	Competition participation on the province level (Hessenliga) at the age of U13 and U17

In contrast to a former study of Hohmann et al. (2018) on younger soccer players, in the U17 age group, the names of almost all study participants were individually reported in the team rosters published by the local media and the website of the Hessen Soccer Federation, thus substantially increasing the study sample of this study. However, the performance levels of game sport athletes are difficult to judge (Roescher et al., 2010; Gonaus and Mueller, 2012; Hoener and Votteler, 2016; Leyhr et al., 2020). To enhance the reliability of the assignments of the soccer players to the different competition performance levels, the records of the soccer performance of the U13 as well as the U17 age group were checked fine-grained, that is, individually player by player, by the head coach of the local competence center of the German Soccer Federation (DFB) who was in charge of the nomination, selection, and education of the youth soccer players between the age period of 12 and 15 years promoted by the DFB during the investigation period. As the scale of the five performance levels of the city, district, county, regional, and Hessen province leagues is not standardized for the different age groups during childhood and adolescence, and thus the age-specific performance levels do not accord perfectly with each other, this might impair the comparability of the individual soccer performances at the U13 and U17 age stages. Thus, in addition to the coach's individual rating, we checked the predictive validity of different age-specific soccer performances in our study sample. The high intercorrelations of the age-specific soccer performance variables (U13 * U15: $r_{tt} = 0.79$, $n = 502$, $p < 0.001$; U13 * U17: $r_{tt} = 0.79$, $n = 502$, $p < 0.001$; U15 * U17: $r_{tt} = 0.89$, $n = 502$, $p < 0.001$) underpinned not only the usability of the criterion variables but also the developmental stability of the individual pathways of the soccer performance development[1].

Statistical Analysis

In order to obtain solid results in regard to the prognostic relevance of the predictors, the data sets of four successive second grade cohorts (2010–2014) were collected, so the samples of the soccer players achieved a sufficient number on the higher competition levels. To gain insight into the prognostic relevance of the 10 predictors (two anthropometric variables and eight motor tests) in the soccer group and to clarify their predictive validity for the single dependent (criterion) variable of the adolescent soccer performance at age U17, univariate ANOVAs were conducted, analyzing mean differences between the five different soccer performance levels. According to Cohen (1988), the magnitude of effects was as classified small ($\eta^2 = 0.01$), medium ($\eta^2 = 0.06$), and large ($\eta^2 = 0.14$).

For the evaluation of motor predictors' prognostic validity, the age influence on the test performances should be considered (Meylan et al., 2010; Carling and Collins, 2014; Hoener and Votteler, 2016; Hoener et al., 2017). So ANOVAs were conducted to check the data set for significant differences of the youth athletes in regard to the yearly birth quarter. To control for confounding effects of the systematic influence of age found in the tests sideward jumping, 20-m sprint, push-ups, sit-ups, and 6-min run, the calendar age (in months) was partitioned out of the results in all 10 predictors by bivariate regression analysis. In the bivariate regression analyses, the test results served as the dependent variable, and the age (in months) as the independent variable (Siener and Hohmann, 2019). Furthermore, to allow for comparisons of the soccer-specific relevance of the different predictors and to estimate the lead of the soccer athletes against the general age group population, all test data were standardized by z-values based on the mean value and standard deviation data of the untrained athletes.

On the side of the talent promotion variables, the (i) club sport diversity was quantified by the number of club sport activities with an official competition participation before or in parallel to the testing and practicing soccer afterwards and thus represented a discrete variable. The participation in a (ii) local talent promotion course offered by the Hessen government sport administration, the attendance of a (iii) sport class of one or both local youth sport schools, and the membership in the (iv) local soccer training center of the German Soccer Federation (DFB) represented dichotomous dummy variables. Whereas, 411, that is, 81.9% of the $N = 502$ study participants, did not take part in any of the three talent promotion measures (ii–iv), 70 children (13.9%) participated in one of the interventions. From the remaining 21 (4.2%) of the investigated youth athletes, 12 of the 51 sport school members exercised also in the local soccer training center, but only seven of the sport school members took part in the governmental talent promotion course. Furthermore, four members of the local soccer training centers visited the governmental talent promotion courses in

[1]The predictive validity of the age-specific soccer performance variables even increased with age, as was shown in the oldest fraction of the investigated sample: U13 * U19: $r_{tt} = 0.87$, $n = 140$, $p < 0.001$; U15 * U19: $r_{tt} = 0.70$, $n = 140$, $p < 0.001$; U17 * U19: $r_{tt} = 0.97$, $n = 140$, $p < 0.001$.

parallel. None of the scholars participated in all three talent promotion programs.

According to former test validation results in youth soccer athletes (Hohmann et al., 2018) and a coach survey including 32 highly qualified soccer coaches ranking the eight test according to their relevance for youth soccer performance, a soccer recommendation score (SRS) was calculated for each participant. The SRS was formed by the mean value of a selection of the five most influential and, respectively, highest ranked general performance prerequisites, thus being a more complex soccer performance predictor than the single tests *per se*. On the basis of the ranking results of the previous studies, each of the five selected tests was hierarchically weighted by a stepwise weight factor (WF) between 1.2 and 2.0 according to their estimated validity for soccer performance. Thus, the 20-m sprint (WF 2.0), sideward jumping (WF 1.8), 6-min run (WF 1.6), standing long jump (WF 1.4), and sit-ups (WF 1.2) were used, because they had turned out to be more soccer-related than the other three tests and the two anthropometric measures. Based on this weighting, the SRS was calculated according to Formula (1).

$$SRS = 2^* z_{20m\ sprint} + 1.8^* z_{sideward\ jumping} + 1.6^* z_{6min\ endurance\ run} + 1.4\ ^* z_{standing\ long\ jump} + 1.2^* z_{situps} \quad (1)$$

For a clearer view of a player's relative chances depending on several predictors, odds ratios (ORs) for the z-standardized performances were computed. On the basis of the OR, the prognostic validity of the test results was obtained. Furthermore, the questions, how many non-talented athletes would be disqualified (specificity in regard to true negatives), and how many talented youngsters would be successfully identified (sensitivity in regard to true positives) by the test battery were analyzed by calculating the odds stepwise between the 0.5% and up to 99.5% rank thresholds in the z-standardized test performances (Hoener and Votteler, 2016). To determine the optimal relation between drafted talents and excluded non-talents, the Youden index (also *Youden's J*) was calculated. This figure ranges between 0 (random result) and 1 (optimum result) and is calculated by summing up the two parameters sensitivity and specificity. Youden's J allows to quantify the prognostic validity independent of the sample size of the two performance groups (Youden, 1950). In this study, the basic assumption of Youden's J that specificity and sensitivity are of equal importance is fulfilled. Unlike in the soccer federations training centers or in sport school classes, at elementary-school age, there is still sufficient capacity in the soccer clubs to promote all promising youngsters. Thus, there is no need to reduce the number of false-positive soccer recommendation. Also, an increase of the number of true positives has not to be preferred one-sided, as almost all male second-class participants in school get in touch with the sport of soccer anyway and thus could be still detected as soccer talents by teachers and the soccer coaches later on.

A path-analytical model based on stepwise multivariate regression analyses examines the causal pathways of influence of independent variables on a dependent criterion variable measured later in time (Bryman and Carter, 1994). Thus, the influence of the 10 performance characteristics assessed at second grade, as well as the influence of the four different talent promotion interventions (diversity of club sport activities besides soccer, participation in the governmental talent promotion program, attendance of a sport school class, and membership of the German Soccer Federation training center) on the later soccer performance, was determined here. In a first step of the regression path analysis, all 10 performance characteristics (eight test performances and two anthropometric measures) and the four talent promotion interventions, plus the soccer performance level at age U13, were included as predictors, and their influence on the criterion variable performance level at age U17 was evaluated. In a second step, the soccer competition performance at age U17 was eliminated from the next regression analysis, and now the formerly independent early soccer competition performance at age U13 served as the dependent criterion variable.

In all procedures, data were analyzed using SPSS version 25.0 (IBM Corp.), and minimum level of significance was set at $p < 0.05$.

RESULTS

Test Performances of the Soccer Players and the Non-athletes

The descriptive performance characteristics of the test participants are presented in **Table 2**.

The early talent screening results for the age-adjusted and z-standardized performance characteristics in **Figure 4** demonstrate in nine of the 10 diagnostics better performances in the soccer players compared with the non-athletes who served as the reference group ($M_z = 0$). As described above, the five test results of the 20-m sprint, sideward jumping, 6-min run, standing long jump, and sit-ups formed the basis of the SRS. The adequacy of this selection is corroborated by the result that the soccer group exhibited already in the talent screening campaign in the second grade especially in these tests much better soccer-oriented performance prerequisites than did the non-athletes.

Predictive Validity of the General Performance Characteristics in Soccer

ANOVAs and Odds Ratios

Within the group of the U9 soccer players ($n = 502$), the ANOVAs demonstrated significant differences in the performance characteristics, which were in line with the differences in the later performance levels reached by the children as adolescents in the U17 age group. Soccer players who reached higher juvenile performance levels (see **Figure 5**) performed better not only in the SRS [$F_{(4;476)} = 16.36$; $p < 0.001$; $\eta^2 = 0.11$] but also in all eight single motor tests: 20-m sprint [$F_{(4;491)} = 12.06$; $p < 0.001$; $\eta^2 = 0.09$], standing long jump [$F_{(4;489)} = 10.95$; $p < 0.001$; $\eta^2 = 0.08$], sideward jumping [$F_{(4;491)} = 9.15$; $p < 0.001$; $\eta^2 = 0.07$], 6-min run [$F_{(4;479)} = 8.77$; $p < 0.001$; $\eta^2 = 0.07$], push-ups [$F_{(4;491)} = 7.79$; $p < 0.001$; $\eta^2 = 0.06$], balancing backward [$F_{(4;491)} = 6.96$; $p < 0.001$; $\eta^2 = 0.05$], bend forward [$F_{(4;486)} = 3.90$; $p < 0.01$; $\eta^2 = 0.03$], and sit-ups [$F_{(4;491)} = 3.27$; $p < 0.05$; $\eta^2 = 0.02$]. In regard to the

TABLE 2 | Descriptive statistics of age, soccer competition performances, two anthropometric, and eight motor diagnostics, soccer recommendation score, and four different talent promotion interventions in second-grade children taking part in the test campaigns 2010–2014 and competing in youth soccer competitions later on in the age groups U13 and U17 until the end of the season 2019/2020.

Variables	Groups	*N*	M	*SD*	SE	Min	Max
Calendar age							
U9: Calendar age (months)	Soccer players	499	95.23	7.24	0.21	82.00	125.00
	Non-athletes	2,159	95.53	6.48	0.14	75.00	127.00
U13: Calendar age (months)	Soccer players	501	148.74	7.70	0.24	156.00	179.00
U17: Calendar age (months)	Soccer players	502	192.47	7.94	0.36	180.00	203.00
Soccer performance							
U13: Performance level (pts)	Soccer players	501	1.89	0.78	0.03	1.00	5.00
U17: Performance level (pts)	Soccer players	502	2.80	1.02	0.05	1.00	5.00
Performance characteristics							
Body height (cm)	Soccer players	490	129.74	5.63	0.25	110.00	147.00
	Non-athletes	1,997	129.45	6.27	0.14	107.00	154.00
Body weight (kg)†	Soccer players	490	28.08	4.89	0.22	18.30	54.80
	Non-athletes	1,997	28.69	6.11	0.14	16.40	70.004.70
Sideward jumping (reps)†	Soccer players	493	25.55	6.14	0.28	11.00	44.00
	Non-athletes	1,993	23.07	6.40	0.14	0.50	44.50
Balancing backwards (steps)†	Soccer players	493	29.76	8.69	0.39	7.00	48.00
	Non-athletes	1,994	26.42	8.98	0.20	3.00	48.00
Standing long jump (cm)†	Soccer players	491	135.78	17.05	0.77	70.00	181.00
	Non-athletes	1,983	125.36	18.86	0.42	57.00	193.00
20-m sprint (s)†	Soccer players	493	4.50	0.33	0.01	3.54	5.58
	Non-athletes	1,992	4.60	0.39	0.01	3.60	7.15
Push-ups (reps)†	Soccer players	493	14.09	4.09	0.18	1.00	26.00
	Non-athletes	1,992	13.24	3.84	0.09	0.00	26.00
Sit-ups (reps)†	Soccer players	493	20.06	5.22	0.23	0.00	35.00
	Non-athletes	1,992	17.51	5.69	0.13	0.00	35.00
Bend forward (cm)†	Soccer players	488	0.87	5.25	0.24	−19.50	15.00
	Non-athletes	1,981	−0.54	6.06	0.14	−23.00	20.00
6-min run (m)†	Soccer players	481	1,019.68	120.40	5.49	604.00	1,359.00
	Non-athletes	1,953	907.31	133.51	3.02	108.00	1,306.00
Soccer recommendation score							
Soccer recommendation score (*z*-value)†	Soccer players	481	−0.29	1.14	0.05	−4.62	3.00
Talent promotion interventions (U17 soccer performance)							
German Soccer Federation training center (pts)*	Members	40	3.98	0.80	0.13	3.00	5.00
	Non-members	462	2.70	0.98	0.05	1.00	5.00
Sport school class (pts)*	Members	51	3.40	1.05	0.15	1.00	5.00
	Non-members	451	2.73	1.00	0.05	1.00	5.00
Governmental talent promotion program (pts)*	Members	27	3.27	1.04	0.20	1.00	5.00
	Non-members	475	2.77	1.02	0.05	1.00	5.00
Club sports diversity (pts)ns	High diversity (≥3)	14	3.21	1.05	0.28	2.00	5.00
	Low diversity (≤2)	488	2.79	1.02	0.05	1.00	5.00

†*Significant between soccer players and non-athletes; *significant between members and non-members; ns not significant between high and low club sports diversity.*

two anthropometric measures, the soccer players' body weight corresponded negatively to the individual performance level [$F_{(4;488)} = 4.43$; $p < 0.01$; $\eta^2 = 0.03$], whereas the body height [$F_{(4;488)} = 1.08$; $p = 0.366$; $\eta^2 = 0.006$] did not go systematically hand in hand with the later-on soccer performance level in the U17 age categories.

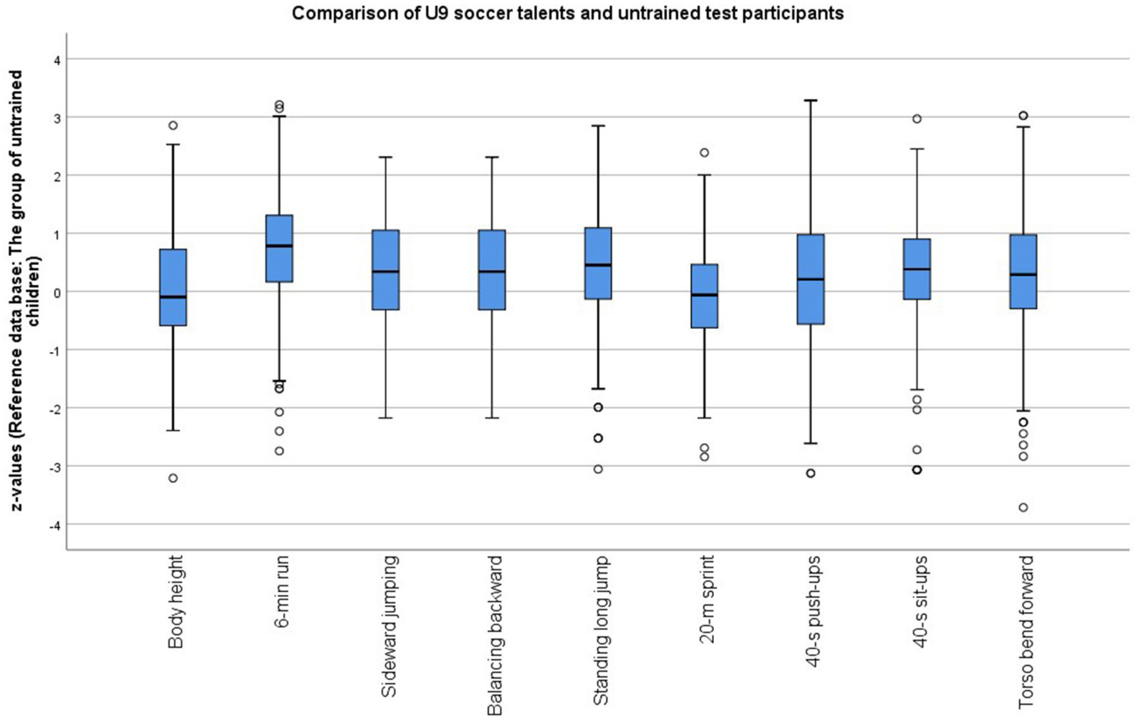

FIGURE 4 | Age-adjusted and *z*-standardized test performances of the soccer players and non-athletes of the second grade of elementary school in the test campaigns 2010–2014.

ORs for each single test as well as for the SRS represent the prognostic validity of the investigated predictors and make the sport-specific relevance of the different tests comparable. In the context of this study, the ORs quantify the relative chances of an U9 participant to reach the performance level 5 until the adolescent age group U17. In **Figure 6**, the ORs were calculated for participants who had achieved an individual test score among the best 16% of the total group ($z \geq 1.0$, corresponding to $PR \geq 84$) in the SRS, and in any of the eight single tests and the two body dimensions. With the use of this cutoff limit, the ORs of the performance characteristics 6-min run ($OR = 4.27$; $X^2 = 19.74$; $p < 0.001$), balancing ($OR = 4.03$; $X^2 = 18.08$; $p < 0.001$), and standing long jump ($OR = 2.18$; $X^2 = 4.47$; $p < 0.05$) show a significant difference between the two talent groups. On the other hand, the ORs for the body weight points at a significant negative perspective ($OR = 0.11$; $X^2 = 6.69$; $p < 0.05$) as the group of the heavier athletes have worse odds as the lighter counterparts.

The ORs for the soccer federation-, school-, and government-based talent promotion interventions were based on the binary code (Yes or No) for the participation in these campaigns. The OR for the diversity of competition participation in other sports before and besides soccer was based on the limit of at least three other sport activities. The chances for the youngsters to reach actually the maximum of soccer performance found in this study and thus to play particularly on the province level at the U17 age were substantially higher for those players who attended the local DFB soccer training center ($X^2 = 22.64$; $p < 0.001$; $\eta = 0.21$). In contrast, the odds for the participants of the afternoon training course of the governmental talent promotion program ($X^2 = 2.15$; $p = 0.142$) and for the members of the sport school classes ($X^2 = 2.52$; $p = 0.112$) were not systematically better than those for the abstainers. In regard to the extent of diversity of the individual training activities in different competitive club sports, those children focusing solely on soccer or taking part in only one or two additional sport were assigned to group 0, whereas the children participating in three or even more competitive sport club activities before or besides their soccer engagement were assigned to group 2. The better odds for the multi-sport children ($X^2 = 3.96$; $p < 0.05$; $\eta = 0.09$) are in line with the quota that three out of 13 children (23%) competing in at least three different club sports besides soccer reached the highest province level in soccer performance at the age of U17.

In regard to the utility of the talent identification campaign, the questions of how many non-talented athletes will be disqualified (specificity of the testing) and how many talented youngsters will be successfully identified (sensitivity of the testing) by the test battery are of great interest (Hoener and Votteler, 2016; Bergkamp et al., 2019). **Figure 7** documents that at a given cutoff limit of $z = 1.0$ ($PR = 84$) in the SRS, according to the sensitivity curve 24.4% of the participants, were correctly identified as future successful soccer players (true positives). The specificity of the testing amounts to 86.3%, which means that this fraction of low talented players (true negatives) would be excluded from talent promotion if the campaign aimed

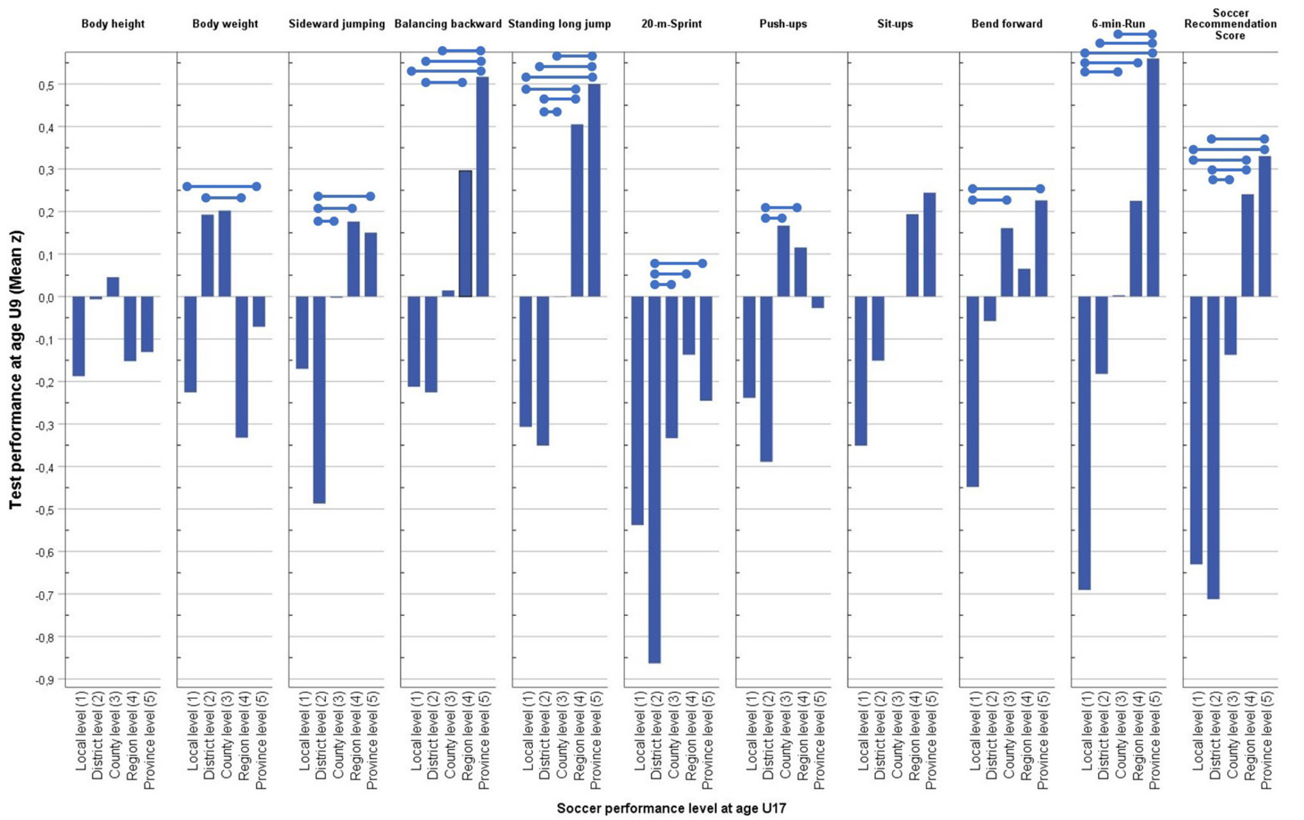

FIGURE 5 | Age-adjusted and *z*-standardized test performances of the U9 participants in regard to the later competition performance levels at adolescence (U17). Data of the 20-m sprint were transformed into positive direction. Variances of subgroups were homogeneous, but not in body weight [Levene (4;488) = 5.39; $p < 0.001$]; significant differences (Bonferroni *post-hoc* test; $p < 0.05$) between subgroups are marked by connection lines).

at securing at least a provincial soccer performance level. To optimize the balance between drafted talents and excluded non-talents, *Youden's J* of the SRS in **Figure 7** documents that the best compromise is reached by a cutoff limit at PR 70 ($z \geq 0.5$), where 51.2% of the future group of successful soccer players could be correctly identified, and 78.3% of the later-on less successful participants would be sorted out. In case of such a cutoff limit, the success rate in the group of the 120 drafted U9 talents would be 19.16%, as 23 of the draftees finally had reached the highest province level at age U17. Comparatively, the base rate in the tested 502 U9 soccer players was 7.97%, as a total of 41 talents reached the highest level in the future.

Regression Path Analysis

Besides the prognostic validity of the early performance characteristics, the long-term influence of different talent promotion interventions is of major importance. In parallel to the testing campaign and besides the 3 weekly school sport lessons of 45-min duration in elementary and grammar schools, the youth athletes are subject to a variety of sport performance-enhancing measures. Thus, in a first step of the path analysis, we investigated not only the prognostic validity of the 10 physical, physiological, and coordinative performance characteristics but also the influence of the (i) diversity of the voluntary club sport participation and of the three official talent promotion interventions, (ii) governmental talent promotion program for the best movers, (iii) sport classes of the two local sport schools, and the (iv) training center of the German Soccer Federation. In the first step, also the U13 soccer performance was added to the list of regressors to predict the U17 soccer performance. In a second step, we left out the U17 soccer performance and substituted it by the U13 soccer performance. Now, the 10 performance characteristics and the four talent promotion measures served to predict the U13 soccer performance. Both regression analyses were tested for multicollinearity. Neither in the U17 regression model ($0.492 < TOL < 0.976$; $1.025 < VIF < 2.033$) nor in the U13 model the tolerance (TOL) coefficients and variance inflation factors (VIFs), respectively ($0.492 < TOL < 0.970$, $1.024 < VIF < 2.033$) confirmed such an intercorrelation between the independent variables that none of these predictors had to be excluded from one of the two combined models (Eid et al., 2017). **Figure 8** shows the complete result of the regression-based path model documenting the statistical relevant pathways of influence of the predictors on the soccer performance development. The configuration of the model components in **Figure 8** is based on the process structure of our abstract talent development model shown in the beginning (see **Figure 1**), thus adding the social talent promotion

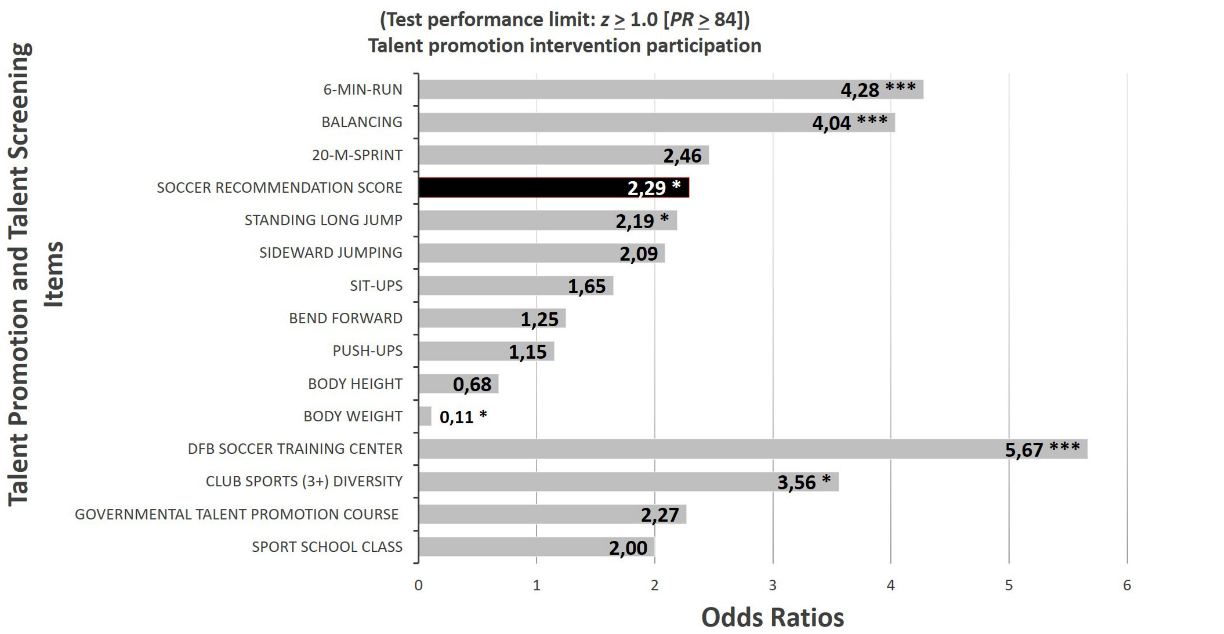

FIGURE 6 | Odds ratios (at the $z = 1.0$ and $PR = 84$ threshold) of the two body dimensions and eight generic motor tests and the soccer recommendation score, as well as of four talent promotion interventions to predict the relative chances of the U9 participants to reach the highest (province) level of soccer competition performance at adolescent age (U17). Significant results are marked by asterisks: $^{*}p < 0.05$; $^{***}p < 0.001$.

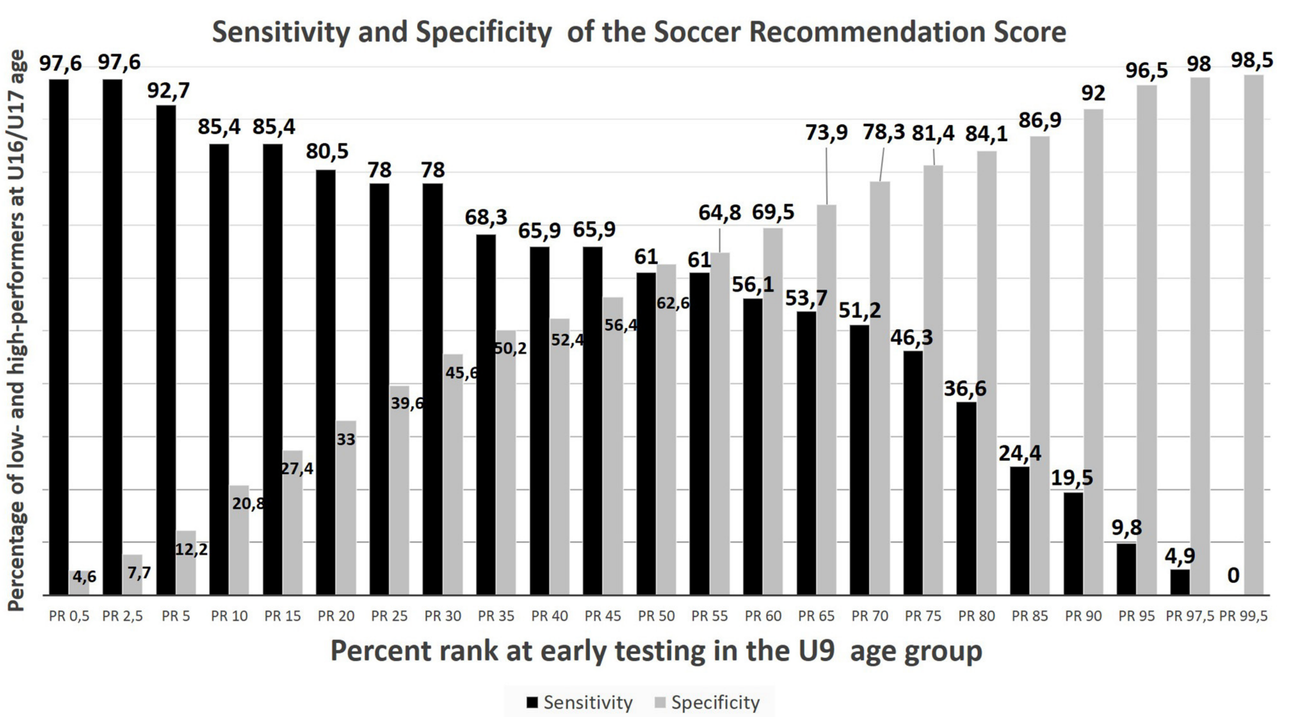

FIGURE 7 | Specificity and sensitivity of the soccer recommendation score (SRS) of the U9 participants to predict a future soccer performance on the highest provincial level (level 5) at adolescence (U17).

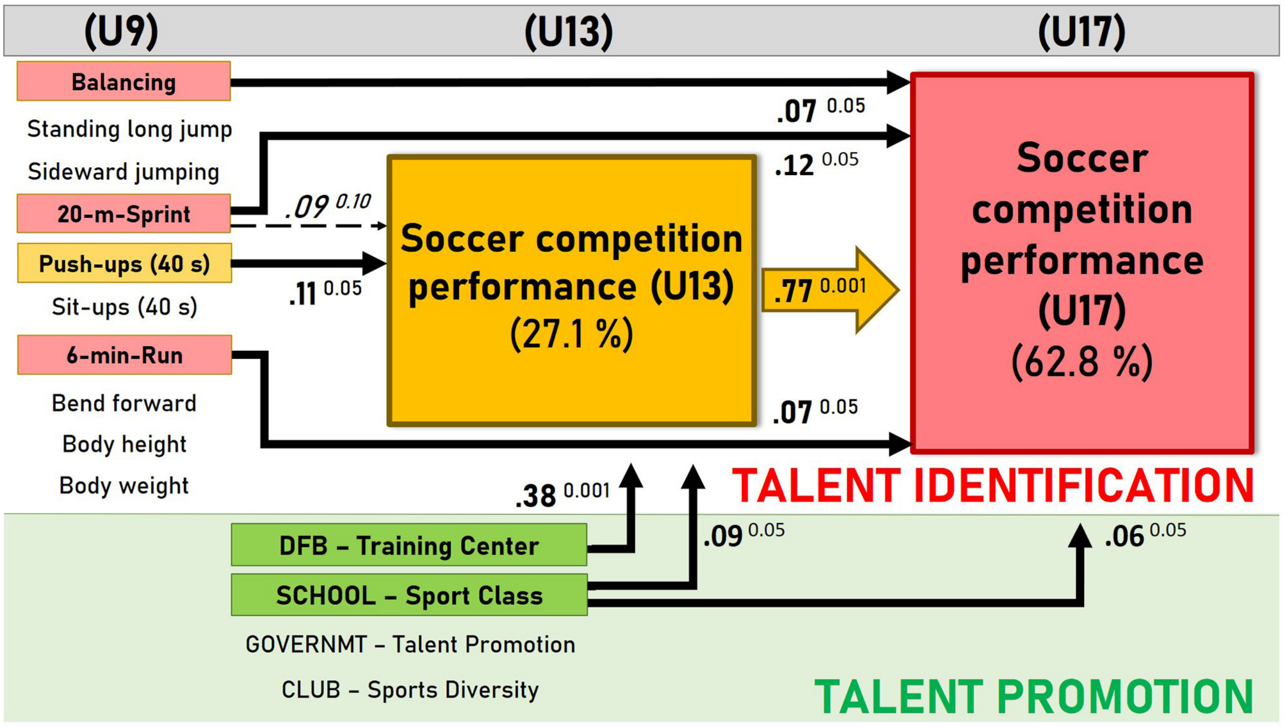

FIGURE 8 | Regression path analysis of early performance characteristics at U9 age and their relevance for midterm performance development in youth and adolescent soccer players ($N = 502$).

interventions from the sport-specific environment of the youth soccer players to the portfolio of the physical, physiological, and coordinative performance characteristics of the soccer athletes.

As can be seen in the path-analytical model in **Figure 8**, the adolescent soccer performance at age U17 [$F_{(15;463)} = 54.83$; $p < 0.001$] is predominantly determined by the intermediate soccer performance at age U13. Besides the intermediate soccer expertise at age U13, the adolescent soccer performance is also significantly influenced by early PF (20-m sprint and 6-min run; $p < 0.05$) as well as MC (dynamic balancing backward; $p < 0.05$). During the early stage of youth development, the intermediate U13 soccer performance [$F_{(14;464)} = 13.71$; $p < 0.001$] is primarily determined by the early MC at age U9, which is in particular represented by the difficult coordination of the upper limbs in the challenging push-up task ($p < 0.05$) and the sprint run performance (20-m sprint; $p < 0.10$), although the latter effect is smaller and only shows a tendency toward significance. The upper body coordination in the push-up test in the second graders shows a direct effect (beta = 0.11) on early soccer competition performance at age U13 and an indirect effect via this mediator on soccer competition performance at age U17. The indirect effect (beta = 0.08) reflects a full mediation because after controlling for the mediator, body coordination has no significant direct effect on soccer performance at age U17 (Preacher and Hayes, 2004). Finally, there was no systematic effect of the standing long jump, sideward jumping, abdominal strength endurance, torso flexibility, body height, or body weight on the soccer performance at early (U13) and late adolescent age (U17).

On the side of the talent promotion measures, a significant relation could be found between the membership in a sport class at school and the soccer competition performance of the children at age U13 (beta = 0.09; $p < 0.05$), and also at the later age U17 (beta = 0.06; $p < 0.05$). The highest effect is seen in the sport school support on the soccer success at age U13 (beta = 0.38; $p < 0.001$). On the other hand, no significant effect could be found between the engagement in the governmental afternoon sport course and the subsequent soccer performance at adolescent age. Also, in the total group, the number of additional club sport activities besides soccer was not related to the soccer competition performance at the ages U13 and U17. As only the players of the lowest and highest performance levels participated to a greater extent in more than one other sport besides soccer training, we obtained a significant curvilinear relation between the early diversity of club sport engagement and the future success in adolescent soccer competition [quadr $R^2 = 0.02$; $F_{(2;497)} = 5.90$; $p < 0.01$].

DISCUSSION

It is imperative that early talent screening and sports orientation campaigns based on the assessment of the performance predictors and competition performance have to be related to a long-term talent development process and properly allocated to defined stages of a complex talent development model. Compared with recent studies (Huijgen et al., 2013; Hoener and Votteler, 2016; Hoener et al., 2017; Leyhr et al., 2018) investigating the prognostic relevance of mainly soccer-specific skills as talent predictors in male youth soccer, this study differs in that it assessed mainly the more general athleticism and MC of a very young male sample over a long-term period from the early talent screening in second grade (U9) until the gateway to expert performance at adolescent age (U17).

The present results are in line with Gil et al. (2007), who assumed only a short-term advantage of larger body dimensions but on the other hand contradict the later importance of the anthropometric variables body height and body weight found by Hoener et al. (2017) in early adolescence for more or less successful adult players. These findings could have resulted from two different factors. On the one hand, the elimination of the calendar age from our test data by partializing out the age (in months) from all test performance data could have led to a more homogeneous "age group." On the other hand, there could exist a considerably lower relative age effect in the early talent development stage investigated in this study compared with middle or late adolescence (Musch and Grondin, 2001; Carling et al., 2009). Due to the early stage of the talent screening campaign, the U9 participants are still far from the pre-pubertal acceleration of the development of body dimensions, which might reduce the impact of the anthropometric predictors on the soccer performance of the young people. Nevertheless, to fully understand the relationship between body size and biological maturity (Meylan et al., 2010; Lago-Peñas et al., 2011; Lovell et al., 2015; Patel et al., 2019) and soccer performance development from childhood to adolescence, more differentiated analyses would be worthwhile.

According to the ANOVA results, and especially the ORs of the PF and MC tests, this longitudinal study verified the prognostic validity of all eight generic motor tests in the sport of soccer. In this context, the tendency of a significant long-term prognostic validity of the MC test balancing backward, as well as the explosive PF test standing long jump already at the U9 age, comes as no surprise (Reilly et al., 2000; Wong et al., 2009; Deprez et al., 2015; Sarmento et al., 2018) and might be an indicator of early athleticism that is relevant for soccer talents, be it innate or a specific outcome of early soccer training experience (Franks et al., 1999). All in all, at least the design of our study is comparable with the longitudinal approach of Hoener and Votteler (2016) and Leyhr et al. (2018), although their studies analyzed the prognostic relevance of soccer-specific motor diagnostics on the talent development stage from early adolescence (U12–U15) until junior age (U16–U19). In contrast, their study focused on elite youth athletes, having already excelled during early, mid, and late adolescence. Although our study was based on more general soccer performance prerequisites, it might help to complete the picture of the soccer performance development reaching from the search for an early soccer-related profile of general athleticism in a very heterogeneous sample at elementary-school age until the soccer-specific talent selection measures at junior age, which are normally based on very homogeneous soccer populations and include high-fidelity diagnostics (Bergkamp et al., 2019). In line with our results, Deprez et al. (2015), Figueiredo et al. (2009), Gonaus and Mueller (2012), Le Gall et al. (2010), and Zuber et al. (2015, 2016) underlined the midterm (≥2 years) relevance of running endurance and sprint speed in youth soccer players. Interestingly, in our study, the 20-m sprint and the 6-min run performances were systematically correlated ($r_{tt} = 0.39$; $n = 484$; $p < 0.001$), which might refer to an age-specific, general running ability. In regard to the direct pathway between balancing and later soccer performance, Mirkov et al. (2010) likewise stressed the high relevance of coordination for future success in soccer. Another reason could be that children who already played soccer before the testing have improved their motor coordination and, thus, achieved better test results. Last but not least, also the participation of 70 soccer athletes in the different talent promotion programs, which stress especially general coordination ability and fundamental movement skills, might have contributed to the long-term impact of dynamic balance on the soccer performance. As a consequence of the particular results in the OR and the path-analytical model, the composition of the SRS should be revisited. It seems that a supplement of the highly valid dynamical balance test could contribute to a better soccer talent forecast at least at the elementary-school age, which would be in line not only with the findings of Mirkov et al. (2010) but also with the test ranking of the coaches obtained before.

The structure of the path-analytical model outlined in **Figure 8** was based on our process-oriented talent development model described in the beginning (see **Figure 1**) and is consistent with the general model of talent development outlined by Abbot and Collins (2002), Fisher and Bailey (2008), and Heller and Hany (1986), where the performance-enhancing effect of the talent promotion environment is taken for granted. It is well-known and in line with our findings that elite sport schools (Granacher and Borde, 2017), as well as the talent promotion training centers of the German Soccer Federation (Hoener et al., 2015), have contributed largely to performance development and sporting success. On the other hand, we could not confirm a positive effect of the province-wide talent promotion campaign "Talent Search and Talent Promotion" of the regional government on the performance of youth soccer players. The lack of evidence might be due to the early-onset, low 90-min per week volume and short duration of the campaign between ages 6 and 10, as well as the generic training program focusing predominantly on fundamental movement skills. So our result is not surprising, as the objectives of this program are not to foster soccer-specific skills but more general PF and MC independent from the children's decision on the talent development pathway. As coach-led, soccer-specific practice necessary for later success (Haugaasen et al., 2014; Hornig et al., 2014) does not happen in this course, it might exert only little effect on future soccer expertise at adolescent age.

Our findings were not fully consistent in regard to the controversial debate of whether a high diversity of early club sport activities enhanced talent development by a greater portfolio of protective coordination patterns and transferable technical skills (Cote and Hay, 2002; Baker, 2003; Baker et al., 2003; Soberlak and Cote, 2003; Cote et al., 2009; Myer et al.,

2015) contributes to better learning pre-requisites to optimize soccer-specific technical skills (Huijgen et al., 2010, 2013) or has more negative than positive consequences for long-term athletic development by impairing sport-specific technical and tactical education due to reduced time, energy, and logistic resources (Helsen et al., 1998; Ward et al., 2007; Forsman et al., 2016a; Zuber et al., 2016). In our path-analytical model, the contribution of the diversity of club sport participation did not play a significant role, as in the total group of all soccer players there was no significant linear correlation with the performance levels reached at adolescence. In general, our path-analytical model confirmed the findings of Ford et al. (2009), Ford and Williams (2012), and Ward et al. (2007), as it did not underline a positive effect of an early diversification of club sport participation. On the other hand, at least the ORs of the diversified club sport participation were in line with Guellich et al. (2017) that such a multi-sport engagement could serve as a promising strategy to reach the highest province soccer performance level later on. The explanation for the missing relation might lie in the fact that only in the lowest and highest performance groups of the soccer players a major fraction of children engaged in three or even more competitive sports. In the medium soccer performance groups of the district or county performance levels (2–3), most of the youth athletes concentrated solely on soccer or participated in one or two additional sports only. Our interpretation for this situation is that at the low soccer performance level, a substantial number of athletes with good general performance characteristics preferred other sports as main disciplines and thus participated in soccer training and competition games just as side events to their main sport. This interpretation is in line with the significant quadratic bivariate regression function found between the training diversity that is the number of sports performed during youth development and the adolescent soccer performance level reached at adolescence. Nevertheless, we assume that the relation between the diversity of early club sport engagement and future soccer success again disappears when the best youth soccer athletes performing on national or international youth level were included, as the findings of Ford et al. (2012) and Hornig et al. (2014) suggest. In our study, all of the province level soccer athletes practiced in the three sports—track and field, tennis, and table tennis only—which is in line with the specialized sampling approach of Sieghartsleitner et al. (2018) postulating that additional side-sport activities should show at least complementary relations and thus provide positive contributions to the main sport soccer to enhance the specific PF or MC profile needed there.

There are some limitations in this study. The operationalization of the individual soccer performance by means of the highest soccer performance level reached by the club team is still debatable (Baker et al., 2015; Bergkamp et al., 2019; Leyhr et al., 2020). To compensate for the lack of individual in-match player performance assessment, we introduced an additional control step to have the individual soccer performance criterion finally checked fine-grained player-per-player by the regional talent coordinator of the German Soccer Federation (DFB). Besides that, we can also assume that due to natural selection and club policies on the higher U17 county and province levels, the individual performances correspond pretty close to the teams' overall soccer performance. Nevertheless, there might be some internal validity problems at least on the lower levels 1–2, which are on a local level. Here, the player participation in a youth club team might also depend to a certain degree on the preference of early peer relations or shorter travel distances to the training and competition sites and thus underestimate the individual soccer performance level. Thus, on the two lowest levels, team success might not fully represent the individual athletes' performance capacity. Furthermore, due to less frequent reporting on individual player participation in the media and internet match reports on the lowest levels 1–2, the range in the criterion soccer performance could be somewhat restricted, so that the pathways between the predictors and the later-on soccer performances found in our study might be underestimated (Bergkamp et al., 2019). Especially, in our path-analytical model, more precisely classified low-level participants could improve the significance and prognostic validity of the different performance characteristics of the U9 players. Besides the low fidelity of the criterion variable team performance level, a limitation of our study is also that the investigated performance levels end up at the sub-elite Hessen province level. From a nationwide perspective on talent identification, only the highest youth soccer performance levels of the U17 Regionalliga (level 6) and Bundesliga (level 7) truly represent youth elite soccer performance. So it has to be stressed that there is still a gap between the soccer performance investigated in this study and the nation's best soccer performances within the U17 age group. In the U9 age group, the generic test battery used here generally allows for a first comprehensive performance diagnosis to identify good movers with a suitable profile of anthropometry, PF, and MC for a deliberate soccer training. Besides the initial quality of the performance characteristics other factors like sport-specific training initiation and soccer experience, learning conditions and facilities, quality of training and training volume, and field position might influence the performance development at youth age. So the lack of information about these potentially confounding variables is a limitation of the present study.

Also, there is still room for improvement in the game sports where test items focusing on technical skills and agility without or in combination with decision-making could be added to improve the prognostics (O'Connor et al., 2016; Ulbricht et al., 2016; Schorer et al., 2017). On the one hand, such predictors of higher fidelity may lead to a better explanation of the variance between the soccer performance groups (Bergkamp et al., 2019). On the other hand, in soccer, Hohmann et al. (2018) observed at elementary-school age a lower prognostic validity of sport-specific skill tests compared with generic physical or physiological tests, which the authors attributed to the higher difficulty of technical tests and the short time span of soccer-specific education. In order to do justice to the multidimensional character of football performance (Huijgen et al., 2010), in future studies at primary school age, the general tests should be supplemented, if not by football-specific tests, then at least by semi-specific tests to test fundamental ball-handling skills (Rylander et al., 2019). Despite such concerns, it is obvious that research has to be extended to the early age group of elementary-school children, as Ford et al. (2020) have reported recently that a substantial fraction of worldwide youth soccer academies have installed talent identification systems at the age group level of 8 to 11 year-old players already. In addition to sport-specific test extensions, psychological test items might also provide further indications of potential future top performers (Morris, 2000; Epuran et al., 2008; Forsman et al., 2016a; Johnston et al., 2018; Murr et al., 2018a,b), although it is still unclear whether such attempts could be a fruitful endeavor at the early stage of talent development during elementary-school age already. At least in the U12 age group, Zuber et al. (2015), as well as Hoener et al. (2015), have made promising attempts to integrate psychological testing in a talent identification campaign of the Swiss Soccer Federation (SFV) and the German Soccer Federation (DFB), respectively. All in all, further research is needed not only to contribute to the extension of the current knowledge on the prognostic validity of motor assessment on this early talent development stage but also to clarify whether such general talent diagnostic campaigns are suitable to support youth sport practitioners in the task of recommending and assigning the right sport to each of the promising individuals (Pion, 2015).

Nevertheless, despite multifaceted and optimized test tasks as well as sophisticated multivariate statistical tools, not every talented athlete can always be surely identified, be it at elementary-school age or during puberty and adolescence. In contrast to linear talent prediction methods, some unexpected players develop into professional athletes, as even during late adolescence very few career paths are straightforward (Elferink-Gemser et al., 2011; Gulbin et al., 2013; Li et al., 2018). Thus, very often unsteady development of performance characteristics (Vaeyens et al., 2008; Fransen et al., 2017) and non-linear pathways to the top of the scene are determined by many interacting dynamic parameters to which each athlete reacts in a unique way (Phillips et al., 2010), and which should be reflected in the research methodology as well (Den Hartigh et al., 2016; Fransen et al., 2017; Leyhr et al., 2020).

CONCLUSION

Our study shows that early talent screening and sports orientation can be used to make valid statements in regard to future success of young soccer players. It also provides reliable empirical knowledge on the prognostic relevance of eight generic PF and MC tests in a regional talent screening and sports orientation campaign. The results show motor predictors' prognostic validity over a long-term period (on average about 8 years) after controlling all test data for calendar age. The specificity of the generic testing in the second grade is very high, and the majority of non-talents is advised to pursue sports other than soccer for which they were better suited. However, due to the medium sensitivity of the testing, recommending elementary-school children to focus solemnly on the sport soccer still remains a very complex practical and theoretical problem. The practical application of the test battery assessing speed, endurance, and coordinative abilities turned out to be a useful tool for talent orientation as a combination of multifaceted testing and a subsequent sports recommendation on the basis of the best match of the individual profile with the concrete demands of specific sports like soccer.

Further studies with alternate methodological approaches, like person-oriented pattern analyses (Zuber et al., 2015, 2016; Zibung et al., 2016), and a promising combination of linear and non-linear prognostic tools (Pion et al., 2016) should be further examined and compared with each other to identify the corresponding strengths and weaknesses. In doing so, the research on talent orientation may provide coaches with more scientifically valid tools for supporting their talent development strategies as well as offering a deeper understanding of the effectiveness of talent promotion interventions in the process of the long-term development of talented youth soccer players.

DATA AVAILABILITY STATEMENT

The data associated with the paper are not publicly available but are available from the corresponding author on reasonable request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Municipality of Fulda, University of Bayreuth. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. The Declaration of Helsinki was checked and adhered to in all parts of this study.

AUTHOR CONTRIBUTIONS

AH contributed on to the design and implementation of the research. MS performed the test data collection. All authors contributed to the final version of the manuscript.

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Premature Professionalisation or Early Engagement? Examining Practise in Football Player Pathways

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There is a growing debate, both in the academic and sporting worlds, about the most appropriate pathway for high potential young players in sport. In this regard, there has been a considerable focus on the age of selection into structured talent development pathways and the nature of the experience once players have been recruited. Given the economic and reputational currency associated with developing professional footballers in particular, it is unsurprising that professional football clubs continue to invest significant financial resources into their academy structures. Understandably, this recruitment policy has attracted substantial attention within the media and research community, with ethical concerns arising surrounding the impact early selection may have on the welfare and the experiences of the young players within the pathway. The aim of this perspective article was to critically consider the research underpinning the early engagement practises of football clubs and the extent to which, and how, the pathway can provide players with the most appropriate starting point for their development. This evidence points to the need to look beyond the prevalent 'early specialisation vs. diversification' debate in youth sport towards a consideration of an early engagement perspective that reflects the biopsychosocial influences on talent development and the socio-political environment that influences decisions. We provide practical recommendations focused on the quality of the early engagement experience.

Keywords: early engagement, premature professionalisation, youth football, talent pathway, player development, specialisation

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INTRODUCTION

The development of talent in football is big business and, across nations, significant financial resources are invested in identifying and developing talented young players. For example, some football academies in the United Kingdom are now adopting an approach whereby players as young as six are required to attend multiple weekly training sessions, with formal club registration beginning at 9 years of age (Elite Player Performance Plan, 2011; Read et al., 2016). This has led to suggestions of "premature professionalisation" of youth sport to the detriment of the young players involved. Of the 265 million people that regularly play football, only 0.04% play in a professional league (Haugaasen and Jordet, 2012) and even the best performing young players are unlikely to maintain progression and become elite senior players (Sæther, 2018). Furthermore, the complexity of talent identification in sport is compounded by the methods used to select young players into professional academies. Typically, young players are identified and then selected based on subjective analysis by coaches on the factors thought to underpin senior performance (e.g., physical, biological or performance determinants; Williams and Reilly, 2000) without due consideration to the non-linear and dynamic nature of the pathway and the non-stable nature of these factors (Abbott and Collins, 2004). Indeed, the importance of a biopsychosocial approach to talent development has been stressed (e.g., Bailey et al., 2010), and football clubs must consider their role in the biopsychosocial development of players. Reflecting this, the purpose of this perspective article was to critically consider early engagement practises in football and the extent to which, and how, the pathway can provide players with the most appropriate starting point for their development. Framed within the socio-political context of the Irish-UK footballing landscape, the discussions within this perspective article are delimited to male football.

The Socio-Political Realities of Modern Football

In addition to the complexity of predicting talent at a young age, and reflective of the biopsychosocial approach described earlier, the cultural and societal influences within football must be addressed to account for the complex system that young players experience, and the cultural milieu generated by the sport, context, and even gender. Scouts and coaches base their selection on the extent to which a young player possesses the skills and ability to compete in a specific cultural context or philosophy (Sarmento et al., 2018). The competitive landscape in football also makes talent identification and selection a strategic and tactical decision (Relvas et al., 2010) and there are certainly systemic drivers that force clubs to select young players. Given the cost of buying senior players and the competitive marketplace, it makes sense that professional academies contract large numbers of players at a young age. For example, the player may turn into the next superstar and, for a relatively small outlay, the club will benefit both on (performance) and off (financially) the pitch. Reflecting football's competitive nature, identifying potentially talented players and selecting them at a relatively young age means that they are not available to another rival club. Given the finite coaching resources, money, facilities, and exposure to competition available to all clubs, decisions of who and when to select and deselect on the pathway are inevitable. However, the socio-political landscape of modern-day football is evolving, and clubs must be systematic, careful, and deliberate in designing player development policies. Understandably, there is growing concern about the influence of academy experiences on young players, especially on those released at various, and often early, points on the pathway (Relvas et al., 2010; Mitchell et al., 2020). Significant academic (Brown and Potrac, 2009) and anecdotal (Calvin, 2018) attention has been paid to the deselection experiences of young footballers, with feelings of anxiety, fear, humiliation, and depression experienced by some young players following deselection. Reflecting the professionalisation of football academies, which have also been referred to as "football factories" (Green, 2009, p.7), some football clubs have been accused of viewing young players as commodities and performing bodies that are disposed of once it is deemed that they do not have the necessary qualities and attributes to succeed at the senior level (Brown and Potrac, 2009). Against this basis, there have been calls to reconsider the pathway experience of aspiring footballers and consider ethical issues and the impact of selection and deselection issues within these environments. There is a growing literature base that emphasises the influences of biopsychosocial factors on talent development with recommendations to delay talent identification (i.e., the age of identification) until later in the pathway, to widening talent development opportunities, and expose young athletes to a range of diverse activities across youth sport (Till and Baker, 2020). It may also be that the distinction between early selection and early specialisation, in football academies for example, is less understood and in reality, the context is more complex than the "diversification is good, specialisation is bad" argument that is often cited (cf. Baker et al., 2020).

EARLY SPECIALISATION OR EARLY FOCUS?

Although early sport specialisation has become a popular research area, a universally agreed definition does not currently exist (Jayanthi et al., 2020; Mosher et al., 2020). Initially, Jayanthi et al. (2013) defined early specialisation as "year-round intensive training in a single sport at the exclusion of all other sports." Jayanthi et al. (2015) later introduced an early specialisation scale, whereby an athlete could be deemed low, medium, or highly specialised based upon three criteria. The authors proposed that the degree of specialisation was influenced by whether the athlete (a) participated in year-round intensive training (more than 8 months per annum), (b) selected one main sport, and (c) quit all other sports to focus on their main sport. Reflecting inconsistencies in terminology throughout the talent development literature (cf. Dohme et al., 2017) a lack of clarity remains, and, in this case, the scale was subsequently questioned because it failed to include all elements that affect an early specialisation pathway, such as training volume and intensity, the type of sport (i.e., individual or team-sport), or the child's autonomy in training (Jayanthi et al., 2020).

Despite the lack of a consensus statement on what constitutes early specialisation (Mosher et al., 2020), and perhaps in response to the structure of competitive youth sport, many researchers and practitioners propose early diversification rather than specialisation as the most appropriate foundation for sporting success (i.e., Bridge and Toms, 2012; DiFiori et al., 2014; Myer et al., 2015; LaPrade et al., 2016; Read et al., 2016; Wilhelm et al., 2017; Güllich et al., 2020). The International Olympic Committee published a statement (see Bergeron et al., 2015) citing generalised concerns associated with youth athletic talent development, including an increased risk of overtraining, burnout and injury. The committee recommended an early diversity of athletic exposure between and within sports, despite acknowledging the need for more definitive evidence. Although there is significant research attesting to the benefits of a diversified early engagement in sport (i.e., Jayanthi et al., 2013;

Côté and Vierimaa, 2014; DiFiori et al., 2014), much of the suggestions on early specialisation have been guided by research that is retrospective in design and lacking specificity to football (i.e., Güllich and Emrich, 2006; Law et al., 2007; Wall and Côté, 2007; Fraser-Thomas et al., 2008; Moesch et al., 2011). The latter point is important, as an evidence-based, sport-specific early specialisation definition is needed before strategies for optimal youth participation, injury prevention, and long-term health and performance can be prescribed (Jayanthi et al., 2020).

Some research has attempted to address the risks associated with youth participation in high-level football. A systematic review by Jones et al. (2019) concluded that high-level youth players have a high probability of sustaining a time-loss injury and, consequently, lose large portions of their seasonal development. However, no research within the review included a matched comparator group of diversified sports players tracked prospectively to compare training, match and overall injury incidence rates. In fact, research by Frome et al. (2019) found that specialised high-level youth footballers were less likely to report any previous sports-related injury than non-specialised athletes. Zibung and Conzelmann (2013) and Sieghartsleitner et al. (2018) also reported that to succeed within the Swiss national football system, a vast amount of domain-specific learning activities within early sport participation is recommended. The paucity and low quality of research to date was highlighted in a recent systematic review of youth sports specialisation and musculoskeletal injury (Fabricant et al., 2016). The review included only three appropriate studies, two retrospective studies and one case-control study. Consequently, there is a need for comparative and prospective research to clarify the relationship between youth sports specialisation and musculoskeletal injury (Fabricant et al., 2016).

Although junior success does not necessarily lead to senior success in football (Collins et al., 2016; Taylor and Collins, 2019), there is evidence that early and prolonged engagement in sport-specific activities is related to senior performance. For example, hours spent in football-specific team practise at an early age is associated with expert levels of achievement in English (Ford et al., 2009; Ford and Williams, 2012; Roca et al., 2012), Swiss (Zibung and Conzelmann, 2013; Sieghartsleitner et al., 2018), and Norwegian (Haugaasen et al., 2014) footballers. Although early diversification can be a pathway to elite performance (Coutinho et al., 2016), a diversified early experience has not been shown to be a significant influence on the attainment of expertise in football (Ward et al., 2007; Ford et al., 2009; Ford and Williams, 2012). In fact, the hours accumulated in football-specific play and practise during childhood and youth is a strong predictor for perceptual-cognitive expertise in football (Roca et al., 2012). Methodological limitations (i.e., retrospective study designs, limited to specific cultural contexts) in this research have to be acknowledged, and there is a need for longitudinal and prospective research that examines the microstructure of the different football activities that support development to better inform the design of early experiences in the football pathway (Coutinho et al., 2016; Davids et al., 2017). However, given the socio-political nature of modern-day professional football, and the systemic drivers influencing academy practises mentioned earlier, it is very unlikely that such a prospective, longitudinal and comparative experiment that could provide meaningful insight into the specialisation vs. diversification debate in a football-specific context could ever take place.

OPTIMISING EARLY ENGAGEMENT IN A SPECIALISED PATHWAY

Zibung and Conzelmann (2013) suggest that football requires large quantities of football-specific learning activities during childhood to achieve high footballing performance levels at the age of peak performance. At some stage, a high potential player must prioritise football to maximise his development and fulfil his potential. Baker et al. (2020) highlight the lack of evidence to identify the appropriate time for young athletes to prioritise their chosen sport in an attempt to fulfil their potential. Despite this, Hendry and Hodges (2018) noted that senior professional footballers report that they started playing football early in childhood and, although they did not specialise exclusively in football during childhood, they devoted the majority of their time to it. An analysis from multiple football nations identified that elite players started their participation in an elite football academy at 11–12 years of age (cf. Ford et al., 2012), which is in contrast to current UK football academy practises which formally begin at age nine (Richardson et al., 2004; Read et al., 2016). As there is a lack of empirical evidence to support early childhood recruitment practises, and given that research appears to favour later selection at around age 11–12, it could be suggested that the age at which academies recruit players should be delayed until early adolescence. Côté's Developmental Model of Sport Participation suggests that at the end of primary school (around age 13), children should have the opportunity to either specialise in their favourite sport or to continue in sport at a recreational level (Côté and Vierimaa, 2014). As this investment begins, support must be provided to manage the diverse sporting commitments of young players. This presents an interesting opportunity within a football academy where a young player is often required to commit to 2–4 days of training/match-play per week (Richardson et al., 2004; Mitchell et al., 2020). Given that children aged 5–17 are recommended to engage in 60 min of moderate to vigorous physical activity daily (World Health Organization Physical Activity Recomendations, 2020), an academy player could be encouraged to engage in a range of activities outside the academy programme. For some, this might allow the opportunity to participate in a different sport or activity; for others, it might provide them with the opportunity to play football in a different setting, such as in school or recreationally that would meet their psychosocial needs (Bailey et al., 2010). Given the physical activity recommendations and the current commitment required by young academy players, if managed appropriately, there would appear to be ample time to engage in age, stage, and developmentally appropriate activities in addition to the structured academy programme. Of course, as intensity and physical demands increase, training loads should be monitored to maximise athletic development and minimise the risk of overtraining and injury, especially during rapid growth periods (Wrigley et al., 2012; Jones et al., 2019; Materne et al., 2020).

A key aim of the talent development process is to provide youth athletes with a suitable learning environment to accelerate or realise their potential (Till and Baker, 2020). Kelly et al. (2020) suggested that moving youth footballers into an advanced learning environment may be associated with positive performance outcomes for high potential players. A similar approach is taken in academia, whereby teachers often move high potential students into more advanced educational settings to provide greater learning opportunities (Kelly et al., 2020). Güllich et al. (2017) and Güllich (2019) reported that higher amounts of football-specific free play and structured practise in other sports during childhood, rather than larger quantities of coach-led football practise, differentiated German players at the highest professional standard. However, both studies' findings are restricted by methodological limitations, including retrospective recall bias, cultural limitations, and neither study recorded the "quality" of practise and free play. Contrastingly, a plethora of research (with similar retrospective recall bias limitations) exists to suggest that large amounts of football-specific practise and unstructured free play during childhood contributes to the development of expert performance (Ford et al., 2009, 2012; Zibung and Conzelmann, 2013; Sieghartsleitner et al., 2018). Therefore, this suggests that a developmental pathway should be structured to provide large amounts of football-specific learning activities, but delivered in a broad, diverse, and developmentally appropriate format (Sieghartsleitner et al., 2018), including as examples, coach-led and peer-led practises, peer-led and self-led unstructured free-play, and skill development.

Bio-Banding: An Example of a Player Development Intervention

Another important consideration when selecting/deselecting players before puberty is the large variation in biological maturation among players of the same chronological age. Children of the same chronological age vary substantially in status (state of maturation) and timing (chronological age at which specific maturation events occur) of maturity (Cumming S. P. et al., 2018). Thus, a youth player competing for selection into a talent pathway may be competing against a player who is biologically advantaged by 6 years (Borms, 1986), despite both players being the same chronological age. Given that early maturation brings physical advantages (such as greater physical size, lean muscle mass, speed, power, and strength; Hill et al., 2020), it is unsurprising that a selection (Cumming S. P. et al., 2018), and performance bias (Hill et al., 2020; Parr et al., 2020) exists in favour of early maturing players.

Categorising youth players based upon biological maturity attributes rather than chronological age is an alternative solution through a process termed "bio-banding" (Cumming et al., 2017). Research into bio-banding in English Premier League academy football has been favourably received by stakeholders (Cumming S. et al., 2018; Reeves et al., 2018). Similarly, "playing up" high potential youth players with chronologically older peers has been suggested to facilitate more appropriate levels of challenge and individual development (Kelly et al., 2020). However, as early biological maturation does not encompass cognitive, emotional, or social development (Cumming S. P. et al., 2018), there is the possibility that categorising players based upon biological maturity alone without considering key psychological developmental influences may be disadvantageous. The influence of biological maturation within youth football is complex and appears to have a greater influence on talent development than the relative age effect (Parr et al., 2020). This is reflected in professional football academy practises, whereby routine monitoring of biological maturity and training load is considered a priority (Salter et al., 2021). More research is needed to conclusively understand performance variations associated with relative age and biological maturity in youth footballers.

The Dynamic and Non-linear Pathway Experience

It is also crucial to recognise how changes in broader society and talent pathways influence the developmental activities of young players. Research exploring the developmental histories of elite and non-elite athletes (e.g., Baker et al., 2003; Côté et al., 2005; Gulbin et al., 2010), as well as more anecdotal descriptions of free-play, diversification and development (as evidenced in the development of elite Brazilian footballers; Ford et al., 2012), is purported to offer clues to best practise, generating "evidence-based" practises which can be adopted and applied by sports and organisations in the pursuit of excellence. However, western society has changed, and children are unable to acquire the same amount of outdoor free-play than that of previous generations (Solomon-Moore et al., 2018). This descriptive focus also fails to appreciate that talent development is a biopsychosocial issue and optimum solutions will be contextualised based on the interaction between physical and mechanical attributes (the "bio"), psycho-behavioural characteristics (the "psycho"), and the sociocultural environment/milieu in which the individual exists (the "social") (Collins and MacNamara, 2019). The onus is on sport organisations to critically evaluate the worth and validity of a particular approach (e.g., diversification, specialisation, or early engagement) to provide the most appropriate development experiences in particular contexts. In football, for example, this may be the provision of structures and experiences that allow high potential players to experience sufficient quantities of both football practise, and developmentally appropriate activities *and* unstructured free play within their developmental pathway. Simply, in sports like football where there is less evidence of the discriminatory power of broader activity (Haugaasen et al., 2014), early selection into an academy setting may not have negative consequences as long as high potential players are provided with an enrichment programme of other activities; a focus on early engagement rather than early specialisation.

The talent development process is non-linear (Collins and MacNamara, 2012) and the complex transition from youth to professional football (Larsen et al., 2014) could be cited as an argument against early selection. Players should be able to transition in and out of the pathway across multiple time points as they progress, although the reality appears to be more complex, and the number of athletes reaching elite levels is constrained by the numbers of professional players a system can maintain. Simply, deselection from football academies is inevitable for the vast majority of players at some stage, and if poorly managed, it can have negative emotional and psychological impacts on young players (Brown and Potrac, 2009). Athletes have also reported questioning their identity, their ability as an athlete, and the role of sport in their lives following deselection (Neeley et al., 2018; Mitchell et al., 2021). Football clubs have a moral and ethical responsibility to focus on the welfare of all players under their care, whether they are selected to progress further or deselected.

However, the pathway experience for deselected young athletes can also be a positive one. Williams and MacNamara (2020) found that high-potential young athletes who were deselected reported that the experience of the talent pathway provided the foundations for future success in other sports, careers, or education opportunities. The talent pathway can provide an environment that develops valuable constructs, (i.e., professionalism and positive performance behaviours), psychobehavioural skills (i.e., social awareness and effective communication), and personal responsibility (i.e., self-motivation and personal drive/desire) which can crossover to alternative domains outside of sport and prove advantageous (Williams and MacNamara, 2020). Similarly, Neeley et al. (2018) identified that deselection from the talent pathway can be accompanied by subsequent personal growth experiences. The authors noted that, despite not progressing, deselected athletes experienced an enhanced sense of personal strength, developed closer social relationships, and recognised new and alternative opportunities. Therefore, it is possible that if structured appropriately, players can have many positive experiences during their time in football academies leading to the development of multiple skills and behaviours that are transferable to many other parts of their lives (Williams and MacNamara, 2020).

It is unlikely that football clubs will cease to select young players at a young age and in fact, the research suggests that early specialisation issues may be less influential in sports like football which requires higher skill and variability than in athletics, for example (Paul et al., 2016). The focus should be on the quality of the experience offered to high potential young players in order to support their development both on and off the pitch (Strachan et al., 2011; Kelly et al., 2020; Williams and MacNamara, 2020).

DISCUSSION

Despite the non-linear nature of talent development, there is a lack of research investigating those who do not make it to the highest level, perhaps leading to survivorship bias within the literature (Taylor and Collins, 2019). The need for more research is evident, and issues of biological, neurological, and social readiness have rarely been considered (Baker et al., 2020). We must consider the viewpoints of the coaches, and critically, the high potential young athletes themselves regarding developmental strategies, since their voices have been largely absent from the discussion to date (Baker et al., 2020). When examining the development of young footballers, it is essential to embrace an interdisciplinary approach (rather than a monodisciplinary one) and adopt a longitudinal design (rather than a cross-sectional one) in the hope of better understanding the prospective value of various influences, and how these may gradually oscillate as players age and are exposed to systematic training (Williams et al., 2020).

Selection and deselection are an inevitable part of any pathway and care is needed in both the decision-making process and the language used to describe these decisions. We offer some practical examples.

- A player's deselection from the highest playing level of the pathway should not be deemed early elimination, but rather as an opportunity for players to be directed to a football environment that is better suited to their needs at *that* stage of their development. A key aim of the talent development process is to provide players with the best possible environment to support their trajectory and development. Nurturing players along a dynamic pathway in environments best suited to their individual needs at particular points of childhood and adolescence requires a system that facilitates multiple entry, exit and re-entry points. This type of coherent development system may seem aspirational given the socio-political context of modern-day football. Nonetheless, the large gap between research theory and sporting practise that exists (cf. Pankhurst and Collins, 2013) must be addressed and it is the responsibility of those working within the football industry at every level to ensure that the welfare of children is at the forefront of all decision making. If conditions can be created whereby an academy manager feels secure in the knowledge that producing players is not the sole outcome measure, a positive player development model can be woven into academy culture (Mills et al., 2014). From a "top-down" approach, this may require the refinement of current governance of youth football and increased collaboration and coherence across the youth football landscape. From a "bottom-up" perspective, it points to the importance of quality academy coaching that recognises the complexity and dynamic nature of the developmental process (UK Sport Pathway Coaching Position Statement, 2020).
- Football clubs and systems should look to provide young players with a variety of playing formats (i.e., modified pitch sizes and futsal), coaching styles (i.e., introduce peer-led free play alongside coach-led practise and competition), and competition structures (i.e., various team sizes and match durations) to provide a football-specific learning experience, but delivered in a broad, diverse, and developmentally appropriate format (Sieghartsleitner et al., 2018).
- We must consider the socio-political factors within organisational structures that influence player development. A lack of formal communication between youth and professional environments, even within the same club or broader system, can hinder the coherent progression of young players into the professional environment (Relvas et al., 2010). In practical terms, this means that open and clear lines of communication need to exist between clubs and coaches operating at different

levels of the game so that players are supported in their development as they progress from youth to adult football.

- Given that many talented young athletes are derailed from the pathway by a range of psychological influences, it would seem prudent that the academy experience supports the development of the psychological skills and characteristics shown to support development within, and transfer between, sports and domains (MacNamara et al., 2010a,b; Taylor and Collins, 2019). Such practises could be facilitated using the 5C's (commitment, communication, concentration, control and confidence), providing the successful, and crucially, early introduction of interpersonal and psychological skill development into coach, player and peer interactions to facilitate long-term development (cf. Harwood, 2008).
- Football clubs and broader systems must adopt a holistic approach to player development, whereby players are provided with the tools and resources to develop as people and succeed both in and outside of football (cf. Larsen et al., 2020). Coaches should provide an environment whereby the teaching of life skills (i.e., effective communication, exhibiting leadership, taking the initiative) is emphasised and integrated alongside the teaching of sport-specific skills (Bean et al., 2018). This becomes sustainable once coaches are able and encouraged to discuss and practise life skills and skill transfer with their athletes (Camire and Santos, 2019). Under these circumstances, there is a focus on the overall development of the person, rather than just the footballer.
- Parents are a key stakeholder in the talent development environment with essential and individualised roles and responsibilities (Côté, 1999; Pankhurst and Collins, 2013). However, many parents of academy players have reported experiencing insufficient levels of communication, feeling undervalued, being treated with a lack of empathy, and feeling worried and uncertain about their child's welfare and future (Harwood et al., 2010; Clarke and Harwood, 2014). To bridge this gap, academy staff must make a conscious effort to spend time developing relationships with parents in order to provide tailored and continuous support in an environment where parents feel welcomed, valued and respected (Newport et al., 2020). Moreover, clubs must make an effort to educate parents early in relation to the necessary motivation-related knowledge and cognitive-behavioural skills to manage themselves and facilitate their child's development throughout their time in the academy (Harwood et al., 2010; Newport et al., 2020). This education may be provided in the form of parent inductions upon entrance into the academy, followed by regular educational workshops and open and transparent discussions between parents, coaches and academy management staff.
- Professional football clubs must make an effort to collaborate with local grassroots clubs and schools, thereby emphasising vertical coherence within the sport (Webb et al., 2016). This may include opportunities for players from grassroots clubs and schools to train with the academies of professional partner teams, regular school holiday camps hosted at partner club locations, and regular fixtures between professional and grassroots clubs.
- Finally, the "rocky road to the top" (Collins and MacNamara, 2012) must be one that is systematic, well-planned, and coherent. The pathway must enable players' transition in and across challenging environments in a structured and supportive manner (Webb et al., 2016). This nested and nurtured approach to player development, with appropriate, well-planned and periodised developmental challenges and experiences (Collins et al., 2016), only becomes achievable when all of the key stakeholders in the game collaborate for the best interests of players.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Morphological and Fitness Attributes of Young Male Portuguese Basketball Players: Normative Values According to Chronological Age and Years From Peak Height Velocity

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The aims of the present study were: (i) to describe the structural and functional attributes of young male Portuguese basketball players aged 12–16 years and (ii) to generate normative data according to chronological age and years from peak height velocity. A total of 281 male Portuguese young basketball players between the ages of 12 and 16 years were assessed in this study. Chronological age, maturity parameters (maturity offset and predicted age at peak height velocity), morphological (body mass, height, and skinfolds and length), and fitness (sprint, change of direction ability, jump, and upper body strength) attributes were measured. Descriptive statistics were determined for the age and maturity status, and the 10th, 25th, 50th, 75th, and 90th percentiles were chosen as reference values. Descriptive and normative values of the players' morphological and fitness attributes, stratified by age and maturity status, are provided. The normative values of age at peak height velocity (category YAPHV = 0) showed that regional basketball players presented average values (50th percentile) of 169.8 cm for height, 173.3 cm for arm span, 55.6 kg for body mass, 3.34 s for the 20-m speed test, 10.31 s for the *T*-test, 4.75 m for the 2-kg medicine ball throw, 66.9 kg for the combined right and left handgrip strength, and 30.1 and 35.9 cm for jump height in the countermovement jump (CMJ) and CMJ with arm swing, respectively. In conclusion, these results may be helpful to quantify and control an athlete's performance over time and to adjust strength and conditioning programs to biological demands.

Keywords: reference values, body size, velocity, change of direction ability, strength, talent programs

INTRODUCTION

Basketball is a complex team sport where physical attributes, physiological performance, technical skills, tactical knowledge, and psychological attributes contribute to the players' and overall team's success (Trninić and Dizdar, 2000; Ostojic et al., 2006; Drinkwater et al., 2008; Torres-Unda et al., 2013, 2016; Ramos et al., 2019, 2020). Due to the multifactorial nature of basketball performance, identifying and selecting young players with the potential to attain high levels of performance in adult age is a difficult task. The variables influencing performance at a young age may be different from those that influence the success of adult athletes (Baker and Wattie, 2018); as has been demonstrated in various sports, the earlier the sport selection takes place, the lower its accuracy (Vaeyens et al., 2009; Te Wierike et al., 2014). However, knowledge of which factors influence players' success at different age categories can be a valuable resource in talent selection and all the talent development process (Hoare, 2000; Torres-Unda et al., 2013).

Recognizing the difficulty of finding valid measures to evaluate a prospective young athlete's potential justifies the need to analyze the morphological and fitness profiles of successful young players at different stages of their development (Vaeyens et al., 2008; Johnston et al., 2018).

The appropriate planning of a long-term training process requires the use of control tests to keep up with the evolution of athletes' morphological and physical characteristics in relation to their specific sport performance (Kuzuhara et al., 2018; Ryan et al., 2018; Myburgh et al., 2020). It was shown that the monitoring of players' attributes is particularly important during periods of accelerated biological development in order to control the adaption to training exposure, to reduce the injury risk, and, thereby, to enhance the coaching effectiveness process (Ryan et al., 2018; Salter et al., 2021). In this regard, establishing normative data for a particular population may improve the sensitivity of the selection criteria (Ryan et al., 2018; Salter et al., 2021) and provide coaching staff with specific references for the athletes' development program by comparing the morphological and physical status of the assessed players with the age normative data for specific populations (Ocarino et al., 2021).

Although the age- and sex-specific physical fitness reference data for Portuguese children and adolescents aged 10–18 years have been presented (Santos et al., 2014), there are no normative data for specific populations of Portuguese young basketball players based on a representative sample. It would be useful to compare the available normative data for Portuguese adolescents with the reference values of the young basketball players' population.

Previous studies on young basketball players highlighted the relevance of anthropometric (i.e., height, body mass, and arm span) and functional (i.e., speed, agility, upper body strength, and jumping ability) attributes in young players' performance (Torres-Unda et al., 2013, 2016; Ramos et al., 2019, 2020). Ramos et al. (2020) found that players from the better-ranked teams were faster, more agile, and had more upper body explosive strength than players from lower-ranked teams. Another study found that height, agility, countermovement jump (CMJ) power, and handgrip strength were predictors of individual performance (evaluated by the Performance Index Rating) in under-14 (U-14) young basketball players (Ramos et al., 2019). In the same study, significant correlations were also identified between playing performance and the anthropometric attributes (i.e., body mass, stature, and arm span) of U-14 young basketball players, suggesting that taller and heavier players perform better in matches than their shorter and smaller peers. In addition, Torres-Unda et al. (2016) observed that players who performed better had longer body lengths and also that players with greater jump capability scored more points.

Furthermore, the variability on the maturation processes may lead to the different biological development levels of young basketball players found in the same chronological age, resulting in a higher physical ability and, consequently, to a superior basketball game performance of those athletes whose biological development was initiated earlier (Torres-Unda et al., 2013, 2016; Ramos et al., 2019, 2020). Previous studies have found differences in anthropometric and physiological capacities, and in biological age, among U-14 Spanish (Torres-Unda et al., 2013, 2016) and Portuguese (Ramos et al., 2019, 2020) male basketball players with different skill levels.

From the talent development perspective, it would be useful to have normative data of the physical attributes according to not only the chronological age but also the maturity status. These reference values can guide coaches' decisions during talent selection programs at different age categories and can also help to interpret better the results achieved by young players during their training process, thus contributing to talent development.

Although several studies on the morphological and physical attributes of Portuguese young basketball players have been conducted (Coelho e Silva et al., 2010; Guimarães et al., 2019a; Ramos et al., 2019, 2020), they did not provide comprehensive normative data, established according to age and maturity status. Furthermore, the results of the studies conducted with young Portuguese basketball players are somewhat contradictory. While some of them confirmed the significant influence of maturity status on physical performance (Arede et al., 2019; Guimarães et al., 2019b), others reported that functional capabilities were largely independent of maturity status, especially after controlling for variations in body size (Coelho e Silva et al., 2008). Therefore, the purpose of this study was two-fold: (i) to analyze the morphological and fitness attributes of young male Portuguese basketball players aged 12–16 years and (ii) to establish normative data according to the chronological age and maturity status of young players. Taking into consideration the influence of biological maturation on a player's individual performance (Torres-Unda et al., 2016; Ramos et al., 2019) and, consequently, on the selection process of young basketball players (Coelho e Silva et al., 2004; Ramos et al., 2019), the normative data will be established according to maturity status.

METHODS

Subjects

In Portugal, the initial stages of the selection process start with the under-14's (U-14) category, when the most promising players aged 12–14 years are selected by the best clubs or regional teams. Every year, the Portuguese Basketball Federation organizes a national tournament, where the best of the country's U-14 and U-16 male regional teams compete for 5 days. Taking advantage of this event, a convenient sample of 281 male basketball players (mean $\pm$ SD $= 14.51 \pm 0.98$ years) between the ages of 12 and 16 years was evaluated in this study. These participants represented the first division male regional selection teams that competed in the Portuguese Festival of Youth Basketball. In agreement with the Portuguese Basketball Federation, the supposed best U-14 ($n = 173$) and U-16 ($n = 108$) male Portuguese basketball players were tested during this tournament, over three consecutive seasons. This allowed us to create an extensive database of the morphological and fitness attributes of high-level young players according to their chronological age and years from age at peak height velocity (YAPHV).

All participants received a clear explanation of the aims and procedures of this study. Only the players whose parents or legal guardians have signed an informed consent form were permitted to participate in the study. The study was authorized by the Ethics Committee of the Faculty of Physical Education and Sport—Universidade Lusófona and was performed according to the Helsinki Declaration.

Procedures

A mix longitudinal design was used for this study. Data related to players' practice experiences (i.e., years of basketball practice) and training load (i.e., hours of practice per week) were collected with a specific questionnaire. Data related to players' morphologic and fitness characteristics were collected by the researchers. The measurements took place on the first day of the tournament to avoid the influence of players' fatigue on the results of measurements. However, some players were measured after the competition had started. In these cases, it was guaranteed that the evaluations were conducted at least 2 h after the game had been played. The test batteries used in the study covered maturity status and morphological and fitness evaluations, which have already been described in detail in a previous paper (Ramos et al., 2020). Anthropometric tests were undertaken before the functional skills tests.

Age and Maturity Status Evaluations

Chronological age (CA), in decimals (decimal age), was calculated subtracting the birth date from the observed date using the reference decimal age tables (Healy et al., 1981). The CA group was defined by the whole year (i.e., 12 years = 12.00–12.99 years, 13 years = 13.00–13.99 years, 14 years = 14.00–14.99 years, 15 years = 15.00–15.99 years, and 16 years = 16.00–16.99 years) (Ramirez-Velez et al., 2017).

The maturity offset (YAPHV) was predicted from a sex-specific equation (Mirwald et al., 2002) and provides the distance in years before or after the age at peak height velocity. The predicted age at peak height velocity (APHV) was calculated by subtracting the predicted maturity offset from the CA obtained at the time of observation (Mirwald et al., 2002). Chronologic age, stature, sitting height, and estimated leg length (stature minus sitting height) were used to predict the maturity offset and are described in *Morphological Evaluation*. Maturity group was defined with the whole year as the midpoint of the range [i.e., $-1 = (-1.50, -0.51)$, $0 = (-0.50, 0.49)$, $1 = (0.50, 1.49)$, $2 = (1.50, 2.49)$, and $3 = (2.50, 3.49)$] (Kalabiska et al., 2020).

All the equations used to predict YAPHV (maturity offset) or the APHV have the same major limitations (Malina and Kozieł, 2014; Malina et al., 2015). The advanced maturity status of male adolescent athletes and the relatively narrow range of variation at the predicted ages of peak height velocity (PHV) may influence the maturity status evaluation during adolescence and may impair its utility and effectiveness on talent identification and development programs when used at a particular moment. Recently, Rommers et al. (2020) have shown that none of the published equations provided an accurate prediction for individuals. However, although the stability of the predictions within individuals are poor and group classification is not exactly accurate, APHV predicted by the Mirwald equation (Mirwald et al., 2002) can be successfully applied among boys who are average (on time) in maturation and during the growth spurt period (~12–15 years). Moreover, Arede et al. (2020) validated the adult height prediction using a small number of unpublished Portuguese cases, according to Sherar et al. (2005). The authors showed an almost perfect relationship and a substantial agreement between the observed values of predicted adult height (PAH) and the estimated values of PAH. Additionally, adult height estimated through the formula of Sherar et al. (2005) was only slightly higher than the adult height estimated by the method of Khamis and Roche (1994). These results reinforce the possible use of the Mirwald equation (Mirwald et al., 2002) even when PAH measures are being considered. Taking into consideration the importance of biological maturity for talent identification, and the difficulties of implementing maturity protocols other than the above-mentioned, the use of references organized by maturity groups, according to Mirwald et al. (2002), and obtained from a sample that supposedly gathers the best U-14 and U-16 male Portuguese basketball players, could provide insights into the sport-specific skills necessary to be ranked among the best national players in each age and maturity group (Huijgen et al., 2010) and may aid coaches to identify young players potentially at risk (Costa e Silva et al., 2017).

Morphological Evaluation

Body mass, stature, sitting height, and three skinfolds—triceps (Caterisano et al., 1997), calf (GML), and subscapular (SBS), were measured according to the International Society for the Advancement of Kinanthropometry guidelines (Marfell-Jones et al., 2006). Arm span and hand span were also measured (Massuça and Fragoso, 2013). Body mass was measured with a Secca body scale (model 761 7019009) to the nearest 0.5 kg, and stature and sitting height were measured with a Siber-Hegner anthropometric kit to the nearest of 0.1 cm. All measurements were made by an ISAK anthropometric technician who holds a level 2 qualification. The intra-observer technical errors of measurements, %TEM (and the coefficient of reliability, R), were well below the accepted maximum for stature ($R \geq 0.98$), 5% for skinfolds ($R = 0.90$–0.98), and 1% for breadths and girths ($R = 0.92$–0.98) (Marfell-Jones et al., 2006). The body composition analysis included the evaluation of relative fat mass (%FM) and absolute free-fat mass (FFM, in kilograms), estimated from the skinfold values. The %FM was calculated as the arithmetic mean of the %FM values obtained through the equations proposed by Lohman [equation 1: $\%FM = 1.35 \times (TRI + SBS) - 0.012 \times (TRI + SBS)^2 - I$, where I is constant] (Lohman, 1986) and Slaughter et al. [equation 2: $\%FM = 0.735 \times (TRI + GML) + 1$] (Slaughter et al., 1988). The body mass index (BMI) was calculated using the formula, BMI = Body mass/Stature^2 (in kilograms per square meter).

Fitness Evaluation

Before the fitness tests, all participants performed a standard 20-min warm-up routine (slow jogging followed by static and dynamic stretching) supervised by the researchers. The players were allowed a 10-min passive rest between tests, as well as water breaks and extra rest time. Each participant was verbally instructed and encouraged to give his/her maximum effort. Three trials were given for each test. The first was a practice trial for the familiarization with the test; the second and third trials were retained for analysis. All players completed seven fitness tests, from which nine variables were collected for analysis. The established order of physical tests allowed avoiding performing two consecutive tests for the upper or the lower body. In each team, due to competition constraints, the players were divided into groups of four elements and went through the established order. All data were collected by the researchers.

Speed Test

The 20-m speed test was performed and consisted of a 20-m linear sprint effort (Jakovljevic et al., 2012). The time of the speed test was recorded in seconds and hundredths of a second using photoelectric cells (Wireless Sprint system, Brower Timing Systems, Salt Lake City, UT, USA), and the best time of two attempts was registered.

T-Test

A *T*-test was used for the change of direction (COD) ability assessment (Delextrat and Cohen, 2009; Jakovljevic et al., 2012). The time was recorded in seconds and hundredths of a second using photoelectric cells (Wireless Sprint system, Brower Timing Systems, Salt Lake City, UT, USA), and the best time of two attempts was registered.

Jump Tests

The vertical jumping ability was tested using the CMJ and countermovement jump with arm swing (CMJ-S) (Bosco et al., 1983). The height (in centimeters) and the relative power (in watts per kilogram) of vertical jumps were recorded with a Chronojump measurement technology (Bosco System, Globus, Italy). The best of two attempts was considered.

Two-Kilogram Medicine Ball Throw

The upper limb explosive strength was tested using the 2-kg medicine ball throw (MBT) (Delextrat and Cohen, 2009). Participants started the test from a sitting position with the back against the wall using a release from the chest. The distance (in centimeters) attained as the best of two attempts was recorded.

Handgrip Strength

Handgrip (HG) strength was assessed with a handgrip test using a dynamometer (Takei Physical Fitness Test, TKK 5001, GRIP-A) (España-Romero et al., 2010). Subjects performed the test twice with each hand, and the sum of the best results achieved by each left and right hand was considered (in kilograms).

Sit and Reach Test

Flexibility was assessed using the sit and reach test (Mayorga-Vega et al., 2014). Each subject was seated barefoot on the floor with legs out straight ahead and with their feet placed with the soles flat against the sit and reach box. With hands on top of each other and palms facing down, each player tried to reach forward along the measuring line as far as possible. The score of the test was recorded to the nearest centimeter as the distance reached by the tip of the fingers. The vertical line of the feet soles was considered as a plane counted as 0 cm. Negative and positive centimeters were considered when the players reached forward, respectively, before and after this vertical plane.

Statistical Analyses

All the analyses were performed using the Statistical Package for the Social Sciences (SPSS, version 22.0, IBM SPSS, Chicago, IL, USA). The normality of the variables was assessed with the Kolmogorov–Smirnov test, and the equality of the variances was established with Levene's test. Intraclass correlation coefficients (Toong et al., 2018) were calculated for the 20-m speed test, *T*-test, jump tests (i.e., the CMJ and CMJ-S height and relative power), 2-kg MBT test, HG test, and the sit and reach test (see **Table 1**). The normality and equality of variances have been checked and confirmed for all variables, and the descriptive statistics (mean and standard deviation) were determined for each age (e.g., 13 years = 13.00–13.99 years) and maturity (e.g., YAPHV) group. Subjects were divided into percentiles, and the 10th, 25th, 50th, 75th, and 90th percentiles were considered as the reference values for each age and maturity group. Complementarily, the 25th, 50th, and 75th percentiles were presented graphically (see figures). Graphs were generated with GraphPad Prism 8.0 (GraphPad Software, Inc., San Diego, CA, USA).

RESULTS

Maturational parameters and the morphological and fitness attributes of U-14 and U-16 young male basketball players who participated in the Portuguese National Basketball Championship for regional selection teams are presented in **Table 2**.

Descriptive and normative values for the players' morphological and fitness attributes, stratified by chronological age and YAPHV, are provided in **Table 3**, **4**, respectively. Complementarily, the 25th, 50th, and 75th percentiles of (i) body size and arm span, (ii) speed and COD ability, (iii) countermovement jumps, and (iv) the 2-kg MBT and HG strength are graphically presented in **Figures 1–4**, respectively.

DISCUSSION

The aims of this study were: (i) to analyze the morphological and fitness attributes of young male Portuguese basketball players aged 12–16 years and (ii) to establish normative data according to players' chronological ages and the years from APHV.

Anthropometric and physiological attributes are relevant for success in youth basketball players (Fragoso et al., 2015;

TABLE 1 | Intraclass correlation statistics for inter-rater reliability for the physical tests.

	ICC[a]	95% CI		*F* test with true value 0			
		Lower bound	Upper bound	Value	df1	df2	Sig.
20-m speed test	0.937	0.921	0.949	30.514	287	287	<0.001
T-test	0.946	0.929	0.959	35.969	197	197	<0.001
CMJ heigth	0.962	0.951	0.969	49.917	287	287	<0.001
CMJ relative power	0.992	0.990	0.994	248.466	287	287	<0.001
CMJ-S height	0.958	0.947	0.966	46.393	287	287	<0.001
CMJ-S relative power	0.980	0.975	0.984	97.796	287	287	<0.001
2-kg MBT test	0.968	0.960	0.974	60.926	294	294	<0.001
HG rigth hand	0.980	0.975	0.984	100.302	292	292	<0.001
HG left hand	0.980	0.975	0.984	99.004	292	292	<0.001
Sit and reach test	0.922	0.903	0.938	24.769	289	289	<0.001

[a]*ICC estimates and their 95% confidence intervals were calculated using SPSS statistical package version 22.0 based on a consistency, two-way random-effect model. CI, Confidence interval; CMJ, Countermovement jump; CMJ-S, Countermovement jump with arms swing; ICC, Intraclass correlation; HG, handgrip; MBT, Medicine ball throw.*

Johnston et al., 2018; Guimarães et al., 2019a) and should also be considered for the long-term development of athletes (Viru et al., 1999). To the best of our knowledge, this is the first study to establish normative values for morphological and fitness attributes according to the age and maturity status of Portuguese young basketball players.

The results of the present study demonstrated that Portuguese young basketball players had bigger body sizes than equivalent aged national schoolchildren when descriptive comparisons were considered (Santos et al., 2014). Young basketball players are, on average, taller (12 years, +15.9 cm; 13 years, +15.6 cm; 14 years, +13.6 cm; 15 years, +13.4 cm; 16 years, +7.1 cm) and heavier (12 years, +3.4 kg; 13 years, +8.9 kg; 14 years, +6.4 kg; 15 years, +8.6 kg; 16 years, +2.1 kg) than Portuguese schoolchildren of the same chronological age (Santos et al., 2014). Portuguese young basketball players were also found to be taller and heavier than their U-14 Portuguese counterparts who were not selected for regional teams (Guimarães et al., 2019a). These findings are in line with previous research, which showed that body size (i) is an important attribute to discriminate the performance levels in young basketball players (Coelho e Silva et al., 2008; Torres-Unda et al., 2016; Ramos et al., 2020) and (ii) represents the key variable for talent identification and the selection process for elite club teams (Torres-Unda et al., 2013; Ramos et al., 2020). These results offer preliminary support and show the need to create specific norms for young basketball players. The established values for the normal population of equivalent age groups seem to be inadequate to grade these athletes.

Furthermore, the regional players from our study appear to be taller and heavier than Portuguese local basketball players when CA is considered (Arede et al., 2021). However, when players' heights were compared according to YAPHV, the results presented by local basketball players (height: −0.5 YAPHV = 166.7 cm; 0.2 YAPHV = 167.6 cm) became remarkably similar to those shown in our study (height: "0" YAPHV group = 169.2 cm) (Arede et al., 2021). In addition, our U-16 elite regional basketball players seem to be shorter and lighter than the basketball players who were selected to participate in the U-16 Portuguese National Team training camp (height = 180.5 vs. 189.7 cm, body mass = 68.8 vs. 81.1 kg) (Arede et al., 2020). However, it is worth mentioning that U-16 national team players were 3.1 years (early mature) and 2.3 years (average) from PHV (Arede et al., 2020), while our U-16 regional team players were 2.04 years from PHV.

When comparing the norms obtained from the young Portuguese basketball players to those of international elite basketball players of the same CA, Portuguese players showed higher mean height values at age 13 (+5.6 cm), quite similar at ages 14 (−0.8 cm) and 15 (+0.4 cm), but considerably lower at age 16 (−7.9 cm) compared to those of Dutch basketball players (Te Wierike et al., 2014). It should be noted that the sample used in the study with Dutch players was relatively small and that the previous comparison must be analyzed carefully. Nevertheless, Portuguese players, when compared to elite Spanish basketball players at age 13, showed lower mean values both for stature (−7.9 cm) and body mass (−10.6 kg) (Torres-Unda et al., 2013). It is worth mentioning that, in this study, Spanish players were 2.3 years from PHV (Torres-Unda et al., 2013), while Portuguese players were 0.54 years from PHV.

When considering the maturity status of the two samples (Portuguese and Spanish), the results of the comparison became very similar. The Portuguese players were much like their Spanish counterparts (Torres-Unda et al., 2013), showing similar mean values of height (+0.9 cm) and of body mass (−1.9 kg). Taken together, these results reinforce the importance of establishing normative values for young basketball players according to their biological maturity. The typical chronological age norms are particularly important when comparing the observed measures with references by age. These references allow tracking a child's growth and understanding the typology of these changes over time. However, growth is a dynamic process during which it is necessary to distinguish between the morphological variability, typical of a specific growth stage, and that resulting from maturity status differences since fitness improvements induced by growth and maturation changes are surprisingly similar to those induced by training and sports experience. In this regard, normative references according to YAPHV may help to focus on the

TABLE 2 | Descriptive statistics (mean ± SD) for training experience, maturational parameters, morphological, and fitness characteristics of U-14 and U-16 male players participated in the U-14 Portuguese Basketball Championship for regional teams.

	U-14 category (*n* = 173)	U-16 Category (*n* = 108)
Practice experience (years)	5.2 ± 2.5	6.7 ± 2.5
Training load (hrs-week^{-1})	6.1 ± 1.6	6.8 ± 2.5
CA (years)	13.8 ± 0.4	15.7 ± 0.4
Maturity offset (years)	0.54 ± 0.7	2.04 ± 0.6
APHV (years)	13.3 ± 0.6	13.6 ± 0.6
Morphology		
Body mass (kg)	60.1 ± 9.9	68.8 ± 9.8
Stature (cm)	173.5 ± 8.4	180.5 ± 7.3
Arm span (cm)	176.4 ± 9.5	186.7 ± 8.6
Hand span (cm)	22.1 ± 1.6	22.6 ± 1.4
BMI (kg/m^2)	19.9 ± 2.2	21.0 ± 2.3
%FM	16.5 ± 5.4	13.7 ± 4.7
Fat-free mass (kg)	49.7 ± 6.7	58.9 ± 7.1
Fitness		
V20-m (s)	3.35 ± 0.22	3.12 ± 0.11
TT (s)	10.35 ± 0.60	9.55 ± 0.50
SUM HG (kg)	69.2 ± 15.7	85.9 ± 15.7
MBT (m)	4.91 ± 0.8	6.13 ± 0.7
CMJ Height (cm)	30.4 ± 4.8	34.4 ± 4.6
CMJ Power (W)	719 ± 143	891 ± 128
CMJ-S Height (cm)	35.9 ± 5.6	41.7 ± 5.5
CMJ-S Power (W)	781 ± 154	982 ± 141
Sit and reach (cm)	–1.3 ± 7.7	4.0 ± 9.7

APHV, age at peak height velocity; BMI, body mass index; CA, chronological age; CMJ, countermovement jump; CMJ-S, countermovement jump with arm swing; MBT, medicine ball throw; SUM HG, sum of right and left handgrip; TT, T-test; V20-m, 20 meters speed test; YAPHV, years from age at peak height velocity; %FM, Fat mass percentage.

critical periods (like PHV) in order to evaluate improvements of certain qualities based on biological references and to adjust the strength and conditioning programs to biological demands. Even recognizing that the used methodology may have limitations and the obtained maturation values may not be exactly accurate, as described in *Methods*, this biological characterization will enable distinguishing growth and maturation results from training-induced performance and setting realistic and challenging goals for individual players (early and later maturers) in the medium and the long term. Maturity status, when used properly, can ensure that: (i) late-maturing players who are technically gifted, within their chronological age, are not discriminated against due to their temporary immaturity (Fragoso et al., 2015) and that (ii) early-maturing athletes normally selected for size-related reasons can have a range of motor skill experiences and specific training volumes adjusted to their advance maturity.

Regarding the fitness attributes, our results suggest that the mean values increased with age in speed, COD ability (except from age 12 to 13), MBT distance (except from age 15 to 16), HG strength (except from age 15 to 16), CMJ and CMJ-S height and CMJ and CMJ power (except from age 15 to 16), and also in the sit and reach test. Similar results were observed when the players were divided according to the YAPHV.

Recent research highlighted speed and COD ability as important attributes for basketball youth, both at the individual and team performance levels (Jakovljevic et al., 2012; Ramos et al., 2019, 2020). U-14 basketball players selected for Portuguese regional teams demonstrated significantly better results in the *T*-test than those non-selected (Guimarães et al., 2019a). The U-16 regional players from our study showed similar results in the 20-m sprint test than the 14- to 15-year-old players who participated in the 2016 U-16 Portuguese National Team training camp (Arede et al., 2019). The regional players from our study were almost 0.5 s faster in the *T*-test than the U-16 players who participated in the 2016 U-16 Portuguese National Team training camp (Arede et al., 2019). However, it must be taken into account that the players from our study were 2.04 years from PHV and the players from the mentioned study were 1.13 years from PHV (Arede et al., 2019).

In addition, the 13-year-old players from our study seemed to demonstrate better results in the 20-m sprint test and the *T*-test than did the U-13 local basketball players from a recent study (Arede et al., 2021). When the speed and COD ability results are compared according to the YAPHV, the differences between the values reported in both studies disappear, and regional players show quite similar results in speed (20-m test: "0" YAPHV group = 3.34 s) and COD ability (*T*-test: "0" YAPHV group = 10.31 s) when compared to local basketball players (20-m test: 0.2 YAPHV = 3.3 s; *T*-test: 0.2 YAPHV = 10.3 s) (Arede et al., 2021). When considering international basketball, the descriptive comparison revealed that young Portuguese basketball players were faster in the 20-m sprint test (12 years, −0.35 s; 14 years, −0.54 s) and in the *T*-test (12 years, −1.74 s; 14 years, −0.62 s) than elite Serbian basketball players of 12 and 14 years (Jakovljevic et al., 2012). However, when compared to Spanish elite basketball players at age 13, Portuguese players showed worse performances in the 20-m sprint test than their Spanish counterparts (Jakovljevic et al., 2012; Torres-Unda et al., 2013, 2016). The observed differences between Portuguese and Spanish 13-year-old basketball players may be explained by the more advanced maturity status of the Spanish players (Torres-Unda et al., 2013). These findings once again emphasize the importance of establishing normative values for physical qualities according to maturity development, in particular for speed and COD ability, described as important attributes in young players' basketball performance and considered as discriminant factors in a team's classification at a national tournament for U-14 regional selection teams (Ramos et al., 2020).

Upper body strength, evaluated by the MBT and HG strength test, was confirmed as an influencing factor on youth basketball performance (Chaouachi et al., 2009; Ramos et al., 2019, 2020). Recent studies reported that U-14 elite basketball players from higher-ranked teams demonstrated better results in the 2-kg MBT than players from the lower-ranked teams (Ramos et al., 2020), and HG strength was identified as one of the predictors of youth basketball players' individual performance (i.e., Performance Index Rating) (Ramos et al., 2019). When compared to other elite Portuguese players aged

TABLE 3 | Descriptive statistics (mean ± SD) and reference values (10th, 25th, 50th, 75th, and 90th percentiles) for morphology of young Portuguese male basketball players, according to their chronological age and maturity status.

		Chronological age (years)					**YAPHV**				
		12	**13**	**14**	**15**	**16**	**−1**	**0**	**1**	**2**	**3**
	N	**12**	**97**	**75**	**70**	**27**	**18**	**62**	**102**	**71**	**28**
Body Mass (kg)	M ± SD	49.0 ± 10.0	59.7 ± 8.9	62.2 ± 10.4	69.9 ± 9.9	66.8 ± 9.4	46.1 ± 6.3	55.5 ± 5.2	64.1 ± 7.8	68.4 ± 6.7	77.7 ± 9.0
	P10	34.0	46.0	49.3	57.9	51.7	35.8	47.8	55.3	59.7	66.9
	P25	40.0	54.5	55.0	64.6	60.0	43.3	51.3	58.0	65.0	70.3
	P50	49.8	59.0	62.0	69.6	68.3	45.5	55.0	62.5	68.5	78.0
	P75	56.1	65.0	70.0	76.6	72.3	49.0	60.0	69.0	72.0	82.3
	P90	–	70.5	75.0	82.3	80.8	56.6	65.0	75.0	77.9	88.9
Height (cm)	M ± SD	165.9 ± 8.8	172.6 ± 8.1	176.2 ± 8.1	181.4 ± 6.9	179.1 ± 8.1	159.6 ± 3.2	169.8 ± 5.2	176.6 ± 5.4	180.9 ± 5.7	188.0 ± 5.5
	P10	154.5	160.4	165.3	172.3	169.1	154.2	162.8	169.3	172.7	181.5
	P25	159.0	168.1	169.1	176.7	172.4	158.4	166.0	173.2	177.0	184.1
	P50	164.3	173.0	176.7	181.3	177.8	159.4	169.0	175.9	181.3	187.9
	P75	174.7	177.5	181.9	185.4	184.7	160.9	174.1	180.0	185.2	191.8
	P90	–	184.0	186.2	190.3	191.1	163.1	176.0	184.3	189.1	196.5
Arm span (cm)	M ± SD	168.9 ± 11.9	175.8 ± 9.2	179.2 ± 9.7	187.5 ± 8.1	185.5 ± 9.4	161.6 ± 4.6	173.2 ± 7.4	180.3 ± 7.2	186.1 ± 6.5	194.3 ± 7.1
	P10	154.3	160.9	162.3	175.9	173.6	154.8	162.8	170.3	176.4	183.9
	P25	157.0	169.1	172.2	180.7	179.3	158.5	168.3	176.0	180.9	190.0
	P50	163.3	177.0	179.9	186.7	183.1	161.0	172.0	180.0	186.1	195.0
	P75	177.5	181.5	185.1	195.0	191.0	164.5	179.0	184.7	190.2	199.1
	P90	–	187.0	189.5	197.8	199.7	168.2	182.0	188.9	196.0	204.4
Hand span (cm)	M ± SD	21.2 ± 1.5	22.0 ± 1.6	22.5 ± 1.5	22.7 ± 1.5	22.5 ± 1.2	20.1 ± 1.6	21.8 ± 1.4	22.6 ± 1.2	22.7 ± 1.4	23.1 ± 1.4
	P10	19.6	20.2	20.7	21.0	20.9	18.0	20.4	21.2	20.7	20.9
	P25	20.0	21.0	21.5	21.5	21.6	18.6	21.0	21.6	21.7	22.1
	P50	20.9	22.0	22.6	22.6	22.6	20.3	21.9	22.6	22.8	23.2
	P75	22.9	23.1	23.3	24.0	23.5	21.4	22.5	23.5	23.5	24.0
	P90	–	23.9	24.3	24.7	23.6	22.3	23.4	24.4	24.3	25.1
BMI (kg/m^2)	M ± SD	17.6 ± 2.1	20.0 ± 2.0	20.0 ± 2.3	21.2 ± 2.4	20.8 ± 2.0	18.1 ± 2.3	19.3 ± 1.7	20.5 ± 2.3	20.9 ± 1.8	22.0 ± 2.6
	P10	14.2	17.7	16.6	18.7	17.6	14.3	17.1	18.0	19.1	18.9
	P25	15.6	18.8	18.6	20.0	19.6	16.9	18.1	19.1	20.0	20.2
	P50	17.8	19.8	20.1	20.8	20.8	17.7	19.3	20.3	20.7	21.9
	P75	19.4	20.9	21.8	22.5	22.7	19.4	20.3	21.8	22.0	23.2
	P90	–	22.4	22.7	24.1	23.3	21.8	21.4	22.9	22.8	25.2
%FM	M ± SD	13.2 ± 3.0	16.7 ± 5.4	16.1 ± 5.3	14.1 ± 5.2	13.2 ± 3.5	15.5 ± 7.6	15.3 ± 4.4	17.0 ± 5.7	14.4 ± 4.6	14.7 ± 5.6
	P10	9.5	11.6	10.0	9.2	8.8	6.3	10.3	9.9	9.2	9.2
	P25	10.7	13.4	12.4	9.7	10.1	10.5	12.6	13.3	11.4	10.2
	P50	12.4	15.3	14.8	13.2	12.5	13.9	14.2	16.2	13.2	14.0
	P75	15.8	18.9	20.0	16.9	15.8	19.5	18.0	20.1	17.1	17.3
	P90	–	25.2	24.0	22.2	18.6	26.1	22.1	24.3	22.1	22.2
Fat-free mass (kg)	M ± SD	42.0 ± 7.9	49.3 ± 6.2	51.7 ± 6.9	59.8 ± 7.2	57.7 ± 6.7	38.0 ± 3.3	46.9 ± 4.2	52.9 ± 4.6	58.4 ± 4.6	65.8 ± 5.1
	P10	30.2	40.2	43.7	50.1	47.8	33.4	40.9	47.1	52.5	58.4
	P25	35.3	46.2	47.2	55.1	53.4	35.6	44.2	49.5	55.6	62.6
	P50	41.7	49.8	51.7	59.6	58.1	38.2	47.2	52.3	58.7	66.0
	P75	48.0	53.7	56.6	64.2	63.2	41.1	49.4	55.4	60.9	70.1
	P90	–	57.7	60.4	70.8	68.4	42.3	52.2	58.4	63.2	73.2

BMI, body mass index; YAPHV, years from age at peak height velocity; %FM, relative fat mass.

12–13.99 years (Coelho e Silva et al., 2010) and 14–15.99 years (Coelho e Silva et al., 2008), the sport practitioners from our sample demonstrated similar results in the HG strength test. Furthermore, the U-16 regional players from our study threw the 2-kg medicine ball (MBT) over a longer distance than did the 14- to 15-year-old players who participated in the 2016 U-16 Portuguese National Team training camp (Arede et al., 2019). It is worth mentioning that the players from our study were 0.9

TABLE 4 | Descriptive statistics (mean ± SD) and reference values (10th, 25th, 50th, 75th, and 90th percentiles) for fitness of young Portuguese male basketball players, according to their age and maturity status.

		Chronological age (years)					YAPHV				
		12	13	14	15	16	−1	0	1	2	3
	N	12	97	75	70	27	18	62	102	71	28
Speed 20-m (s)	M ± SD	3.42 ± 0.19	3.35 ± 0.22	3.30 ± 0.23	3.13 ± 0.12	3.09 ± 0.11	3.42 ± 0.21	3.34 ± 0.25	3.26 ± 0.19	3.14 ± 0.17	3.15 ± 0.13
	P10	–	3.66	3.61	3.31	3.24	3.67	3.69	3.52	3.38	3.31
	P25	3.55	3.48	3.47	3.19	3.14	3.64	3.50	3.38	3.24	3.26
	P50	3.46	3.34	3.27	3.12	3.09	3.47	3.30	3.23	3.12	3.14
	P75	3.27	3.20	3.13	3.04	3.00	3.30	3.15	3.09	3.03	3.04
	P90	3.10	3.06	3.00	3.00	2.91	3.06	3.04	3.03	2.95	2.97
T-Test (s)	M ± SD	10.25 ± 0.47	10.35 ± 0.57	10.28 ± 0.68	9.56 ± 0.49	9.50 ± 0.53	10.54 ± 0.79	10.31 ± 0.63	10.21 ± 0.61	9.67 ± 0.66	9.61 ± 0.53
	P10	–	11.20	11.33	10.16	10.27	11.84	11.21	11.10	10.69	10.46
	P25	10.69	10.68	10.76	9.90	9.82	10.76	10.72	10.64	10.04	9.91
	P50	10.32	10.33	10.16	9.50	9.44	10.47	10.31	10.15	9.57	9.54
	P75	9.77	9.93	9.76	9.10	9.09	10.02	9.83	9.73	9.15	9.21
	P90	9.43	9.62	9.43	9.03	8.84	9.57	9.57	9.47	8.94	9.02
Sum HG (kg)	M ± SD	56.4 ± 18.1	69.1 ± 15.9	71.9 ± 14.0	87.7 ± 13.2	86.2 ± 13.1	52.5 ± 10.3	66.9 ± 12.2	78.1 ± 12.3	83.7 ± 16.3	93.4 ± 12.4
	P10	39.5	51.6	56.9	70.6	68.9	41.2	51.06	63.9	68.1	77.3
	P25	44.0	58.9	63.9	78.0	73.7	44.8	59.3	69.5	76.0	83.4
	P50	54.1	69.2	71.0	86.7	84.2	50.1	65.6	77.8	84.1	92.6
	P75	63.9	78.4	81.3	97.7	96.7	57.7	73.8	84.9	93.0	105.2
	P90	–	91.9	90.4	108.6	107.2	71.6	83.9	95.6	101.7	109.6
MBT (m)	M ± SD	4.25 ± 0.92	4.84 ± 0.72	5.19 ± 0.84	6.13 ± 0.62	6.13 ± 0.72	3.97 ± 0.55	4.75 ± 0.60	5.39 ± 0.55	6.05 ± 0.64	6.49 ± 0.70
	P10	3.30	3.88	4.17	5,31	5.23	3.37	4.09	4.67	5.24	5.39
	P25	3.49	4.36	4.66	5.55	5.55	3.51	4.23	5.09	5.51	6.06
	P50	4.24	4.83	5.23	6.11	6.02	3.75	4.79	5.37	6.02	6.66
	P75	4.66	5.40	5.69	6.61	6.83	4.15	5.11	5.69	6.56	7.03
	P90	–	5.80	6.44	7.04	7.07	4.88	5.73	6.14	6.91	7.28
CMJ height (cm)	M ± SD	30.2 ± 3.1	29.8 ± 5.1	31.7 ± 4.7	33.9 ± 4.4	35.9 ± 4.7	27.8 ± 5.6	30.1 ± 5.0	31.7 ± 4.9	38.8 ± 4.8	33.6 ± 4.7
	P10	25.4	23.18	25.6	27.4	28.5	20.7	23.5	25.5	27.3	26.9
	P25	27.9	26.5	28.1	31.4	31.3	23.6	26.8	28.3	30.8	31.1
	P50	29.8	29.5	31.6	33.9	35.8	28.1	29.9	31.6	33.8	34.2
	P75	32.1	32.7	34.7	37.2	39.4	29.9	32.8	35.0	37.1	37.5
	P90	–	37.05	37.4	39.5	42.0	36.9	36.8	38.8	40.2	38.8
CMJ Power (w/kg)	M ± SD	12.1 ± 0.6	12.0 ± 1.2	12.4 ± 1.0	12.9 ± 0.8	13.3 ± 1.0	11.7 ± 1.1	12.1 ± 1.1	12.4 ± 1.2	12.9 ± 0.9	12.7 ± 0.9
	P10	11.25	10.52	11.13	11.74	11.69	9.94	10.53	11.25	11.5	11.3
	P25	11.74	11.38	11.66	12.46	12.61	10.97	11.39	11.81	12.33	12.30
	P50	12.06	12.10	12.37	13.01	13.38	11.59	12.22	12.34	12.99	12.74
	P75	12.48	12.64	13.14	13.40	14.08	12.14	12.70	13.18	13.51	13.38
	P90	–	13.64	13.75	14.01	14.44	13.82	13.45	14.02	14.14	13.96
CMJ-S Height (cm)	M ± SD	35.3 ± 3.7	35.4 ± 5.8	37.4 ± 5.2	41.3 ± 5.3	43.6 ± 5.5	32.3 ± 5.6	35.9 ± 5.9	37.9 ± 5.4	41.1 ± 6.0	40.4 ± 5.0
	P10	31.2	27.9	30.7	35.0	36.4	24.7	28.8	30.9	32.3	34.1
	P25	31.9	31.2	34.4	38.2	39.3	27.6	31.3	34.7	37.4	37.5
	P50	34.1	34.9	37.2	41.9	42.9	31.8	35.6	37.2	41.2	40.3
	P75	38.6	38.8	40.8	44.9	46.5	36.5	40.0	41.7	45.4	43.4
	P90	–	43.9	42.7	47.1	52.8	39.8	42.8	45.0	47.4	46.6
CMJ-S Power (w/kg)	M ± SD	13.1 ± 0.7	13.1 ± 1.4	13.5 ± 1.0	14.3 ± 0.9	14.7 ± 1.1	12.6 ± 1.2	13.2 ± 1.2	13.6 ± 1.3	14.3 ± 1.1	14.0 ± 0.9
	P10	12.37	11.64	12.16	13.08	13.15	10.85	11.65	12.18	12.63	12.6
	P25	12.55	12.34	13.05	13.81	13.99	11.80	12.30	13.06	13.70	13.34

(Continued)

TABLE 4 | Continued

		Chronological age (years)					YAPHV				
		12	13	14	15	16	−1	0	1	2	3
	N	12	97	75	70	27	18	62	102	71	28
	P50	12.99	13.14	13.50	14.30	14.73	12.54	13.14	13.51	14.19	14.10
	P75	13.57	13.91	14.20	14.94	15.34	13.43	13.96	14.34	15.08	14.56
	P90	–	14.53	14.70	15.37	16.20	14.38	14.55	15.12	15.54	15.08
Sit and Reach	M ± SD	−2.5 ± 8.1	−1.2 ± 7.5	−0.9 ± 8.1	3.6 ± 9.7	6.0 ± 10.0	−3.0 ± 5.8	−2.0 ± 7.6	0.6 ± 7.7	2.2 ± 10.2	5.9 ± 11.5
(cm)	P10	−11.5	−11.0	−11.6	−10.0	−7.4	−11.4	−11.1	−10.5	−13.4	−13.2
	P25	−10.3	−7.8	−7.2	−4.0	−2.1	−7.4	−8.5	−5.0	−5.1	−3.4
	P50	−2.8	−1.0	−2.0	3.0	5.0	−2.1	−2.4	0.8	2.0	6.8
	P75	3.5	3.9	5.0	11.6	14.0	1.1	4.6	5.3	10.0	15.3
	P90	–	8.1	10.9	15.8	21.1	5.5	7.8	11.2	15.3	23.1

CMJ, countermovement jump; CMJ-S, countermovement jump with arm swing; MBT, medicine ball throw; SUM HG, sum of right and left handgrip; TT, T-test; V20-m, 20 m speed test; YAPHV, years from age at peak height velocity.

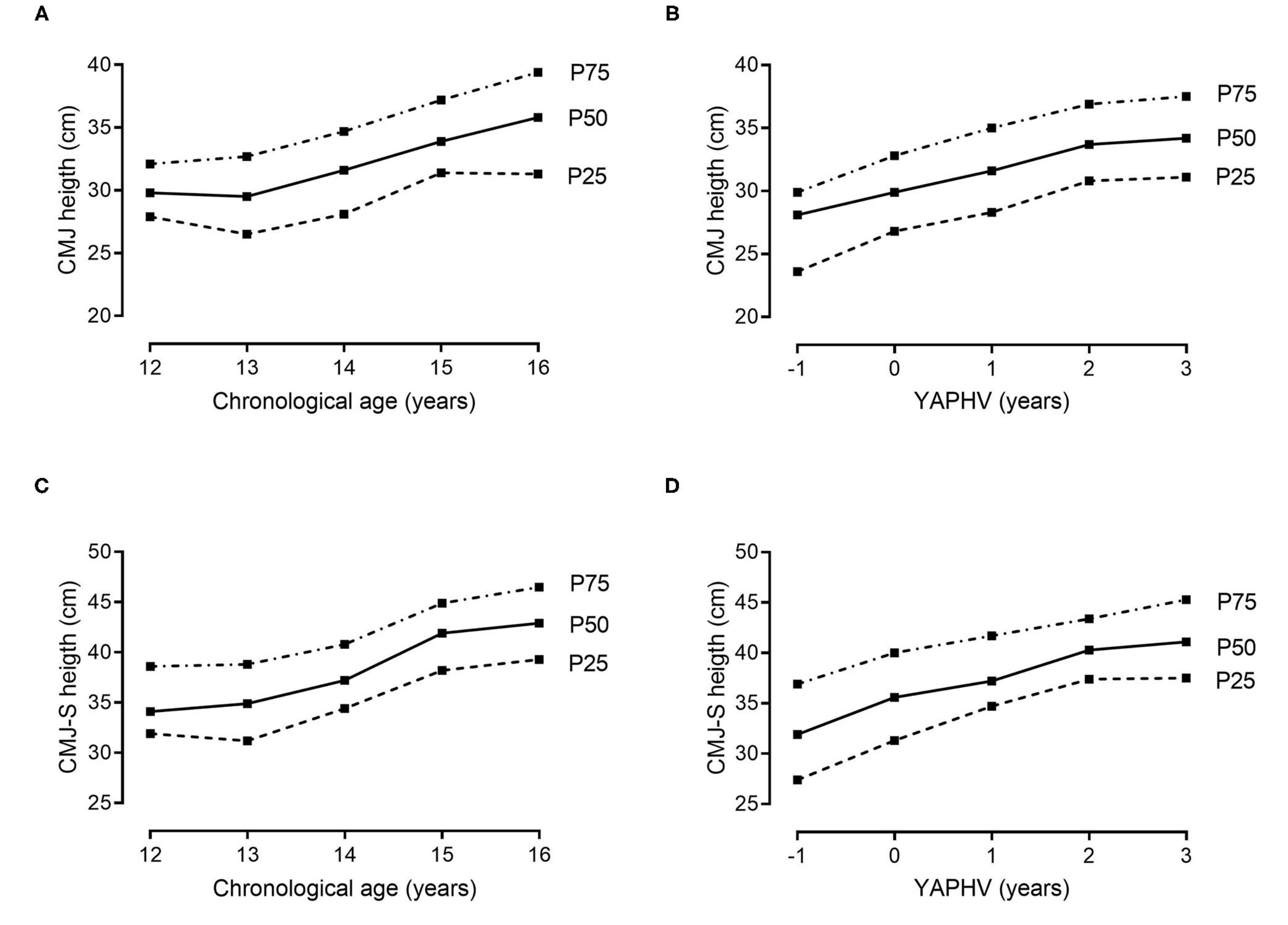

FIGURE 1 | References values (10th, 25th, 50th, 75th and 90th percentiles) for body mass, stature and arm span of young Portuguese male basketball players, according to their chronological age and maturity status.

years ahead of PHV when compared to the players selected for the U-16 Portuguese National Team training camp (Arede et al., 2019), which could have influenced the results. Several studies highlighted the relevance of maturity status for basketball players' upper body strength and power (evaluated by the 2-kg MBT), where more mature players show higher upper body power than

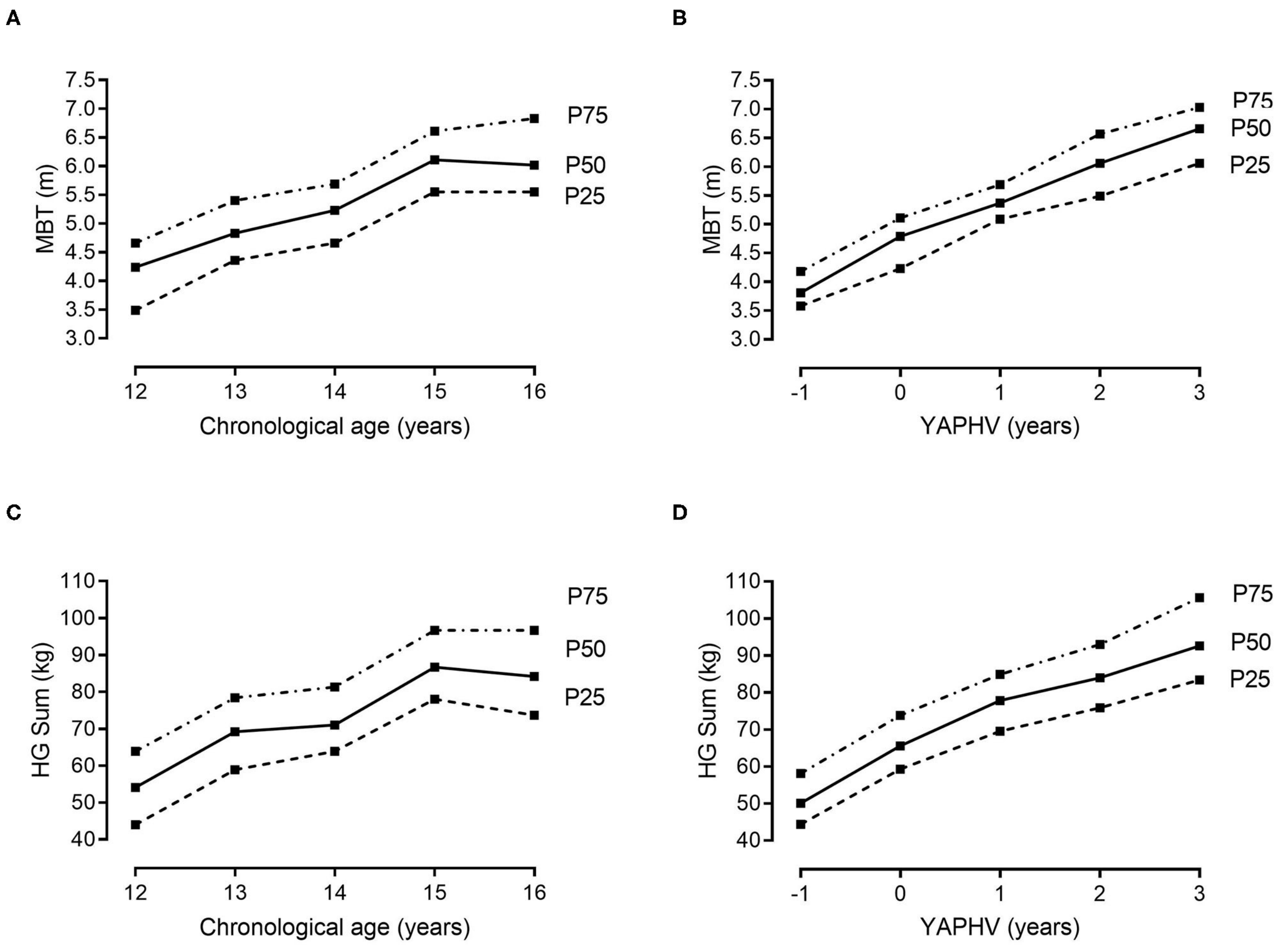

FIGURE 2 | References values (10th, 25th, 50th, 75th and 90th percentiles) for speed and agility of young Portuguese male basketball players, according to their chronological age and maturity status.

less matured players (Coelho e Silva et al., 2008, 2010; Arede et al., 2019).

Jumping ability was singled out as a relevant attribute for basketball performance since vertical jumps are among the most prevalent actions performed by basketball players in both defense (e.g., rebounding and blocking) and offense (e.g., shooting and rebounding) (Ostojic et al., 2006). A previous study of 125 young Australian basketball players revealed significant differences in the vertical jump among players of different skill levels (Hoare, 2000). The best players tended to jump higher when compared to other players (Hoare, 2000). Our results for the CMJ heights of 12- and 13-year-old Portuguese basketball players were similar (12 years, +1.5 cm; 13 years, −1.5 cm) to those presented by Coelho e Silva and colleagues, while our 14- and 15-year-old basketball players jumped less, 1.8 and 4 cm, respectively, than the Portuguese national level players of the same chronological age (Coelho e Silva et al., 2010). These results can be explained by the difference in the players' competitive levels. In our study, the sample consisted of the best Portuguese regional players, while Coelho e Silva et al. (2010) analyzed players from five youth clubs who played at a district level. Another explanation may be related to the time lapse between the data collections and the variations in body size and physical fitness levels due to environmental influences and the trend of increasing body size and faster growth rate described in the special literature (Malina, 1991). Furthermore, our U-16 regional players showed similar results in the CMJ and CMJ-S to the U-16 prepubertal players who participated in the 2016 Portuguese National Team training camp (Arede et al., 2019). These results are interesting since, in our study, the players were 2.04 years to the PHV, while the U-16 prepubertal players were 0.31 years from the PHV, which suggests that the national-level players, who were less mature, may still be improving their jumping ability and will surpass the results presented by the regional players introduced in this study.

Regarding the comparison with international basketball players, our results demonstrated that young Portuguese basketball players had a similar jumping ability to Greek basketball players of the same chronological age (13 years, −0.1 cm; 14 years, −1.2 cm; 15 years, +0.3 cm; 16 years, +0.5 cm) (Kellis et al., 1999). It is worth noting that there

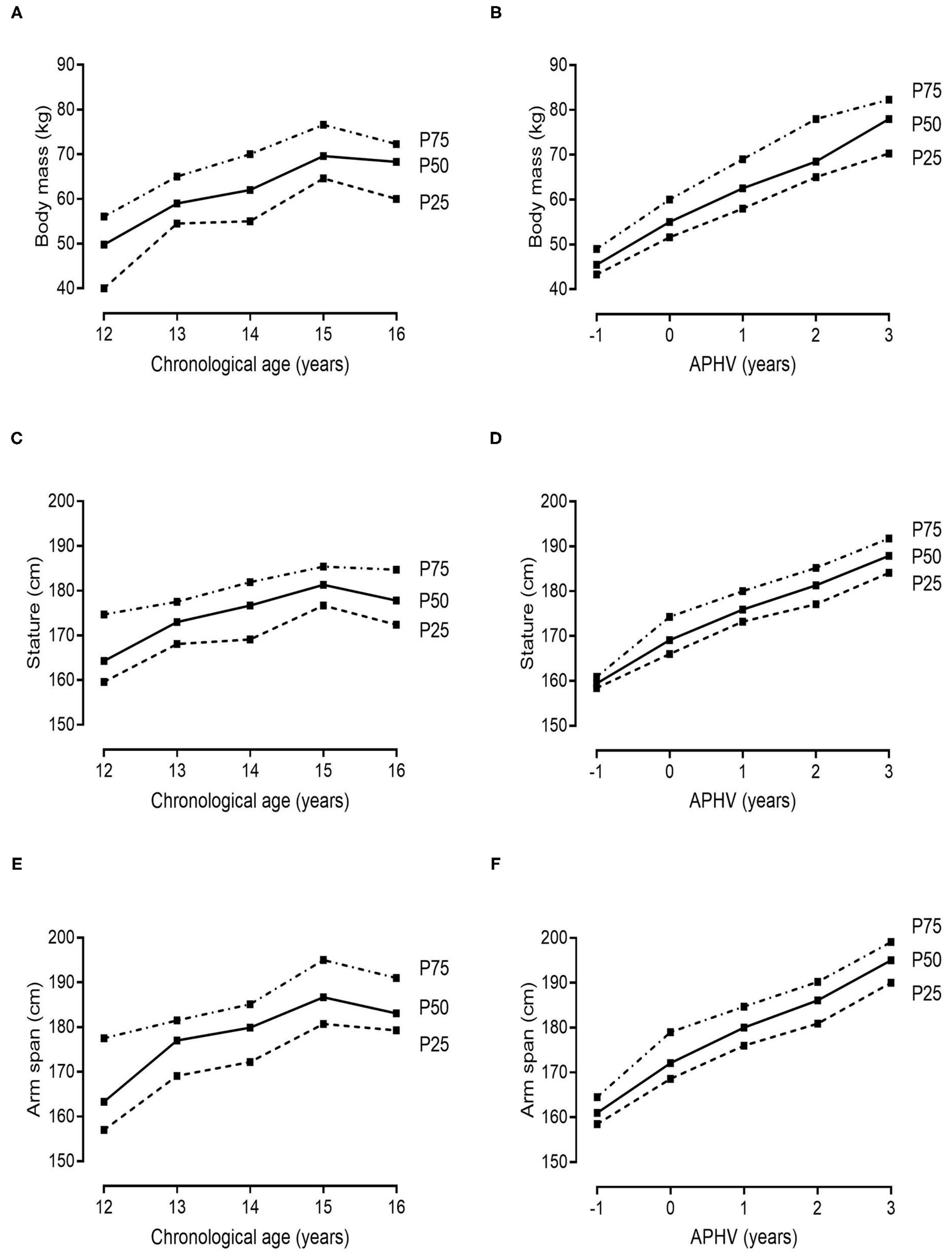

FIGURE 3 | References values (10th, 25th, 50th, 75th and 90th percentiles) for CMJ and CMJ-S height of young Portuguese male basketball players, according to their chronological age and maturity status.

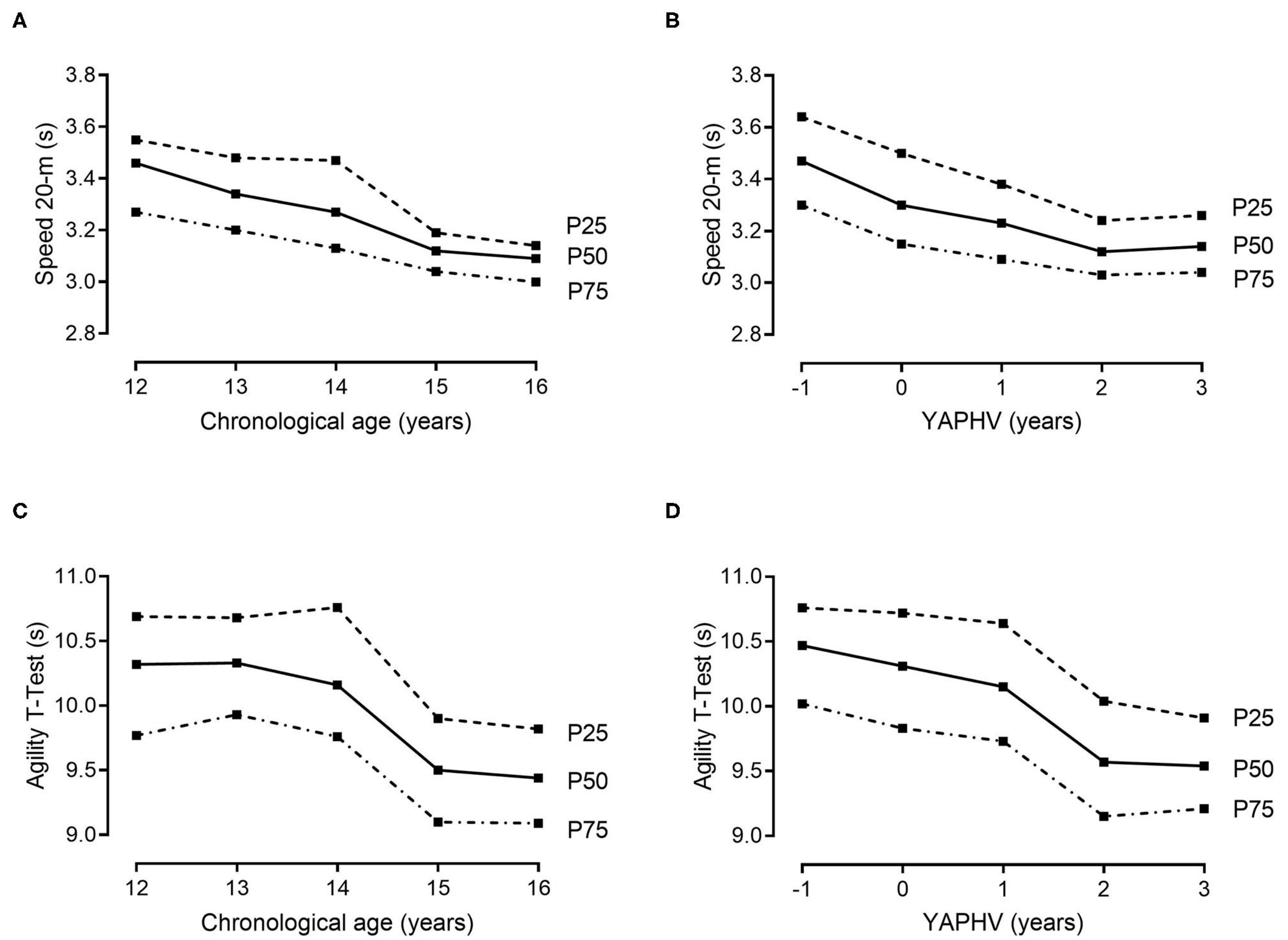

FIGURE 4 | References values (10th, 25th, 50th, 75th and 90th percentiles) for MBT and HG strength of young Portuguese male basketball players, according to their chronological age and maturity status.

is almost a 20-year difference between the two studies, and the differences in strength and power between generations can influence the previous comparison (Kellis et al., 1999). However, when compared to Spanish basketball players, the differences in the jumping height between the two samples increased considerably. On average, 13-year-old Portuguese basketball players jumped less 11.3 cm (Torres-Unda et al., 2013) and 7.6 cm (Torres-Unda et al., 2016) in the CMJ-S test than did elite Spanish players of the same chronological age. An individual's growth and abilities change rapidly during adolescence and can adopt different individual growth ratings over time (Moran et al., 2020). This reinforces the importance of an athlete's categorization in maturity-related groups (i.e., pre-PHV, circa-PHV, and post-PHV) in order to better understand and, if possible, anticipate their physical changes. Children during pre-PHV, due to their neuromuscular plasticity and increased tissue pliability (Eston et al., 2003), can typically recover more quickly from fatigue-inducing resistance training sessions (Faigenbaum et al., 2008) and, consequently, can stand shorter rest intervals during their resistance training programs designed to improve muscle strength and motor control. Furthermore, some young athletes may show "adolescence awkwardness," which typically occurs 6 months before PHV, which can possibly explain the temporary motor skill disruption, such as coordination, movement economy, and, consequently, sports performance. This developmental phenomenon is particularly evident in athletes with an early-onset adolescent growth spurt (Philippaerts et al., 2006; Quatman-Yates et al., 2012), making maturity categorization a positive tool to prevent and explain motor skill irregularities. Additionally, athletes circa-PHV should avoid excessive loadings due to their skeletal fragility and lower motor control patterns, and children during post-PHV should participate in hypertrophy-based resistance training, taking advantage of their body composition growth due to their higher anabolic hormone concentrations and knowledge about resistance training (Lloyd et al., 2014).

To better understand the reasons that lead to the high level of performance in adulthood, it is important to analyze the pathways of young players, aiming to identify the attributes that distinguish young players who were selected at each stage of their long-term development. In this sense, comparing the realities and experiences of different European countries seems quite interesting and useful.

In summary, this study presents specific normative values of Portuguese young basketball players according to their chronological age and maturity status. Having in mind the recent publication of Santos et al. (2014), our findings suggest that basketball players had a bigger body size (between 15.9 cm at 12 years and 7.1 cm at 16 years) than the normal Portuguese population, highlighting the importance of using athlete-specific norms. Moreover, maturity-related growth differences among male adolescent athletes are well-documented in available literature (Malina et al., 2004). During a growth spurt, male athletes of the same chronological age can differ by as much as four or five biological years. This biological difference can result in great physical fitness advantages for early-maturing boys (Coelho e Silva et al., 2008, 2010; Torres-Unda et al., 2013, 2016; Arede et al., 2019, 2021; Ramos et al., 2019, 2020), supporting the need for establishing normative data according to maturity status. Therefore, the identification of performance-related attributes of young basketball players must always consider the different stages of development for each capacity, the individual growth rate, and the average speed of acquisition considering two subsequent periods of development of a particular attribute.

PRACTICAL APPLICATIONS

The present study provides a first for age- and maturity-specific morphological and fitness reference standards for young Portuguese basketball players aged 12–16 years. This characterization is especially useful when used to quantify and control athletes' performance over time. Even though recognizing that the regression equation of Mirwald et al. (2002) may have some limitations, it can also be of great use if complemented with other longitudinal measurements, like stature and leg length. These morphological and fitness references will help: (i) to distinguish the growth and maturation results from training-induced performance; (ii) to detect physical and fitness weaknesses and attributes during growth and contribute to their correction; (iii) to fix realistic and challenging goals for each player in the medium and the long term; (iv) to identify the adolescent awkwardness particularly evident in athletes with an early-onset adolescent growth spurt; (v) to assure that late-maturing players who are technically gifted are not discriminated due to their temporary immaturity; (vi) to guarantee that early-maturing athletes, normally selected for size-related reasons, can have a range of motor skill experiences and specific training volumes adjusted to their advance maturity; (vii) to prescribe shorter rest intervals during resistance training programs to pre-PHV children; (viii) to avoid excessive loadings to circa-PHV children due to their skeletal fragility and lower motor control patterns; and (viiii) to prescribe hypertrophy-based resistance training to children during post-PHV due to their higher anabolic hormone concentrations and knowledge about resistance training.

Therefore, the references presented in this study cannot be a training tool to be used at a precise moment as an individual recommendation, *per se*, but instead, they can be of help when coaches focus on the reliability of frequent measurements of growth (growth tracking) to capture the individual reality over a period of time.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

This study was reviewed and approved by the Ethics Committee of the Faculty of Physical Education and Sport—Universidade Lusófona and was performed according to the Helsinki Declaration. Written informed consent was obtained from all participants for their participation in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Talent Selection Strategies and Relationship With Success in European Basketball National Team Programs

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There is limited knowledge of the talent selection strategies used by national sporting organizations to identify and develop talented players in basketball. Therefore, we aimed to explore differences in selection strategies between European youth basketball national team (NT) programs, and how they relate to the program's success. Specifically, we examined differences in the number of youth NT players and within-country variance in the 1988–1999 generations between 38 countries (*n* men = 38, women = 32). Further, we tested if the number of youth NT players and within-country variance was related to the NTs senior ranking, youth ranking, and youth-to-senior player promotion, using generalized Bayesian multilevel models. We further checked the moderating effect of the amount of licensed basketball players in each country. On average, 15.6 ± 2.0 male and 12.4 ± 1.8 female players were selected per generation. Over a third of the NTs consistently selected a higher or lower number of players than the average, with a difference of 8.1 players (95% CI [5.8, 10.8]) for men and 7.6 players (95% CI [5.4, 10.0]) for women between the countries with the highest and lowest average. When licensed players were used as moderator, the differences decreased but did not disappear, in both genders. There was an above 99.3% probability that a higher number of players was positively related to higher men's senior and youth rankings, and women's youth ranking. Within countries, generations with a higher number of youth players generated more senior players, with a probability of 98.4% on the men's, and 97.3% on the women's side. When licensed players were used as moderator, the probabilities for these relationships remained largely unaffected, apart from women's youth ranking, which sank to 80.5%. In conclusion, the selection strategy in basketball NT programs varies between European countries and selecting a higher number of players possibly relates to better long-term performance and more players promoted to the senior NTs. These findings show that talent development programs should make conscious decisions about their selection strategies as it can affect their success.

Keywords: talent identification, team sport, sport federation, national sporting organizations, youth national team, countries

INTRODUCTION

Nations, through sporting organizations, are making increasingly large investments to achieve sporting success (De Bosscher et al., 2015). An important part is the investment in talent development and pathways to increase the performance at the senior level (De Bosscher and De Rycke, 2017; De Bosscher et al., 2018). In team sports, especially in Europe, one of the main talent development programs organized by the national federations are the youth national team (NT) programs, which aim at developing better senior NT players.

These talent development programs can adopt different strategies aiming to reach their ultimate goal. Previous literature has, for example, contrasted two different strategies (Güllich and Emrich, 2012; Barth et al., 2018). The first – an individualistic approach – is characterized by an early selection of players followed by a long-term development of this particular group resulting in a low turnover of players. The second – a collectivistic approach – is characterized by selecting and de-selecting players throughout the pathway with a higher turnover of players (Güllich and Emrich, 2012; Barth et al., 2018). Earlier research has shown that talent development programs in team sports are generally characterized by a collectivistic approach. In German Olympic sports NT programs, for example, only around half of the involved players remained selected from one season to the next (Güllich and Emrich, 2012). In team sport youth NTs, between a third and a half of the players are de-selected from one season to the next (Barreiros et al., 2012; Güllich, 2014; Wrang et al., 2018).

However, a recent study found that European youth basketball NT programs have a lower turnover of players, with 70–80% re-selected from 1 year to the next (Kalén et al., 2020). Furthermore, another study showed that European senior basketball NT players had played an average of around three youth championships (Kalén et al., 2017). These findings suggest that basketball youth NT programs might use more of an individualistic approach. While these findings suggest a more individualistic approach, no previous study has directly analyzed the characteristics of European youth NT selection strategies. Although several studies have investigated selection strategies in a variety of sports (Güllich, 2014; Barth et al., 2018; Bjørndal et al., 2018), there is little knowledge of how much the selection strategies differ between different programs or countries within the same sport.

While the individualistic and collectivistic approaches are built on different ideas of how talent identification and selection should be made, both aim at maximizing international success by promoting the athletes from the youth program with the best possibility of high performance at the senior level. This allows us to compare the success of different selection strategies. Earlier basketball research has, for example, found a relationship between higher rates of re-selection in youth NT programs and better long-term performance of the senior NT (Kalén et al., 2020). A possible explanation discussed is that higher re-selection rates might be an indication of better organization and clearer strategies within the program, which has been shown to lead to better performance (De Bosscher et al., 2015). It is, therefore, possible that there exists an association between countries' selection strategies and their performance over time.

Further, as the idea behind both more individualistic and more collectivistic approaches is that senior success is created by promoting athletes from the youth program, the selection strategies aim to maximize the number of youth players who reach the senior NT. That is, the number of senior NT players that were selected in the youth NTs is another measure of how successful different selection strategies are. An earlier study has found that players who participated in European senior basketball championships had, on average, played 2.3 and 3.2 youth championships, for men and women, respectively (Kalén et al., 2017). It was also found that better-performing men's teams had a higher number of accumulated youth championships in the rosters (Kalén et al., 2017). It is therefore likely that having players with youth NT experience can help the team's performance. The proportion of youth NT players who reach the senior NT seem to vary significantly between sports and countries. For example, in Portugal, over 50% of youth male volleyball NT players, but only around 35% of the male football players reach the senior NT (Barreiros and Fonseca, 2012). Meanwhile, in German man's football, it has been reported that only 5% of players make the transition from youth to the senior NT (Schroepf and Lames, 2018). While this difference probably can be explained in part by differences in study methodology, it does suggest that there may be differences between different countries in the proportion of players that do reach senior NTs.

One challenge in researching talent selection strategies is to understand to what degree they reflect conscious strategical decisions made by the programs, and to what degree they are the result of factors outside the programs themselves. For example, aspects such as national sport policies, the financial and sporting strength of clubs, the professional status of youth coaches, and the popularity of the sport might very well play an important role in shaping the selection strategies used. It is, however, generally difficult to find reliable measures comparing multiple countries for most of these factors. One measure that is attainable across European countries is the number of licensed players. Although the link between sport participation in a country and success is somewhat complicated (De Bosscher et al., 2015), investigating the moderating effect of the number of licensed players could give an initial indication of how much the strategies might be influenced by factors outside the programs.

Given the differences in selection strategies, both between sports and countries, more detailed studies are needed to better understand selection strategies used in different sports and countries. Further, given the scarce literature, it is of interest to explore how effective different strategies are at generating sporting success. The main purpose of the current study was, therefore, to explore talent strategies used in European basketball NT programs and how they might relate to the success of the NT programs. The specific aims were: (a) Examine if selection strategies for youth NTs differ between countries. (b) Examine if the selection strategy is associated with the success of the NT program. (c) Examine to what degree the number of licensed players in each country moderates the effects for aims (a) and (b). (d) We also aimed to evaluate the senior NT debut age and the proportion of senior NT players that have played in the youth NTs.

MATERIALS AND METHODS

The current study consists of retrospective analyses of register data on participation in basketball championships for players from European countries. We used official data on players' NT participations, NT rankings, and number of licensed players in the countries. The participation data was registered by the organizing committee of each competition in the official competition system used during the championships. The ranking points are calculated by the International Basketball Federation based on the official final game results and is used for seeding in future championships. The number of licensed players was self-reported by each national basketball federation. All data was obtained from the official website of the International Basketball Federation (FIBA; fiba.com). The analyses were performed separately for men and women. An overview of the study can be seen in **Figure 1**.

Sample

For the analysis of differences in selection strategy and its effect on country ranking, the participation history of all players from the 1988 to 1999 generations, that had played at least one youth championship was used – corresponding to championships played 2004–2019. We refer to a generation as all players born in the same calendar year (i.e., players born 1988 comprise one generation, 1989 another, etc.). On the men's side, 6619 players, from 38 countries and 408 country-generation combinations were included. On the women's side, 4,433 players from 38 countries and 254 country-generation combinations were included. Only players from countries in which a minimum of five of the twelve generations participated in youth championships were included.

For the analysis of selection strategy effect on the number of youth NT players that reach the senior NT, we included only players born 1988–1995. This subsample consisted of 4,389 male players from 269 country-generation combinations and 2,932 female players from 232 country-generation combinations. We chose this subsample as all players born 1995 and earlier had reached age 25 in the last included season (2019). Using age 25 as a cut-off for having made senior debut allowed us to conclusively classify all included players as either having reached the senior NT or not, in line with earlier studies (Wrang et al., 2018). Furthermore, the senior debut analysis confirms that 89–90% of senior NT players that played youth NT had debuted at age 25 (see section 3.4), supporting the soundness of the cut-off.

For the analysis of the proportion of senior NT players with youth NT experience and their senior debut age, the participation history of all players who had participated in a senior NT

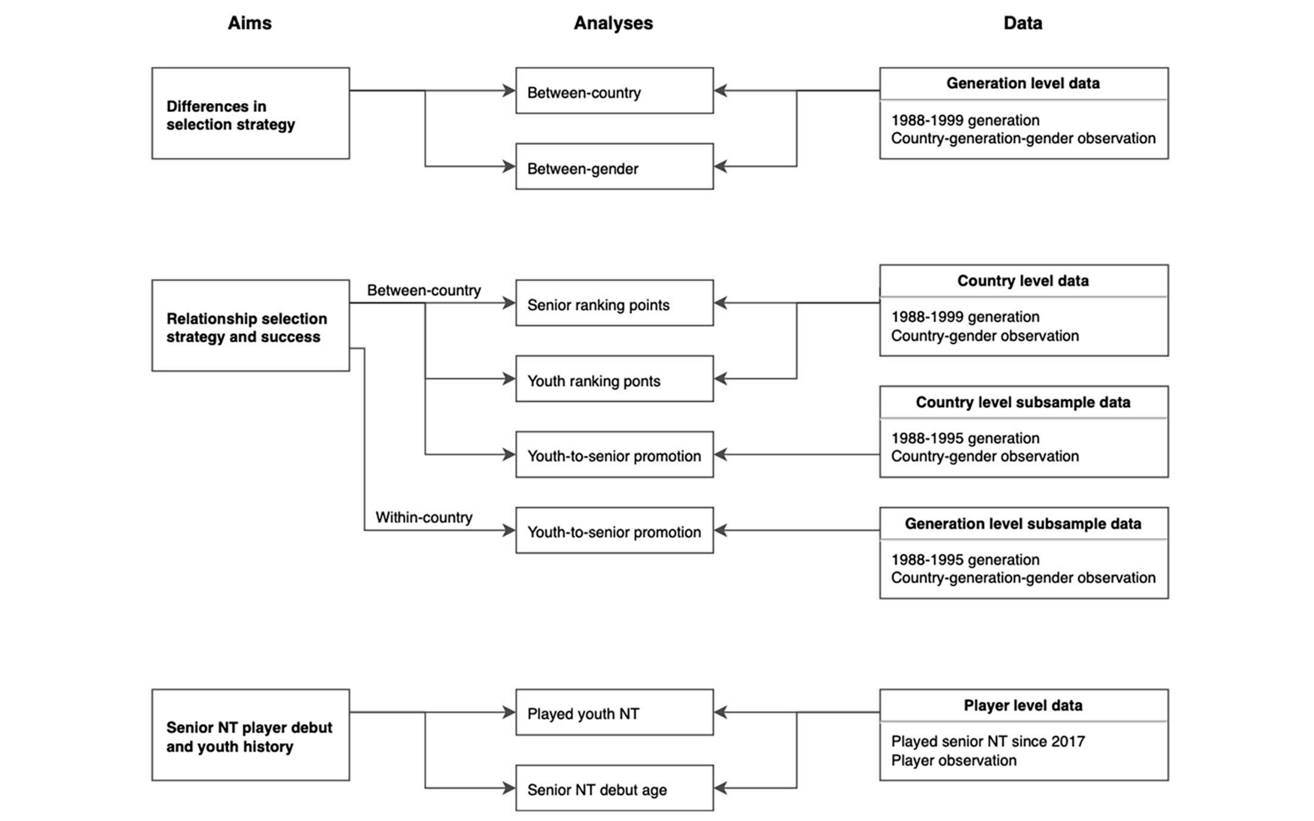

FIGURE 1 | Flowchart of aims, analyses, and data of the study.

championship since 2017 was used. On the men's side, 348 players who had participated in the 2019 World Cup or 2017 Eurobasket were included. On the women's side, 293 players who had participated in the 2019 Eurobasket, 2018 World Cup, or 2017 Eurobasket were included.

Variables

To quantify the selection strategy, we first counted the number of players that had played at least one youth championship in each generation and country (Nr Youth Players). For each country, we then calculated the average number of youth NT players per generation, as well as the coefficient of variation (CV) between the generations. The CV was expressed as the percentage of the mean and calculated as 100 × country standard deviation/country mean.

Based on the goals of talent programs discussed in the introduction, we used three different measures of NT program success: (1) senior ranking points, which indicates how well the senior NT has performed over time; (2) youth ranking points, which indicates how well the youth NTs have performed over time; and (3) the number of youth NT players that reach the senior NT, indicating how successful the youth NT program is at promoting players to the senior NT (youth-to-senior NT promotion).

Both the senior and youth ranking points are calculated by FIBA based on the NT performance over the last eight seasons and are calculated separately for men and women. The senior ranking points are based on the results in the senior European and World Championships (Eurobasket and World Cup), as well as the respective qualifications. The youth ranking points are based on the performance in the annual U16, U18, and U20 European Youth Championships, as well as the biennial U17 and U19 World Youth Championships. The rankings were transformed to a 0–1 range, where 1 represents the maximum number of ranking points attainable. The ranking was further transformed using the formula (ranking $\times$ (n − 1) + 0.5)/n, as beta regressions cannot handle 0's in the outcome variable (Smithson and Verkuilen, 2006).

To quantify the youth-to-senior promotion success, we counted the number of players in each of the 1988–1995 generations that had played at least one youth championship and one official game with the senior NT before or at the age of 25 (Nr Senior Players). For each country, we then calculated the average number of youth-to-senior NT players per generation.

We used the reported number of licensed basketball players for each gender in the country as a potential moderating variable on the relationship between programs' strategy and success. Visual inspection of the data revealed the number of licensed players per country to be approximately log normal. It was, therefore, transformed using a natural logarithmic transformation to avoid problem with skewness.

For the analysis of the proportion of senior NT players with youth NT experience and their senior debut age, we classified players as "played youth" or "senior only", depending on if they had participated in at least one youth championship or not. The players' senior debut age was calculated by subtracting their birth year from the year in which they played their first official senior NT game (championship or championship qualification).

Analysis

To analyze the difference in selection strategy between countries, as well as the general difference between genders, we fitted a Bayesian linear multilevel model (Gelman and Hill, 2007), with nr youth players as the outcome, using generation level data. The model included a gender effect, and generations were nested within country. The posterior predictive distribution of specific countries' means and CV of nr youth players were compared to the overall mean and CV within each gender to determine which countries had a diverging selection strategy diverging. CV was computed by dividing the estimated standard deviation by the estimated mean within each posterior draw. Further, the posterior predictive distribution of the difference between the country with the highest and lowest number of players, as well as between genders were estimated. A moderator model was fitted by updating the original model with a separate effect for the number of licensed players within each gender. This allowed us to test to what degree potential differences in selection strategies are driven by the number of licensed players in each country.

To analyze the effect of selection strategy on the senior and youth ranking points, we fitted a multivariate Bayesian beta regression (Smithson and Verkuilen, 2006), with the senior and youth ranking points of each country as outcomes, using country-level data. We used a beta-regression as the ranking points have a lower and upper bound, restricting the potential values. The model included an effect for gender, as well as separate effects for mean and CV of nr youth players within each gender. A moderator model was fitted by updating the original model with an effect for the number of licensed players within each gender. This allowed us to test to what degree the relationship between selection strategy and country ranking is explained by the number of licensed players in each country. We present the posterior predictive distribution of the relationship visually, together with the observed values for each country.

We analyzed the effect of selection strategy on youth-to-senior NT promotion success in two ways: a between-country analysis (in line with the ranking points analysis), and a within-country analysis of how nr youth players in each generation affect the nr senior players from that generation. For the first one, we fitted a Bayesian linear regression (Gelman and Hill, 2007), with the standardized mean nr senior players as the outcome, using country-level data. The model included an effect for gender, as well as separate effects mean and CV of nr youth players within each gender. For the second, we fitted a Bayesian Poisson multilevel regression (Gelman and Hill, 2007), with nr senior players as the outcome, using generation level data. We used a Poisson regression as nr senior players is a count variable. Generations were nested within country, and the model included an effect for gender, as well as a separate effect for nr youth players for each gender. For both models, a moderator model was fitted by updating the original model with effects for the number of licensed players and senior ranking points within each gender. This allowed us to test to what degree the relationship between selection strategy and nr senior players is explained by the number of licensed players in each country and the countries long-term performance. We present the posterior predictive distribution of the relationship visually, together with the observed values for each country in the country-level analysis, and posterior prediction for each country in the within-country analysis.

All analyses were performed in R 4.0.3 and models were fitted in STAN using the brms package (Bürkner, 2017). As we did not possess strong prior subject knowledge, we used weakly informative priors in all models to only provide slight regularization and, therefore, avoid overconfidence in the results. The models were estimated using a Hamiltonian Monte Carlo algorithm with four chains, each with 5,000 warm-up and 5,000 sampling iterations. No models showed any divergent transitions and the maximal $\widehat{R}$ value was 1.0015 across all models (Betancourt and Girolami, 2015). Models were compared with their respective moderator model using the relative approximate leave-one-out cross-validation (ELDP loo), where the model with the value further from zero show worst predictive performance (Vehtari et al., 2017). Compatibility intervals (CI) were calculated using the highest-density intervals. The interpretation of, for example, the 95% CI is that there is a 95% probability that the value falls within this range. Furthermore, the probability of direction (PD) was calculated for the effects. The PD provides an estimate between 0.5 and 1 indicating the probability of the effect being positive for positive effects and negative for negative effects. For example, PD = 0.5 indicates an equal probability that the effect is positive or negative, while PD > 0.999 indicates that the effect is almost certain (Makowski et al., 2019). The datasets analyzed and the software for this study can be found in the Open Science Framework repository https://doi.org/10.17605/OSF.IO/ZHVDS.

RESULTS

Descriptive statistics for each country can be found in **Supplementary Tables 1, 2**, for men and women, respectively.

Selection Strategy

The average number (and standard deviation) of players that had played youth championship per generation is presented for each country and gender in **Figure 2**. To test for the potential influence of the number of basketball players in each country, a multilevel regression model with the number of licensed players as moderator was used. The moderator model showed marginally

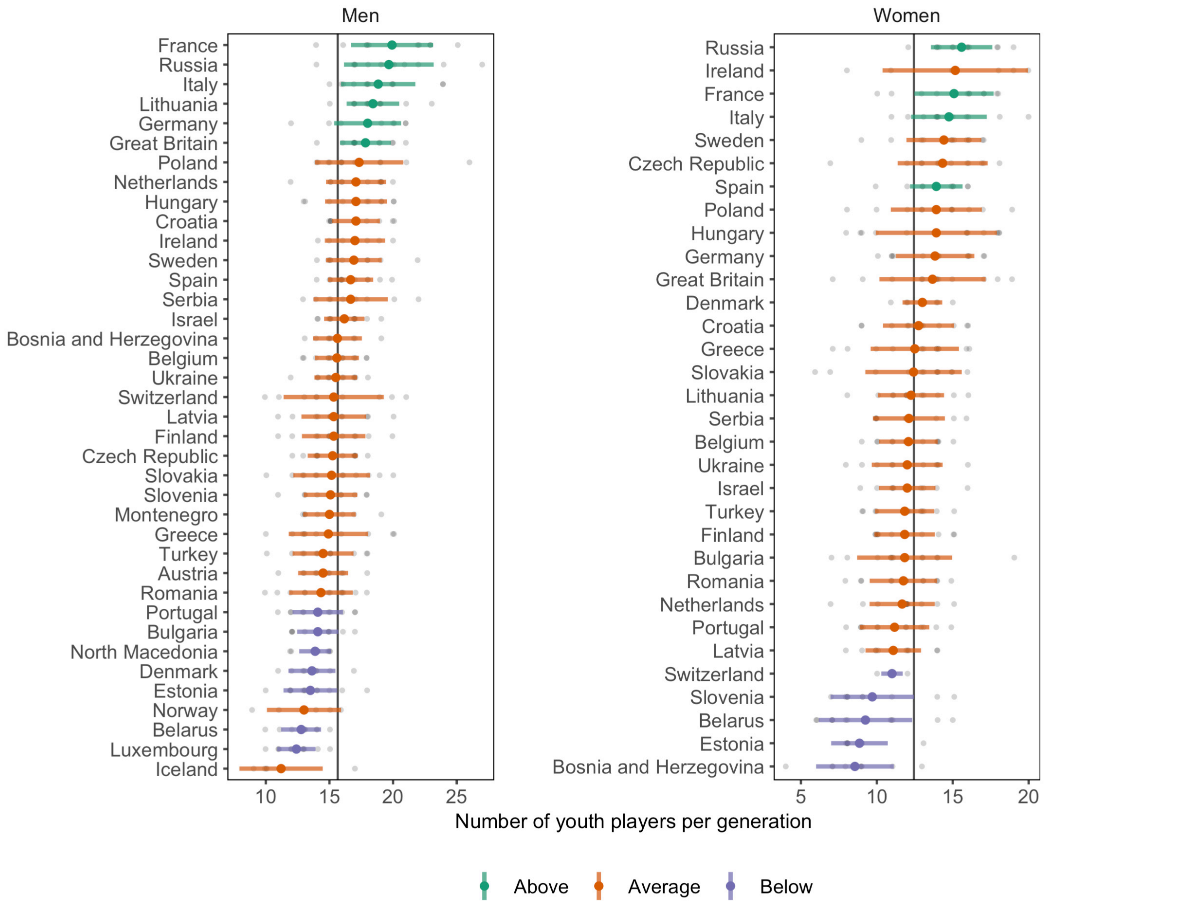

FIGURE 2 | Average number of youth players per generation for each country, with colors indicating differences from overall average.

better predictive performance (ELDP diff = −4.1, SE = 2.8). The posterior predicted distribution and observed values of the relationship between the number of licensed players, on a log scale, and the average number of players per generation is shown in **Figure 3**.

On the men's side, countries had an average of 15.6 ± 2.0 players per generation that had played youth championships, ranging from 11.2 to 19.9 players. The average CV for the number of players between generations within each country was 15.0 ± 4.3%, ranging from 9.0 to 29.2%. The median number of reported licensed male players per country was 11,651 (IQR = 3,411–25,360), ranging from 540 to 546,632.

Six countries had a higher, and seven a lower-than-average number of players per generation (PD > 0.950), indicated by color in **Figure 2**. When the number of licensed players was used as moderator, two countries had a higher, and two had a lower-than-average number of players per generation. The estimated difference between the highest and lowest countries was 8.1 players (95% CI [5.8, 10.8]), and in the moderation model for the number of licensed players 6.9 players (95% CI [4.6, 9.5]). No country differs from the overall average CV. In the moderation model one country showed a lower-than-average CV.

On the women's side, countries had an average of 12.4 ± 1.8 players per generation that had played youth championships, ranging from 8.6 to 15.6 players. The average CV for number of players between generations within each country was 20.1 ± 6.1%, ranging from 6.4 to 33.3%. The median number of reported licensed female players per country was 5,221 (IQR = 2,099–11,158), ranging from 425 to 332,555.

Five countries had a higher, and five a lower-than-average number of players per generation (PD > 0.950), indicated by color in **Figure 2**. When the number of licensed players was used as moderator, one country had a higher-than-average number of players per generation, and no country a lower. The estimated difference between the highest and lowest countries was 7.6 players (95% CI [5.4, 10.0]), and in the moderation model for the number of licensed players 6.2 players (95% CI [4.1, 8.6]). Two countries had a below-average CV, with no change in the moderation models.

There was an average of 3.2 more male than female players per generation, 95% CI [2.7, 3.8]. The within-country variation was 5.1 percentage points lower in men compared to women, 95% CI [1.9, 8.3 points]. When the number of licensed players was used as moderator, the difference in the average number of players diminished to 2.9, 95% CI [2.2, 3.5], and the difference in within-country variation remained largely unaffected (4.7, 95% CI [1.3, 8.0]).

Selection Strategy and Country Ranking

Result for the relationship between countries' selection and ranking points, together with the moderating effect of nr licensed players is shown in **Table 1**. The moderator model did not show better predictive performance (ELDP diff = −5.0, SE = 5.8). The relationship between the average number of youth players per generation and ranking points is shown in **Figure 4**.

On the men's side, a higher number of youth players per generation positively related to both senior and youth ranking (PD > 0.999 and PD = 0.998). When the number of licensed players was used as moderator the positive relations held (PD = 0.989 for senior; PD = 0.968 for youth). On the women's side, a higher number of youth players per generation positively related to both senior and youth ranking with a probability of 0.907 and 0.993, respectively. However, when licensed players were used as moderator the positive relations became weaker (PD = 0.706 for senior; PD = 0.805 for youth).

There was a 0.873 probability that a higher CV related to lower youth ranking points on the women's side. When the number of licensed players was used as moderator this relation decreased

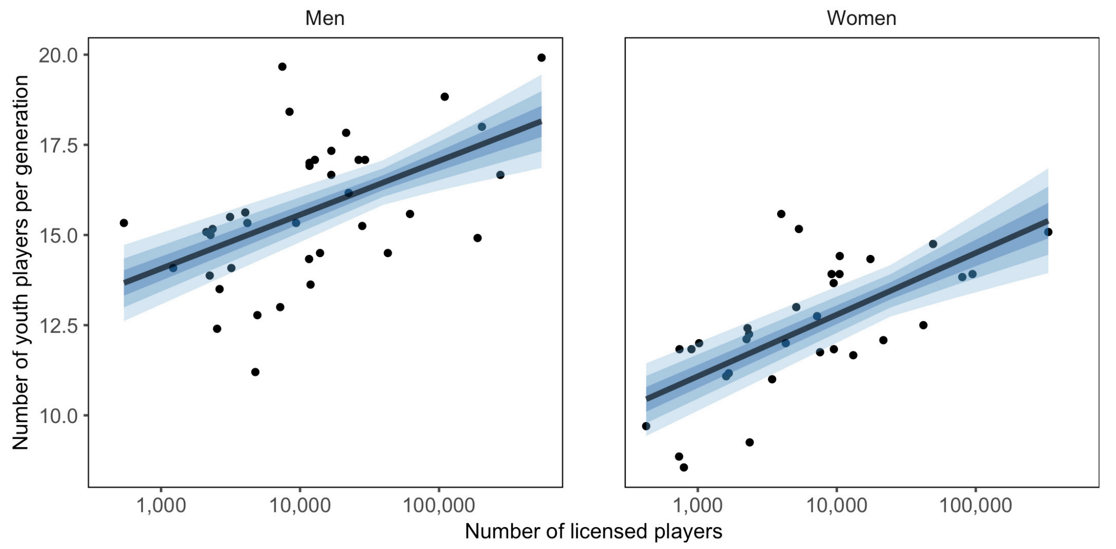

FIGURE 3 | Relationship between countries' reported number of licensed players (on log scale) and mean number of youth players per generation, with 50, 80, and 95% CI of posterior predicted distribution.

TABLE 1 | Multivariate Beta-regression estimates for influence of countries' mean and CV of youth players per generation on youth and senior ranking points.

	Model			Moderator model		
	Est	95% CI	PD	Est	95% CI	PD
Senior ranking						
Men						
Intercept	−0.98	[−1.30, −0.65]	>0.999	−1.09	[−1.43, −0.77]	>0.999
Mean nr youth players	0.58	[0.27, 0.86]	>0.999	0.41	[0.05, 0.75]	0.989
CV nr youth players	0.06	[−0.27, 0.39]	0.646	0.04	[−0.28, 0.35]	0.603
Nr licensed players				0.38	[−0.03, 0.76]	0.969
Phi	2.06	[1.60, 2.49]		2.15	[1.69, 2.59]	
Women						
Gender	0.28	[−0.23, 0.78]	0.859	−0.06	[−0.68, 0.55]	0.577
Mean nr youth players	0.27	[−0.15, 0.65]	0.907	−0.13	[−0.64, 0.34]	0.706
CV nr youth players	−0.04	[−0.31, 0.22]	0.624	0.03	[−0.23, 0.27]	0.579
Nr licensed players				0.63	[0.12, 1.13]	0.992
Phi	1.90	[1.41, 2.38]		2.08	[1.58, 2.56]	
Youth ranking						
Men						
Intercept	−2.55	[−3.10, −2.01]	>0.999	−2.67	[−3.26, −2.11]	>0.999
Mean nr youth players	0.61	[0.21, 1.02]	0.998	0.46	[−0.02, 0.95]	0.968
CV nr youth players	−0.05	[−0.48, 0.35]	0.589	−0.06	[−0.47, 0.35]	0.599
Nr licensed players				0.34	[−0.25, 0.94]	0.869
Phi	1.77	[1.25, 2.27]		1.82	[1.30, 2.34]	
Women						
Gender	1.08	[0.36, 1.78]	0.999	0.66	[−0.19, 1.48]	0.940
Mean nr youth players	0.64	[0.13, 1.16]	0.993	0.27	[−0.36, 0.86]	0.805
CV nr youth players	−0.17	[−0.47, 0.12]	0.873	−0.13	[−0.41, 0.17]	0.800
Nr licensed players				0.77	[0.20, 1.34]	0.994
Phi	1.83	[1.27, 2.35]		2.09	[1.50, 2.64]	
Relative model performance						
ELDP diff (SE)	−5.0 (5.8)			0		

CV: coefficient of variation; ELDP diff: relative approximate leave-one-out cross-validation; SE: standard error; CI: compatibility interval; PD: probability of direction.

(PD = 0.800). There was a < 0.650 probability of relationships between the CV and the men's and women's senior ranking, as well as men's youth ranking, both with and without including moderation effect for the number of licensed players.

Selection Strategy and Youth-to-Senior NT Promotion

Results for the relationship between countries' selection strategies and the youth-to-senior promotion, together with the moderating effect of nr licensed players and senior ranking is shown in **Table 2**. The moderator model showed a considerably better predictive performance (ELDP diff = −165.3, SE = 4.3). The relationship between the average number of youth players per generation and amount of youth players that had debuted with the senior NT at age 25 per generation is shown in **Figure 5**.

On the men's side, a higher number of youth players per generation was possibly related to a higher number of players reaching the senior NT (PD = 0.833). However, when licensed players and senior ranking were used as moderators, the probability of a positive relationship decreased (PD = 0.706). On the women's side, a higher number of youth players was possibly related to a lower number of players reaching the senior NT (PD = 0.833). However, when licensed players and senior ranking were used as moderators, the probability of a negative relationship decreased (PD = 0.738). The probability of the relationship between the CV and the number of players reaching the senior NT was ≤ 0.800 for both genders, both with and without including moderation effect for the number of licensed players and senior ranking.

Results for the within-country relationship between a generation's number of youth players and the youth-to-senior promotion, together with the moderating effect of nr licensed players and senior ranking is shown in **Table 3**. The moderator model showed a considerably better predictive performance (ELDP diff = −1,368.1, SE = 19.6). The relationship between a generation's number of youth players and the number of them that had debuted with the senior NT at age 25 is shown in **Figure 6**.

On both the men's and women's side, a higher number of youth players in a generation was related to a higher number of the youth players reaching the senior NT for both men and women (men PD = 0.984; women PD = 0.973). When licensed players and senior ranking were used as moderators, the

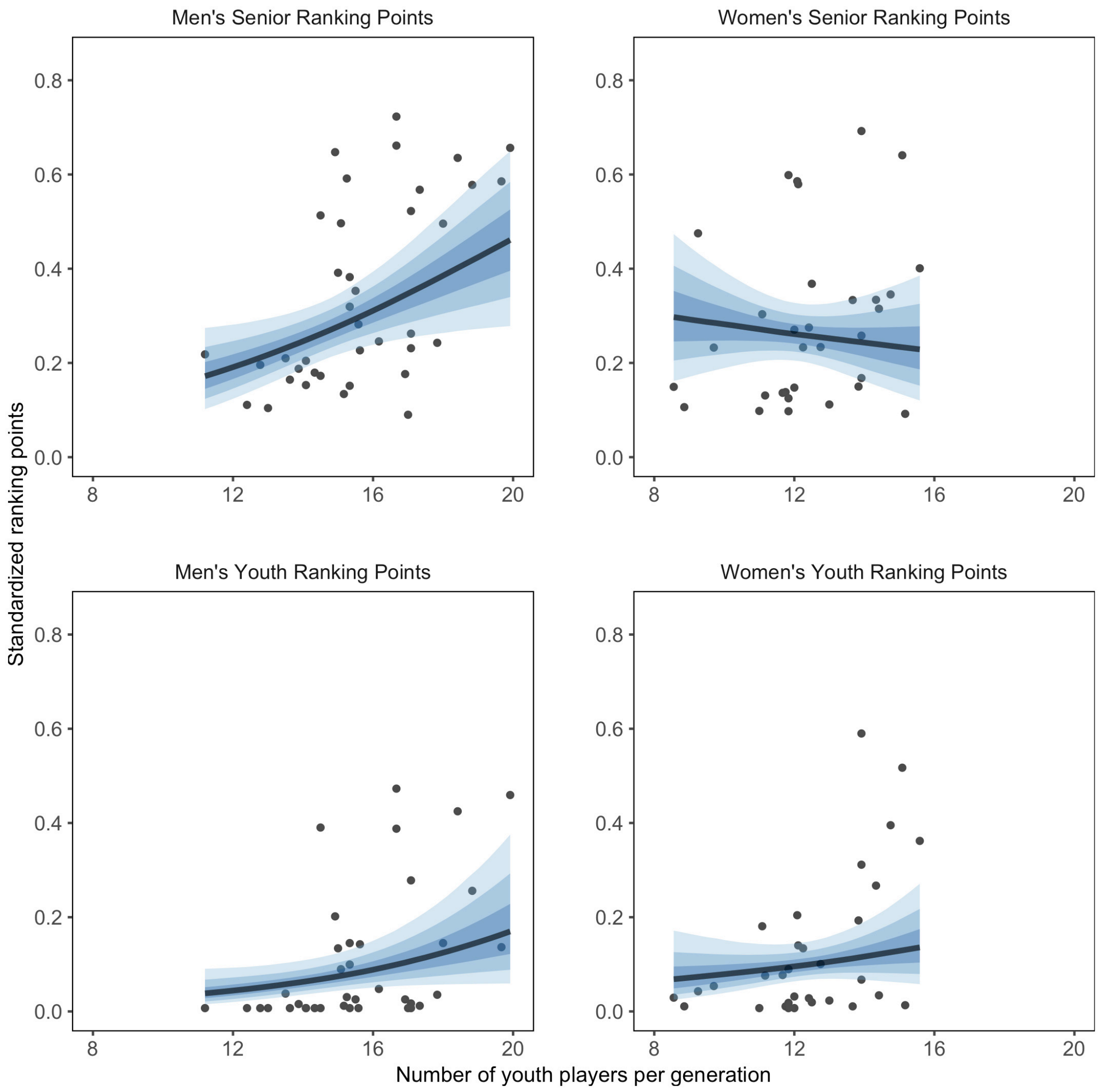

FIGURE 4 | Relationship between countries' mean number of youth players per generation and ranking points controlled for number of licensed players, with 50, 80, and 95% CI of posterior predicted distribution.

probability of a positive relationship increased (men PD = 0.989; women PD = 0.992).

Senior Debut

In the last two men's senior championships, 303 of the 348 (87%) participating players had played in the youth NTs. The median senior debut age was 22 years (IQR = 20–24 years) for players who had played in youth NTs, and 25 years (IQL = 24–27 years) for players without youth NT experience. Of the players that had played in youth NTs, 269 (89%) had debuted at age 25. The distribution of debut age is shown in **Figure 7**.

In the last three women's senior championships, 268 of the 293 (91%) participating players had played in the youth NTs. The median senior debut age was 20 years (IQR = 19–23 years) for players who had played in youth NTs, and 26 years (IQL = 23–27 years) for players who only had played in the senior NT. Of the players that had played in youth NTs, 243 (91%) had debuted at age 25. The distribution of debut age is shown in **Figure 7**.

DISCUSSION

In this study, we aimed to explore differences in selection strategies between youth basketball NT programs of European countries, and how they relate to the programs' success. The main findings of this study were: (a) countries select an average of 15.6 males and 12.4 female players per generation, with individual generations differing 15.4% from the male, and 20.1% from female average; (b) countries differed considerably between each other in the average number of youth players selected per generation, but with great similarities in amount of variations between generations; (c) higher number of

TABLE 2 | Linear regression estimates for influence of countries' mean and CV of youth players per generation on mean number of youth players that reach senior.

	Model			Moderator Model		
	Est	**95% CI**	**PD**	**Est**	**95% CI**	**PD**
Men						
Intercept	1.89	[1.58, 2.21]	>0.999	1.86	[1.35, 2.38]	>0.999
Mean nr youth players	0.13	[−0.14, 0.40]	0.833	0.09	[−0.26, 0.44]	0.706
CV nr youth players	−0.14	[−0.46, 0.19]	0.800	−0.13	[−0.48, 0.19]	0.776
Nr licensed players				0.06	[−0.37, 0.48]	0.618
Senior ranking				0.06	[−1.47, 1.55]	0.530
Women						
Gender	−0.03	[−0.53, 0.49]	0.544	0.21	[−0.60, 1.05]	0.690
Mean nr youth players	−0.20	[−0.63, 0.21]	0.833	−0.17	[−0.71, 0.37]	0.738
CV nr youth players	0.07	[−0.19, 0.32]	0.705	0.07	[−0.20, 0.34]	0.712
Nr licensed players				0.03	[−0.53, 0.56]	0.551
Senior ranking				−0.70	[−2.34, 0.95]	0.804
Residuals						
Sigma	0.74	[0.61, 0.87]		0.75	[0.62, 0.89]	
Relative model performance						
ELDP diff (SE)	−165.3 (4.3)			0		

CV: coefficient of variation; ELDP diff: relative approximate leave-one-out cross-validation; SE: standard error; CI: compatibility interval; PD: probability of direction.

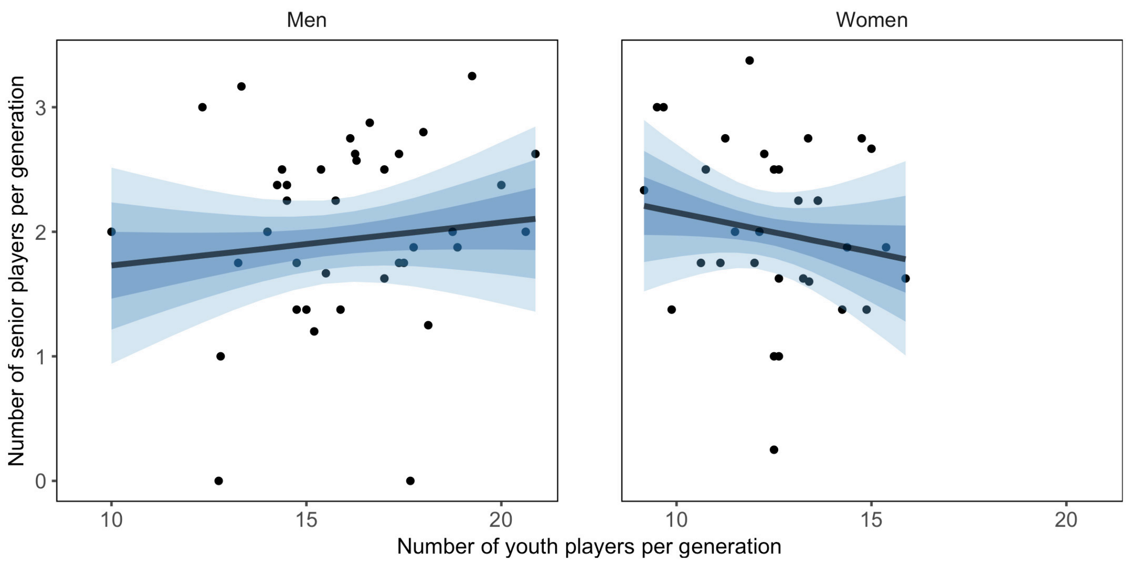

FIGURE 5 | Relationship between countries' average number of youth players per generation and the number of players that reach senior controlled for number of licensed players, with 50, 80, and 95% CI of posterior predicted distribution.

youth players per generation was related with a better youth and senior NT ranking in both genders; (d) there was no clear relationship between the within-country variation and NT ranking; (e) within countries, generations with a higher number of selected youth players had a higher youth-to senior NT promotion; and (f) the number of licensed basketball players in each country explain part of, but not all of the difference in selection strategies and its effect on the performance.

The talent identification process has been widely studied in individual and team sports (Johnston et al., 2018; Till and Baker, 2020; Williams et al., 2020). Specifically, basketball studies concluded that motor abilities (Erčulj et al., 2010) and maturational status (te Wierike et al., 2015; Arede et al., 2019b, 2020) play an important role in players' selection process and the progress of their careers. The present study revealed that the average number of players who participated in youth championships per generation was around 16 players in the men's category and 12 in the female's category. As the NT consists of 12 players per tournament, the generally most used strategy seems to be leaning toward being more individualistic than in earlier studies in other

TABLE 3 | Multilevel Poisson regression estimates for within-country influence of number of youth players on number of players that reach senior per generation.

	Model			Moderator Model		
	Est	**95% CI**	**PD**	**Est**	**95% CI**	**PD**
Men						
Intercept	0.64	[0.52, 0.77]	>0.999	0.73	[0.50, 0.95]	>0.999
Nr youth players	0.12	[0.01, 0.22]	0.984	0.13	[0.02, 0.24]	0.989
Nr licensed players				0.02	[−0.16, 0.20]	0.602
Senior ranking				−0.32	[−0.98, 0.34]	0.836
Women						
Gender	0.10	[−0.07, 0.28]	0.878	0.13	[−0.19, 0.46]	0.792
Nr youth players	0.12	[0.00, 0.23]	0.973	0.15	[0.02, 0.27]	0.992
Nr licensed players				−0.11	[−0.29, 0.09]	0.865
Senior ranking				−0.30	[−1.03, 0.45]	0.791
Random effects						
Sigma intercept	0.17	[0.02, 0.29]		0.17	[0.02, 0.29]	
Sigma nr youth players	0.08	[0.00, 0.18]		0.08	[0.00, 0.18]	
Relative model performance						
ELDP diff	−1368.1 (19.6)			0		

CV: coefficient of variation; ELDP diff: relative approximate leave-one-out cross-validation; SE: standard error; CI: compatibility interval; PD: probability of direction.

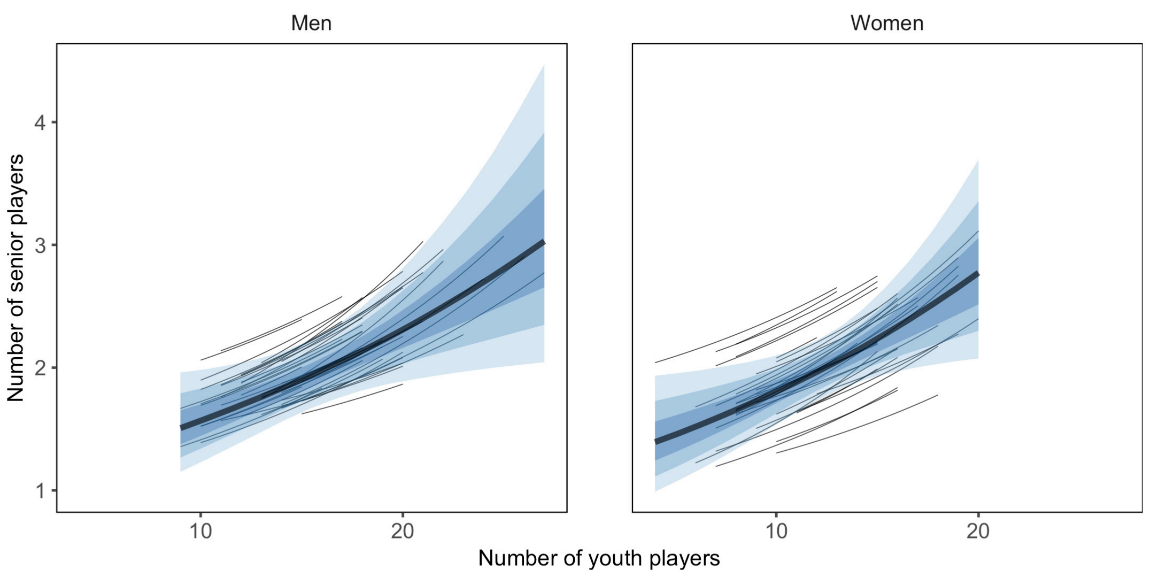

FIGURE 6 | Within-country relationship between number of youth players and number of players that reach senior in a generation controlled for number of licensed players and senior ranking, with 50, 80, and 95% CI of posterior predicted distribution. Lines indicate posterior prediction for each country.

sports (Güllich and Emrich, 2012; Barth et al., 2018). Similar differences between sports have been found when studying the number of players re-selected from 1 year to the next, where the re-selection was much higher in European NT basketball than in both German and Portuguese football (Barreiros and Fonseca, 2012; Güllich, 2014; Kalén et al., 2020). These observed differences between sports could probably be related to the sport's popularity within specific countries, which might increase the number of licensed players in these sports and, consequently, the number of players available to be selected.

When comparing selection strategies between countries, we found a considerable amount of variation in the average amount of players selected per generation. When controlling for the effect of number of licensed players, the variation decreased but did not disappear. This suggests that although some of the differences in the number of players selected seem to be explained by the number of players the NTs have available to select from, there are still considerable differences in selection strategies. This is, to our knowledge, the first study of differences in selection strategies between countries in team sports. However, it is in line with De Bosscher and De Rycke (2017), that found differences in the

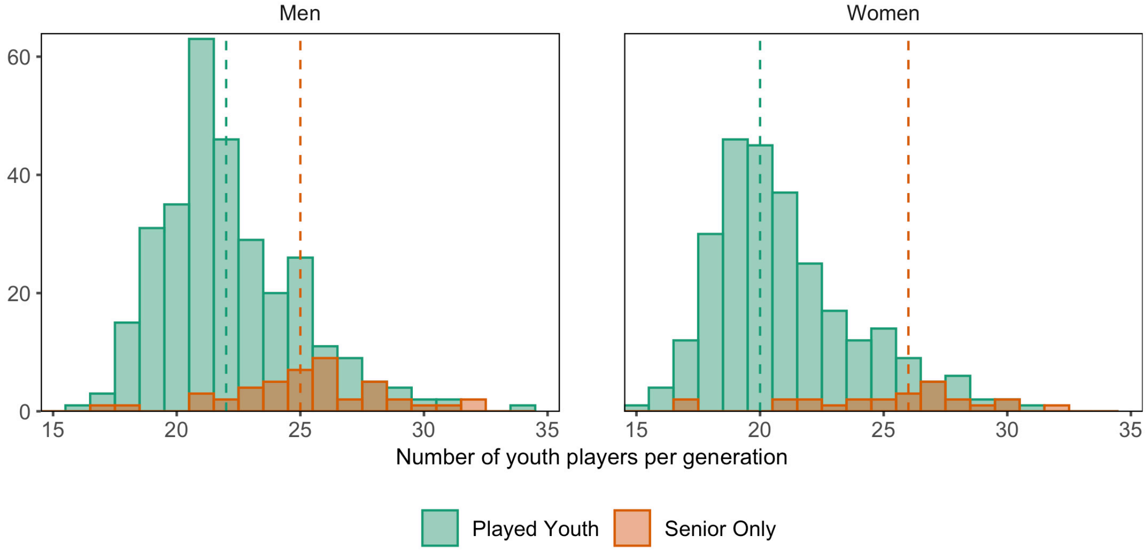

FIGURE 7 | Distribution of senior national team (NT) debut age, by gender and if player had played in youth NTs or not. Dashed line indicates median debut age.

type of support services given in talent development programs between different countries.

The main aim of investing resources in national talent development programs, such as the basketball youth NTs, is to increase the country's international performance (De Bosscher et al., 2018). In the current study, we measured the NT programs' success using the official FIBA ranking points, which are given to countries based on their results during the last 8 years. It, therefore, provides a measure of the country's long-term success. Furthermore, the rationalization for investing resources in talent development programs is that it produces success by promoting the best athletes to the senior teams, either through long-term development of a small number of early selected athletes (individualistic approach) or through trying out a larger number of athletes by continuous selection and de-selection (Barth et al., 2018). Regardless of the approach adopted, one central goal of the youth NT programs is, therefore, to promote youth NT players to the senior NT. We measured how many players debuted with the senior NT in the different countries, as well as within-county differences between generations.

The results of the present study seem to, overall, support the idea that more collectivistic approaches show better long-term effects both when it came to team performance and promoting players to the senior NTs. This is in line with earlier findings that both individual coaches and talent programs do not seem to identify future successful senior athletes much better than chance (van Rens et al., 2015; Schorer et al., 2017), and that we have limited knowledge of how to effectively identify and develop talent (Johnston et al., 2018; Till and Baker, 2020). Earlier talent research has largely focused on identifying factors that influence the development toward becoming an elite player (Torres-Unda et al., 2013; Garcia-Gil et al., 2018; Arede et al., 2019a), but there is very limited evidence on the influence of organizations selection strategies.

A possible explanation for the lack of a clear relationship between selection strategy and long-term performance on the women's side is the low number of players selected, and the small spread between countries in comparison with the men's side. Further, considerably fewer countries participate in each championship on the women's side, which affects the distribution of ranking points. Finally, the lack of relationship between the number of youth players and the number of players promoted to the senior NT on a country level could be expected, as each country has a more or less fixed number of spots on the senior NT roster. Our findings, therefore, seem to suggest that the proportion of senior NT players that are promoted from the youth NT program is relatively stable between countries. Given the small number of players who are involved in the NT programs, it would be of interest to study selection strategies and success including both NTs and clubs. For example, considering both reaching senior NT and becoming a professional athlete as outcomes.

Earlier studies have found that more efficiently structured and organized talent development programs have higher success (Gonçalves et al., 2011; De Bosscher et al., 2015). We used the amount of variation in the number of youth players between the different generations as a measure of the stability of the country's selection strategy. While we found some differences in stability between countries, this measure did not influence either the NT ranking or the youth-to-senior NT promotion. It might, however, be questionable to what degree the variation in number of selected players per generation reflect the degree of structure and organization of the program. It could be possible that this measure is influenced by factors external to the program, such as the number of highly skilled players available in the specific generation, number of players missing championships due to injuries and similar (te Wierike et al., 2015; Arede et al., 2019b). More studies looking at the organizational stability of youth NT programs are therefore needed before we should draw any conclusions from these results.

We further analyzed the proportion of senior NT players that had previously played in the youth NTs and their senior NT debut age. Nine of ten senior NT players had played in the youth NTs, which is similar to earlier reports in Norwegian handball (Bjørndal et al., 2018). This is, however, higher than six and seven of ten in Portuguese volleyball and soccer, respectively (Barreiros and Fonseca, 2012). These differences are likely to be the result of differences both in culture between countries, and popularity of the different sports. Furthermore, players with youth NT experience generally debuted at an earlier age, and about 90% of youth NT experienced players had debuted at age 25.

While we found that countries differed considerably in the number of players selected for the youth NTs over 12 generations, we do not know if this is a result of conscious strategic decisions or unconscious consequence of the condition in which the selections are made. It has been found that team sport coaches primarily make player selection decisions based on instinct and "gut feeling" (Christensen, 2009; Roberts et al., 2019). This is an indication that the differences in selection strategies might emerge from, for example, cultural differences in coaches' reasoning to a higher extent than decisions on an organizational level. Multiple ways of increasing talent selection efficacy have been proposed, with the common theme of making selection criteria more explicit and less reliant purely on coaches' tacit knowledge and intuitions (Musculus and Lobinger, 2018; Sieghartsleitner et al., 2019; Johnston and Baker, 2020). Even though our results do not give conclusive evidence of what selection strategy is the best, they do suggest that the selection strategy potentially influences the possibility for long-term success. National sporting organizations should, therefore, make sure that their selection strategies are the result of conscious and explicit decisions.

It is unclear to what extent the selection strategies reflect conscious strategic decisions or result from factors outside the NT programs, such as club structures, quality of youth coaches, or national policies. It is also unclear to what extent the higher success of programs selecting a higher number of players is a result of the selection strategies used, and how much is explained by other factors. Therefore, further studies are needed to more thoroughly study how to explain actual strategies and their outcomes. For example, by studies on a club or regional level, using more holistic and deeper research methods, and longitudinal studies – potentially with interventions.

A limitation of the current study is that we only included the total number of licensed players in the country as a potential reason behind differences in selection strategy and its effect on success. While we were limited to this measure, as it was the only one available across all included countries, future studies should address the influence of more detailed influences. Examples of interesting measures to include in future studies are the number of available players at the specific moment of selection in different generations, the strength of clubs in the country, and the number of professional youth coaches in the country. As many of these measures are hard to reliably attain across all European countries, more holistic case studies, using interviews with coaches, review of strategy documents, and detailed information on surrounding influences would add valuable knowledge on the area. Further, the number of licensed players was self-reported by each national federation, and there might be discrepancies in how these values were obtained.

Another limitation is the summary view that the number of selected players (and re-selection proportion) gives of selection strategy. For example, having a core of early, long-term involved players that reach the senior NT, combined with a high turnover of the other players would in these analyses be a more collectivistic approach. Although this should probably be considered an individualistic approach. More studies using person-centered approaches to look at players' pathways would provide more detailed views of selection strategies.

CONCLUSION

We can highlight four findings from this study of selection strategies in European basketball NT programs. First, there are considerable differences in selection strategies between European basketball youth NT programs, with a difference of eight players per generation between countries that select the highest and lowest number of youth players. Second, NT programs that select a higher number of youth players seem to perform better, both at the youth and senior level. Third, differences in the number of licensed basketball players explain part of the difference in selection strategy between countries; it explains almost none of the relationship between selection strategy and success on the men's side but a small part of the relationship on the women's side. Fourth, within countries, generations with a higher number of selected youth NT players produce a higher number of senior NT players.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are publicly available. This data can be found here: https://doi.org/10.17605/OSF.IO/ZHVDS.

AUTHOR CONTRIBUTIONS

AK, AP-F, and EL conceptualized the study. AK collected and analyzed the data. AK and AP-C wrote the original manuscript draft. AP-F, AP-C, EL, and ER reviewed and edited the manuscript. EL and ER supervised the work. All authors contributed to the article and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.666839/full#supplementary-material

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Conflict of Interest: AK worked as a youth national team assistant coach for Sweden during some of the seasons included in the current study. The Swedish Basketball Federation was not involved in any way in the conception of the study, nor in the collection, analysis, and interpretation of the data and results.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The Athletic Intelligence Quotient and Performance Outcomes in Professional Baseball

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The focus on quantifiable data in sport performance has led to incremental advantages in baseball and has played an important role in the development of new hitting, pitching, fielding, and coaching strategies. Recently, researchers and team representatives have considered the impact of additional factors in baseball, including cognitive functioning. In this study, predictive validity for the Athletic Intelligence Quotient (AIQ) was examined vis-à-vis performance outcomes in professional baseball. Specifically, AIQ scores were obtained from 149 Minor League Baseball (MiLB) players prior to the 2014 baseball season and their subsequent performance was assessed through traditional and newly emphasized baseball statistics. Using hierarchical multiple regression, it was demonstrated that the AIQ predicted statistically significant relationships with hitting and pitching statistics, after controlling for other variables. Given the recent impact of analytics in professional sports, the potential importance of the AIQ in the selection and coaching process was discussed.

Keywords: baseball, AIQ, athletic intelligence, major league baseball, cognitive assessment, intellectual ability assessment, professional sports, athletes

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INTRODUCTION

In Major League Baseball (MLB), the evaluation of athletic talent is a high stakes enterprise. According to a recent Forbes article (Ozanian, 2015), the average MLB team is now worth $1.2 billion. Considering the enormity of the baseball business, it is understandable that major efforts would be made to gain any advantage in player selection and development. However, even with significant time and money being spent, a solution to the puzzle of sport success has remained elusive.

In its history, sport performance research has included measurement of physical characteristics/abilities (e.g., anthropometric measures; Hoffman et al., 2009), personality constructs (e.g., coachability and mental toughness; Friend and Leunes, 1990), newly developed performance statistics (i.e., sabermetrics; Beneventano et al., 2012) and a range of cognitive factors. Though the relationship between cognitive functioning and sport expertise has been investigated widely, the specific factors studied and the manner in which they have been measured have varied considerably (Voss et al., 2010). As such, it has been difficult for organizations, coaches, practitioners, players, and others to fully understand the role of cognitive functioning in the game of baseball.

Nevertheless, several studies have recently made a strong case for the role of cognitive functioning in athletic performance (Fadde and Zaichkowsky, 2018; Brenton et al., 2019). For instance, in 2013 Faubert found that expert athletes were significantly better than amateur athletes and non-athletes in processing a non-sport-specific, complex dynamic visual task. In light of the growing research in this area, some have argued that the cognitive domain may, in fact, be the determining factor separating elite athletes (i.e., "playmakers") from non-elite athletes (Zaichkowsky and Peterson, 2018).

In spite of the aforementioned research, cognitive assessments continue to be under-utilized by professional teams in the measurement of athletic talent. Further, the instruments that have been employed to date are limited in the information they provide. Perhaps the most well-known cognitive measure used in sports is the Wonderlic Personnel Test (WPT-R), a measure of general mental ability (GMA; Wonderlic Inc, 2002). However, the results of several research studies have indicated that scores from the Wonderlic test do not significantly predict performance outcomes in sports (Mirabile, 2005; Kuzmits and Adams, 2008). When taken together with studies on expert performance in other fields, such findings have led eminent researchers to conclude that measures of GMA have not yet demonstrated predictive power in sports (Ericsson, 2014). In fact, we agree with this point, but we believe that the failure of previous research to establish connections between measures of GMA and athletic performance has to do with which cognitive abilities have been measured (or not measured) in such research (e.g., Wonderlic).

In the field of cognitive assessment, there are several competing theories of intellectual abilities. However, few of the existing theories have obtained consistent empirical evidence for their foundational principles (Flanagan et al., 2013). According to multiple theorists and researchers, the theory of intelligence with the most supportive evidence is the Cattell-Horn-Carroll (CHC) theory of cognitive abilities (Alfonso et al., 2005; Flanagan et al., 2006). CHC theory has been widely investigated and applied in many fields. Its evidence base includes neurocognitive, developmental, and factor analytic research (Schneider and McGrew, 2018). Additionally, based on its strong empirical support, CHC theory has served as a foundation for significant revisions made to the most widely used intelligence and academic achievement tests (e.g., Wechsler Intelligence Scales for Children, 5th Edition; Alfonso et al., 2005; Flanagan et al., 2013).

Previous research has established correlations between specific CHC abilities and occupational success in a wide range of occupations (Dawis, 1994; Gardner, 1994; Lohman, 1994; Ackerman and Heggestad, 1997). Until recently, however, CHC theory had not been applied to the measurement of mental abilities and processes considered essential in elite athletes. One of the benefits of applying this theory to the domain of sports is that it provides a standard language that coaches, practitioners, and athletes can use to discuss the cognitive strengths and weaknesses of athletes. In addition, CHC theory provides a framework for conclusions drawn about athletes' specific cognitive strengths and weaknesses, and these conclusions can be drawn with confidence.

It has been proposed that the CHC Theory of Intelligence may include as many as 18 broad cognitive abilities, which are each composed of several narrow abilities (Schneider and McGrew, 2018). Based on CHC Theory, not all intellectual abilities are expected to correlate with athletic performance; however, there are several that would be directly related. With this in mind, Bowman and Goldman created the Athletic Intelligence Quotient (AIQ). Four broad CHC abilities were chosen for inclusion in the AIQ: visual spatial processing, long-term storage and retrieval, reaction time, and processing speed (Bowman and Goldman, 2014).

Importantly, the AIQ does not include measures of other cognitive abilities that are more academic in nature (e.g., verbal knowledge, quantitative reasoning, etc.). This represents a significant difference in test composition when compared to existing measures of GMA (e.g., Wonderlic) and aligns the AIQ more with the more dynamic cognitive measures that have been shown to differentiate novice and elite athletes (Faubert, 2013).

Briefly, the AIQ was designed to assess "Athletic Intelligence," in a manner consistent with the foundational principles of CHC Theory. According to Bowman et al. (2020), Athletic Intelligence includes the cognitive abilities that enable athletes to optimally visualize their surroundings in real time, learn and recall game information fluently, react quickly and accurately to stimuli, and sustain rapid decision making for extended periods. Thus, Athletic Intelligence is a highly specialized subset of previously identified and validated broad CHC abilities [i.e., visual spatial processing (Gv), Learning Efficiency (Gl), Reaction Time (Gt), and Processing Speed (Gs)]. Data from pilot research, reported in Bowman et al. (2020), was subjected to a confirmatory factor analysis which supported the AIQ being broken out into these four factors.

Initial validity evidence for the AIQ was established through a study in which athletes' scores were compared to obtained scores on the Wonderlic Personnel Test and the ImPACT test (Lovell et al., 2000). The participants in this study included 93 Division 1 NCAA men's lacrosse, men's soccer, and women's soccer players attending a northeast university (Crimarco et al., in preparation). Significant correlations were found between the visual spatial processing and long-term memory factors of the AIQ and the Wonderlic test, suggesting some overlap between these measures. Importantly, however, neither the Reaction Time nor the Processing Speed factors of the AIQ correlated significantly with the Wonderlic test, thereby demonstrating discriminant validity. Significant correlations were also found in expected directions between composites of the ImPACT and factors on the AIQ. For instance, the AIQ Reaction Time and Processing Speed factors correlated significantly with the ImPACT reaction time composite. These findings demonstrate convergent validity.

More recently, research has been undertaken to examine the relationships among AIQ factors and performance outcomes in the National Football League (NFL) (Bowman et al., 2020). Specifically, 146 NFL prospects were administered the AIQ at the 2015 and 2016 NFL Scouting Combines, and their scores were analyzed in relation to subsequent performance in the NFL. The results of this study revealed that specific AIQ factors accounted for a statistically significant increase in the explanation of variance in game statistics (e.g., rushing yards per carry) as well as overall ratings of player success (i.e., weighted career approximate value) beyond other important factors (i.e., draft order).

Finally, another study has recently demonstrated that players in the National Basketball Association (NBA) have significantly higher scores on three of the four factors of the AIQ, when compared to players in the G League or International Leagues (Hogan et al., in preparation).

There are other factors that impact performance in both athletics and measures of cognitive functioning. Within our targeted sample, two potential variables are age and country of origin, especially given the language barrier in the administration of such tests. To that end, although the AIQ was initially developed in English, it has since been translated into Spanish. The availability of Spanish-language cognitive measure is of critical importance when assessing the relationships between cognitive factors and athletic performance in baseball, as 26.5% of MLB players were Latino, as of opening day 2018 (Gentile and Buzzelli, 2021). Age effects have also been well documented in terms of cognitive development and decline (Salthouse, 2019). While not central to our main hypotheses, these variables were assessed to statistically control for potential confounds.

Hypotheses

In light of the existing research on cognitive functioning and sport performance, we advanced the following hypotheses:

H1: The 4 factors of the AIQ (i.e., visual spatial processing, long-term storage and retrieval, reaction time and processing speed) would account for a statistically significant increase in the explanation of variance in traditional and new (sabermetric) hitting statistics (e.g., batting average, on-base plus slugging (OPS) percentage) beyond age, country of origin, and infield/outfield position.

H2: The 4 factors of the AIQ would account for a statistically significant increase in the explanation of variance in traditional and new (sabermetric) pitching statistics [e.g., earned run average (ERA), Fielding Independent Pitching (FIP)] beyond age and country of origin.

H3: Given the novelty of this data set, we also chose to explore the possibility of interactions among AIQ factors for both the pitching and hitting data, which could add to further variance explained by our models.

MATERIALS AND METHODS

Experimental Approach to the Problem

The independent variables selected for inclusion in this study included AIQ factor scores, age, position, and country of origin. Age and country of origin were included to account for any differences resulting from diverse experiential/linguistic backgrounds (e.g., Latin American baseball academies) or cognitive development/decline. The specific dependent variables were chosen because they reflect performance outcomes in baseball. By controlling for the effects of age, position, and country of origin it was possible to identify the unique contributions of the AIQ in the prediction of professional outcomes in baseball.

Subjects

A total of 149 Minor League Baseball (MiLB) players from a single major league organization were administered the AIQ prior to the start of the 2014 season. Performance statistics were then obtained at the conclusion of the 2014 season. Of the 149 athletes, 73 were position players and 76 were pitchers. Participants ranged in age from 19 to 37 (M = 24.6, SD = 3.14). The position players included 57 from the United States and 16 from Latin America. The pitchers included 66 players from the United States and 10 from Latin America. Access to this sample was a unique opportunity and we collected as many cases as the opportunity would allow. Power analyses using G*Power (Faul et al., 2007) suggested that we had power >0.90 for detecting medium effect sizes given our intended regression analyses.

Instruments

Athletic Intelligence Quotient

The athletic intelligence test is a measure of cognitive ability composed of 10 subtests (see **Table 1** for subtest descriptions and reliability coefficients). At the time of this study, it was individually administered by a software program on the Samsung Galaxy Tab, with the ice cream sandwich version of the android operating system. Subtests are presented in a fixed, successive order, with audio/visual instructions provided before the start of each task. The administration time for the AIQ generally ranges from 35–38 min. Resulting scores on the AIQ include a Full Scale AIQ Score (FSAIQ), four factor scores (i.e., visual spatial processing, reaction time, processing speed, and learning efficiency), and 10 subtest scores. In order to minimize the likelihood of Type I error, in this study, only the four factor scores were analyzed with respect to performance outcomes in baseball. See the AIQ Professional Manual for information about each subtest and factor (Bowman and Goldman, 2014). More detailed information about the development of the AIQ and evidence of its validity with respect to athletic performance data is available in Bowman et al. (2020).

Baseball Performance Measures

Hitting and pitching statistics from all MiLB players who took the AIQ were collected by one MLB team throughout the 2014 baseball season. Although these statistics are publicly available, they were compiled by an MLB team, who was tracking the performance of their minor league players. This MLB team then made the performance statistics available to the authors.

Season statistics included: batting average (AVG), slugging percentage (SLG), OPS, Isolated Power (ISO), walks plus hits per inning pitched (WHIP), ERA, and FIP. Batting average is the number of hits obtained per at-bat. SLG represents the total number of bases a player records per at-bat. It differs from batting average in that all hits are not valued equally. OPS is the sum of a player's on-base average and their SLG. ISO is a player's SLG minus their batting average. WHIP is self-evident. ERA is the number of earned runs allowed per 9 innings

TABLE 1 | AIQ subtest descriptions.

Subtest	CHC narrow/broad ability	Reliability	Description
Shape rotations	Visualization/visual spatial processing	0.77 Test-re-test	Measures the ability to mentally rotate shapes in one's mind and see how they would look under different circumstances. In particular, examinees are presented with a given target shape and they must decide whether the shapes below it are the same (only rotated) or are different and would need to flipped over to look the same.
Paired associative learning	Associative memory/learning efficiency	0.91 Internal consistency	Assesses the ability to form a mental link between random stimuli. In particular, the examinees are presented with 16 pictures that have been paired with random two-digit numbers. They are shown each pair for 2 s before having to provide the missing two-digit numbers when presented with the pictures alone. This procedure is then repeated for a two additional trials.
Object scanning	Perceptual speed/processing speed	0.81 Test-re-test	A cancelation task measuring the ability to quickly scan a visual field to locate 3 target shapes among both targets and distractors.
Route finding	Spatial scanning/visual spatial processing	0.57 Test-re-test	Assesses the ability to find the shortest route between two locations as quickly as possible, while having to avoid obstacles.
Simple reaction time	Simple reaction time/reaction time	0.79 internal consistency	Examinees are instructed to press a button as fast as possible after a stimulus (i.e., square) appears on the screen. When the response key is pressed, the square disappears from the screen. If the response key is not pressed within 1,000 ms of the presentation of the square, it will automatically disappear. The time between presentations of the square (viz., interstimulus interval) varies between 500 and 2000 ms. The subtest scores are based on both speed and accuracy, with omissions and commissions resulting in lower scores.
Memory for shapes	Visual memory/visual spatial processing	0.90 Internal consistency	Assesses visual memory by asking examinees to study an array of 16 shapes. Next, the examinees are presented with each of the original shapes, but they are out of order on the bottom of the screen. They must then drag the shapes to their correct locations.
Number matching	Perceptual speed/processing speed	0.81 Test-re-test	On this task, two multi-digit numbers are presented side-by-side on the screen. The examinee must indicate whether the two numbers are the same or not. The examinee has 2 min to make as many comparisons as possible.
Choice reaction time	Choice reaction time/reaction time	0.77 Internal consistency	Assesses reaction time and detectability by presenting two target stimuli and three distracter stimuli in random order. The examinee must press the response key as quickly as possible when presented with one of the two target stimuli, but must refrain from pressing the key when any of the three distracters are presented. If the response key is pressed, the image is removed. If the key is not pressed, the image disappears after 1,000 ms. Again, the resulting subtest scores are based on both speed and accuracy, with omissions and commissions resulting in lower scores.
Design matching	Spatial relations/visual spatial processing	0.84 Test-re-test	Examinees are shown a design at the top of the screen and they must replicate the design by touching empty boxes until each one matches the stimulus.
Paired associative learning delayed	Associative memory/learning efficiency	0.83 Internal consistency	This subtest is administered approximately 30 min after the first paired associative learning task is given. It assesses the examinee's ability to recall the information learned from the three previous trials.

pitched. Finally, FIP is similar to ERA, but it focuses solely on the events a pitcher has the most control over – strikeouts, unintentional walks, hit-by-pitches and home runs. It entirely removes results on balls hit into the field of play. The means and standard deviations for these performance statistics are included in **Table 2**.

Procedures

The assessment protocol was briefly described before participants were asked to provide informed consent, which included their express right to discontinue responding to assessment questions at any time. When the athletes arrived at the evaluation room, they were individually led to the testing station by a trained administrator who briefly explained the testing procedures. Next, an examiner initiated the computer program for the participants and presented them with headphones for audio instructions.

RESULTS

Hitting Data

To obtain a full picture of players' hitting abilities, we used the following measures: Batting AVG, SLG, OPS, and ISO. As shown in **Table 3**, these measures were highly correlated; subsequently, we ran a reliability analysis, which yielded a Cronbach's alpha level of 0.88, suggesting that these separate scores were reliably assessing the same underlying construct. For the sake of parsimony, we created a single composite measure standardizing all four hitting measures, then averaging across the standardized values for each player. This composite measure was then entered into a hierarchical multiple regression as the dependent variable, using the following model: block 1: age of athlete, whether the athlete was from the US or not; block 2: whether the athlete played in the infield or outfield; block 3: the four factors of the AIQ – visual spatial processing,

TABLE 2 | Means and standard deviations of baseball statistics.

Hitting statistics (*N* = 73)	**M**	**SD**
AVG Batting average	0.25	0.03
SLG Slugging percentage	0.37	0.06
OSP On base plus slugging	0.70	0.08
ISO Isolated power	0.12	0.04
Composite hitting measure	0.0	0.90
Pitching statistics (*N* = 73)		
ERA Earned run average	3.73	1.11
WHIP Walks plus hits per inning pitched	1.34	0.26
Fielding independent pitching (FIP)	3.22	0.74

processing speed, reaction time, and learning efficiency; block 4: the interactions between the four factors of the AIQ. Our exploratory analysis for the interaction terms of the AIQ yielded no significant results, so we dropped that block and re-ran the regression with just blocks one through three. Overall, the full model was significant, R^2 = 0.27, F(7,62) = 3.27, p = 0.005, but since neither reaction time nor learning efficiency were significant, these two variables were trimmed from the final model.

Table 3 provides the descriptive statistics of the composite hitting variable and each of the predictor variables, along with the zero-order correlations. Of note is that the visual spatial processing factor was significantly correlated with the hitting composite measure, as well as SLG and OPS, and was marginally correlated with AVG. Using a standardized composite measure to assess hitting, essentially creating a latent variable, increases the power of the analyses and avoids repeating the same essential finding across four strongly overlapping measures. Regression analyses on the component measures shows mostly the same pattern except for batting average. The pattern of the component measures are best captured by the zero order correlations which speak to the impact of the AIQ measures on the hitting metrics. The other factors of the AIQ did not demonstrate significant correlations with these hitting statistics.

Table 4 shows the results of the regression analysis, broken out by hierarchical order of entry. Age of athlete was marginally positively correlated with better hitting, being from the United States was associated with better hitting and outfielders had better hitting than infielders. Among the significant AIQ measures, better visual spatial processing was associated with better hitting, but slower processing speed yielded better hitting. These last two variables demonstrate the utility of the AIQ with its four factors and basis in CHC theory, explaining an additional 7.6% of the variance in hitting, above and beyond the descriptive variables of age, country of origin, and field position.

Pitching Data

To evaluate pitching data, we examined the variables of ERA, WHIP, and FIP, starting with an evaluation of their intercorrelations. Although not as large in magnitude as the hitting data, these measures were moderately to strongly correlated. Based on this finding, we decided to evaluate these measures separately in a series of parallel hierarchical multiple regressions with the following model: block 1: age of athlete, whether the athlete was from the US or not; block 2: the four subscales of the AIQ – visual spatial processing, processing speed, reaction time, and learning efficiency; block 3: the interactions between the 4 factors of the AIQ. Neither of the analyses focused on the WHIP and the FIP yielded significant results; however, the analysis of ERA demonstrated a significant overall model, R^2 = 0.35, F(12,58) = 2.62, p = 0.007. Due to non-significant findings, processing speed, learning efficiency, and all non-significant interaction terms of the AIQ measures were trimmed from the model.

Table 5 provides the descriptive statistics of the three pitching measures and each of the predictor variables, along with the zero-order correlations. Reaction Time was significantly negatively correlated with ERA, and marginally correlated with WHIP. Additionally, long-term efficiency was significantly positively correlated with FIP.

Table 6 shows the results of the regression analysis of ERA, broken out by hierarchical order of entry. The pattern of results did not emerge until the final step of the model, but in earlier steps age and reaction time were marginally related to ERA and RT was negatively related to ERA. However,

TABLE 3 | Descriptive statistics and zero-order correlations for hitting variables and AIQ measures (*N* = 73).

	M	**SD**	**AVG**	**SLG**	**OPS**	**ISO**	**Visual spatial processing**	**Reaction time**	**Processing speed**	**Learning efficiency**
Hitting Composite Measure	0	0.9	0.83**	0.99**	0.96**	0.86**	0.24*	0.16	0.08	−0.01
AVG	0.25	0.03		0.78**	0.82**	0.41**	0.22†	0.20†	0.21†	0.03
SLG	0.37	0.06			0.91**	0.89**	0.24*	0.14	0.06	−0.02
OPS	0.70	0.08				0.72**	0.24*	0.17	0.10	0.00
ISO	0.12	0.04					0.19	0.06	−0.07	−0.05

†*p* < 0.10, **p* < 0.05, ***p* < 0.01.

TABLE 4 | Hierarchical regression of hitting composite measure as a function of age, country of origin, field position dichotomy, and AIQ factors.

Step and predictor variable	R^2	ΔR^2	sr^2	β
Step 1	0.12*	0.12*		
Age			0.19	0.19*
Country of origin			−0.25	−0.25*
Step 2	0.17**	0.05*		
Field position: infield or outfield			−0.23	−0.22*
Step 3	0.24**	0.08*		
Visual spatial processing			0.31	0.23*
Processing speed			−0.34	−0.24*

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

these main effects were qualified by a significant interaction between visual spatial processing and RT. As shown in **Figure 1**, when Reaction Time is slow (1SD below the mean RT), higher visual spatial processing is related to better (lower) ERA, whereas when RT is faster (1SD above the mean RT), lower visual spatial processing is related to better ERA. Once again, as shown in **Table 6**, a combination of the AIQ measures explained a statistically significant 20% of the variance in pitching (ERA), above and beyond the descriptive variables of age and country of origin.

DISCUSSION

Previous research has demonstrated some success in utilizing sabermetrics, measures of physical abilities, personality measures, and cognitive factors to predict players' performance outcomes in baseball. The current research adds to the growing body of research on cognitive factors in baseball by investigating a state-of-the-art assessment based on the CHC Theory of Intelligence. To that end, specific aspects of cognitive functioning were predictive of hitting, with models based upon age, country of origin and AIQ factors explaining 27% of the variance in performance.

Notably, the measures of visual spatial processing and processing speed of the AIQ were significant predictors of hitting. This relationship makes intuitive sense, as hitters must process factors such as the trajectory, spin rate, and location of incoming pitches. They also need to be cognizant of their own body mechanics and maintain proper orientation and spacing as they swing. A player's visual spatial processing and processing speed would likely impact each of these skills. Additionally, visual spatial processing, processing speed, and reaction time each demonstrated marginally significant correlations with batting average, in particular. Reaction time, too, would seem to be an important factor for hitters, especially since pitches traveling at 100 mph take just 400 ms to travel from the pitcher to the hitter. This does not leave much time for the player to engage the skills above, make the snap judgment to swing or not, and then swing the bat.

With respect to pitching, cognitive factors were also predictive, with models including age, country of origin and AIQ accounting for 32% of the variance in ERA. In particular, reaction time was significantly correlated with pitchers' ERA and marginally correlated with WHIP. One may not necessarily think of reaction time as being quite as important in pitching as it is in hitting, because the delivery to the plate is largely a self-timed action. However, it is possible that reaction time plays a role in other important aspects of pitching, such as fielding one's position, covering bases, and holding runners on base. Each of these parts of the game would necessitate immediate processing of information. Additionally, the reaction time factor of the AIQ may tap elements of a player's broader executive functioning, which may also contribute to their performance.

Overall, the results from this study are consistent with previous findings in that elite athletes show a superior advantage in decision-making and problem-solving (Voss et al., 2010; Jacobson and Matthaeus, 2014). Presumably there is some natural advantage for these athletes, which then get honed over the course of experience. Further, some of the evidence suggests that a distinct skill set may be developed, relating specifically to baseball skills (Nakamoto and Mori, 2008). The current results add to the existing literature by placing the cognitive skills within a broader context of cognitive assessment, namely CHC Theory. Further, the current results also account for some significant demographics and include interactions that have not been previously assessed.

Specifically, the significant interaction between visual spatial processing and reaction time for pitchers indicate that there may be different cognitive mechanisms at play that contribute to a pitcher's success on the mound. In fact, the pattern we found suggests two avenues to a lower ERA: one in which pitchers rely more on their strong visual spatial processing if their reaction time is slow, and conversely, one in which pitchers rely more on their immediate processing of information (i.e., reaction time) if their visual spatial processing is poor. It is possible that this interaction effect reveals different processes for pitchers who rely more on effective pitch location as opposed to the velocity and/or movement of their pitches.

TABLE 5 | Descriptive statistics and zero-order correlations for pitching variables and AIQ measures (N = 76).

	M	SD	WHIP	FIP	Visual spatial processing	Reaction time	Processing speed	Learning efficiency
ERA	3.73	1.13	0.77**	0.57**	−0.11	−0.33**	−0.03	0.09
WHIP	1.34	0.26		0.72**	−0.03	−0.23†	−0.01	0.14
FIP	3.22	0.74			0.16	−0.06	0.12	0.26*

*†$p < 0.10$, *$p < 0.05$, **$p < 0.01$*

TABLE 6 | Hierarchical regression of ERA as a function of age, country of origin, and AIQ measures.

Step and predictor variable	R^2	ΔR^2	sr^2	β
Step 1	0.07	0.07		
Age			0.07	0.07
Country of origin			0.27*	0.28
Step 2	0.15**	0.08*		
Visual spatial processing			−0.09	−0.11
Reaction time			−0.24*	−0.25
Step 3	0.28***	0.13***		
Interaction between visual spatial Processing and reaction time			0.36***	0.42

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

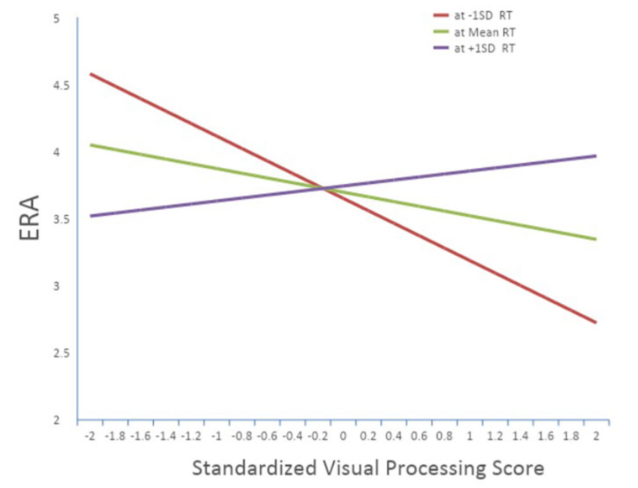

FIGURE 1 | Interaction of visual spatial processing with reaction time on ERA.

The current research also provides insight into the interrelationships between the various measures of successful performance in MLB players. In particular, as noted in **Table 2**, there is considerable overlap between the various sabermetrics, particularly those relating to hitting. This overlap was so great that we elected to combine these stats into a single composite measure. Typically this statistical technique yields the best overall assessment since any error loading on one measure is canceled out by error loading on any other measures. However, it is clear that these different measures were largely interchangeable in this study.

As with all research, there were limitations. The current sample relied solely on demographics such as age, position, and country of origin and the cognitive measures assessed in the AIQ. The variance predicted by these measures appears to be higher than that of previous efforts to predict performance based upon cognitive assessment, but without a direct comparison within the sample, it is impossible to assert definitively that one set of cognitive measures is significantly better than another. Further, the inclusion of other factors, such as physical prowess, deliberate practice, and personality may also capture some of the variance explained by the AIQ measures in the sample. Conversely, by holding some of these other factors constant, it is possible that more significant findings could be found with the AIQ.

Future research should look to replicate and extend these findings. With a good deal of the variance in performance still unexplained, there is considerable room for developing a model with even greater predictability. Such improvement could come from increased sample sizes, allowing a greater focus on the different positions. A wider range of measures offers the possibility of either consolidation of predictive power or greater predictive power, depending on how much overlap exists between the various domains of performance, personality, and cognitive factors. It also would be possible to compare which of the 10 subtests of the AIQ yield the most utility in making predictions, which could help tailor assessments more specifically to the game of baseball, as the AIQ was designed for use across multiple sports.

Ultimately, even though a solution to the puzzle of sport success is likely to remain elusive indefinitely, the current findings suggest that the measurement of specific cognitive abilities contributes to a better understanding of performance in professional baseball. As teams work to strategically draft and develop players in this high-stakes game, it would appear that improved understanding of players' athletic intelligence would be advantageous.

PRACTICAL APPLICATIONS

Based on the findings from the present study, there appears to be a growing evidence base for the validity of the AIQ (Bowman et al., 2020; Crimarco et al., in preparation; Hogan et al., in preparation). As the results of this investigation suggest, strong cognitive abilities alone cannot necessarily compensate for differences in physical skills, work ethic/deliberate practice, or personality functioning in terms of performance outcomes. However, knowledge of athletes' cognitive strengths and weaknesses still serves several important purposes. Perhaps most importantly for practitioners, it may help them find a goodness of fit in coaching/player development strategies to optimize outcomes for the athletes.

As an example, if practitioners are able to identify that aspects of a hitter's visual spatial processing are weak, it may lead to exploration of strategies designed to enhance their understanding and recognition of the trajectory, spin, or location of a pitch. It could also lead to new ways of helping the hitter perceive his body in space, to improve consistency in his physical mechanics at the plate. For those in the sport psychology and strength and conditioning fields, it is often critical to identify how athletes think, learn, and process information. Thus, there is a clear need for a valid and reliable cognitive assessment, such as the AIQ, that can be used to help practitioners better understand and assist their athletes.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JB assisted with literature reviews, data collection, statistical analyses, and manuscript writing. RB assisted with statistical analyses, manuscript writing, and editing. SG assisted with literature reviews, data collection, and manuscript writing and editing. AA assisted with data collection and manuscript writing and editing. All authors contributed to the article and approved the submitted version.

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Sparsely Wiring Connectivity in the Upper Beta Band Characterizes the Brains of Top Swimming Athletes

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Human brains are extremely energy costly in neural connections and activities. However, it is unknown what is the difference in the brain connectivity between top athletes with long-term professional trainings and age-matched controls. Here we ask whether long-term training can lower brain-wiring cost while have better performance. Since elite swimming requires athletes to move their arms and legs at different tempos in time with high coordination skills, we selected an eye-hand-foot complex reaction (CR) task to examine the relations between the task performance and the brain connections and activities, as well as to explore the energy cost-efficiency of top athletes. Twenty-one master-level professional swimmers and 23 age-matched non-professional swimmers as controls were recruited to perform the CR task with concurrent 8-channel EEG recordings. Reaction time and accuracy of the CR task were recorded. Topological network analysis of various frequency bands was performed using the phase lag index (PLI) technique to avoid volume conduction effects. The wiring number of connections and mean frequency were calculated to reflect the wiring and activity cost, respectively. Results showed that professional athletes demonstrated better eye-hand-foot coordination than controls when performing the CR task, indexing by faster reaction time and higher accuracy. Comparing to controls, athletes' brain demonstrated significantly less connections and weaker correlations in upper beta frequency band between the frontal and parietal regions, while demonstrated stronger connectivity in the low theta frequency band between sites of F3 and Cz/C4. Additionally, athletes showed highly stable and low eye-blinking rates across different reaction performance, while controls had high blinking frequency with high variance. Elite athletes' brain may be characterized with energy efficient sparsely wiring connections in support of superior motor performance and better cognitive performance in the eye-hand-foot complex reaction task.

Keywords: activity cost, energy efficiency, elite swimmers, phase lag index, wiring cost

INTRODUCTION

Human brain is complex and has multiple levels of organization. The realization of cognitive function is a result of coordination and multilevel coupling of various brain regions, including information encoding, decoding, and communication (Jun et al., 2019). These processes come at high metabolic costs (Shulman et al., 2009) that are used for signaling activity (i.e., electrochemical signal generation, propagation, and synaptic communication across neurons; Herman et al., 2009; Sanganahalli et al., 2016; Yu et al., 2018) and for non-signaling processes (i.e., supporting housekeeping mechanisms and maintaining resting potential; Engl and Attwell, 2015; Yu et al., 2018). This is supported by experimental studies showing a large amount of energy are required to maintain the electrical activity of neurons and the organization of neural networks in the mammalian brain (Laughlin and Sejnowski, 2003; Hasenstaub et al., 2010; Sengupta et al., 2010). Previous study suggested that the high-order brain may make certain economic trade-offs during their function, tending to minimize the energy cost while maximize the output efficiency (Laughlin and Sejnowski, 2003). The energy consumption rate can be captured by electroencephalogram (EEG) frequency components and shows a linear relationship with the brain activity rate (Buzsaki et al., 2012). However, little is known about the determinants of the energy-efficiency in the brain. Recently, a study suggested that the learning process, which relied on synaptic plasticity, might promote efficient coding at a low cost (Yu et al., 2018). In the present study, we investigated whether the long-term professional athletic training such as swimming would influence the efficiency of energy consumption in the brain by alerting the functional connectivity.

In professional sports, the intrinsic functional state of the brain, such as the sensitivity of sensory perception, the degree of concentration, the speed of information processing, and the degree of neuromuscular control (Pei, 2020), is essential to athletes' performances. EEG is a non-invasive technology with a million second temporal resolution. It can be used to detect the neural activities from the scalp reflecting functional states of the brain. For example, golfers with expert putting skills showed increased frontal midline θ power and parietal α2 power (Baumeister et al., 2008), increased α and β power were found in the left hemisphere of rifle shooters during the preparation process before aiming, and increased θ power was found along the frontal midline during the aiming phase (Hillman et al., 2000; Doppelmayr et al., 2008); increased δ and θ frequency activity were found during ball sports exercises (Ermutlu et al., 2015); increased α activity was found in the left hemisphere of archers as the aimed (Salazar et al., 1990); increased α and β activity was recorded from widely distributed sites on the scalp after treadmill exercise (Mierau et al., 2009; Schneider et al., 2009); decreased α activity and increased β activity were found during cycling (Kubitz and Mott, 1996); and an increased α/β index in the frontal lobe was related to long-term fatigue from cycling (Nielsen et al., 2001).

Functional connectivity is used to quantify statistical interdependencies among physiological time series recorded from different brain areas (Lee et al., 2003; Fingelkurts et al., 2005). The brain functional connectivity can be evaluated by coherence, Granger causality (Granger, 1969), phase coherence (Tass et al., 1998), synchronization likelihood (Stam and van Dijk, 2002), phase lag index (PLI) (Stam et al., 2007), and the imaginary part of coherency (Nolte et al., 2004). PLI quantifies connectivity strength on the basis of phase synchronization and was designed to overcome the volume conduction problem (Stam et al., 2007). Research has found that an individual's functional brain connectivity profile is unique and similar to one's fingerprint (Finn et al., 2015). An individual can be identified from a large group of subjects solely relying on the basis of the connectivity matrix, especially in the frontoparietal networks (Finn et al., 2015). In the context of sports, distinguish relationships between different sport events and the characteristics of brain networks have been reported. For example, functional connective edges in the right hemisphere was significantly greater than those in the left hemisphere during shooting (Liwei et al., 2018). Table tennis players showed reduced EEG coherence in multiple frequency bands comparing to novices (Zhiping et al., 2016). However, there has scarce EEG research on the brain functional connectivity to reflect the cost-efficiency of professional athletes.

Swimming is a speed event relying on cyclical movements and requires high levels of reaction, movement and displacement speeds. Long-term systematic physical and skill training leads to superior reaction behaviors in professional athletes (Mori et al., 2002; Williams et al., 2002; Kida et al., 2005; Simonek, 2011). Specifically, a study showed that the hand-foot coordination was positively correlated with swimming speed and competitive performance (Takagi et al., 2004). In the same vein, the complex reaction (CR) (i.e., a type of choice reaction) is considered as a behavioral characteristic that distinguishes elite swimmers from thousands of beginner swimmers (Guang et al., 2013). However, it is unknown what role energy cost-efficiency plays in the CR performance. Hence, the present study aimed to (1) seek for potential electrophysiological markers identifying top swimmers; and (2) explore the brain energy cost-efficiency of ES using functional connectivity methods.

MATERIALS AND METHODS

Participants

Twenty-one elite swimmers (ES) from Shanghai Swimming Management Center (**Supplementary Tables 1–4**) and 23 college students with no history of specialized swimming or other professional sports training (control group, CG) were recruited. All participants read and signed informed consent forms. The study was approved by the Ethics Committee of the Fudan University. Participants were all right-handed. The handedness was determined by self-reports and verified by the observation of their hand use in writing and performing the task. None of them had reported a history of mental illness. The EEG and behavioral data of 5 elite swimmers and 7 controls were excluded from the analysis because their EEG signals contained too many instabilities or drifts. The final sample consisted of 16 ES and 16 CG ($n = 32$, 15 Female). Sixteen swimmers (13 master-level) were distributed to 5 specialties (6 Free style; 4 Backstroke; 3 Breaststroke; 2 Individual Medley; 1 Butterfly) (for participant demographics, see **Supplementary Tables 1, 2**).

Experimental Procedures

Participants were seated comfortably in an armchair in a soundproof room. The experiment started with a 2-min waking eyes-closed (EC) period, followed by a 2-min eyes-open (EO) period with eyes fixed on a screen with a crosshair. Then, participants were required to perform the CR task while keeping the head still, followed by another EC (2 min) and EO (2 min) states. After each state, there was a 1-min short break. EEG signals were recorded throughout the process. Prior to perform the CR task, participants were instructed to practice several trails till they successfully completed one trail by themselves. In the CR task there were 8 trails and each trial involved 6 different blocks connected by directional arrows, and every block contained 4 balls connected by lines. The participant was required to use left/right finger or foot to indicate the location of the ball which appeared in one of the four corners of the screen (i.e., left finger = upper left, right finger = upper right, left foot = lower left, and right foot = lower right). If the participant responded correctly, the ball would disappear. Participants were required to respond as quickly and accurately as possible while keeping the head stable. The trial-by-trial reaction time and the total number of errors were

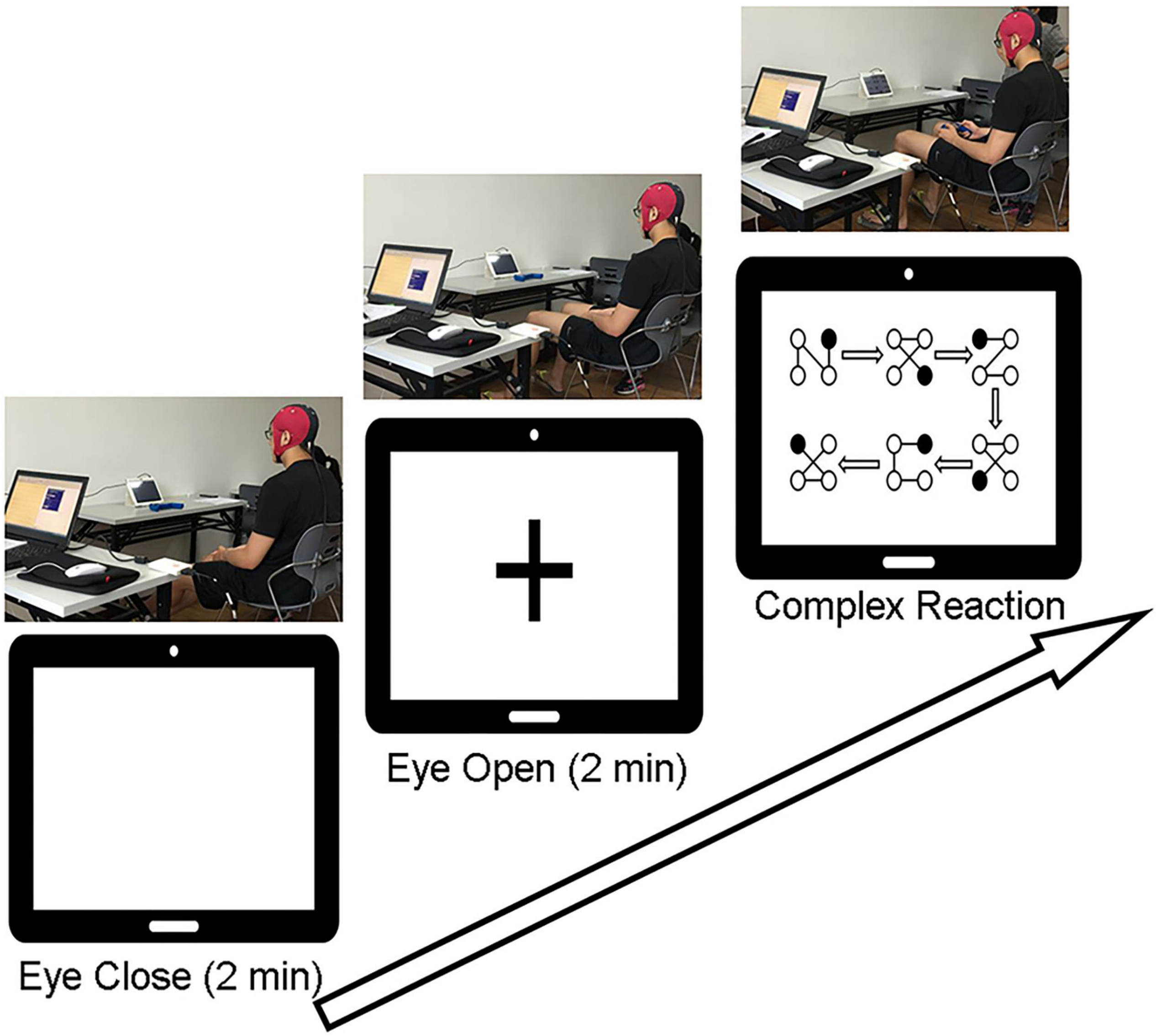

FIGURE 1 | Experimental procedures. Participants were asked to keep their eyes closed for 2 min without thinking about anything and then to keep their eyes open and fixed on the "+" in the middle of the screen for 2 min. After a 1-min break, they were required to complete 8 trials of the complex reaction task according to the instructions on the screen.

documented. The experimental procedure is illustrated in detail in **Figure 1**.

EEG Recording and Data Preprocessing

EEG signals were recorded from an 8-channel EEG system (eego, ANT Neuro, Berlin, Germany) and digitized at a sampling rate of 1,000 Hz. The reference electrode was placed between the Cz and Pz channels, and others (Fpz, Fz, F3, F4, Cz, C3, C4, and Pz) were distributed around the frontal and parietal areas according to the extended 10–20 international system. The impedance of all electrodes was kept below 10 kΩ.

EEG data were preprocessed in EEGLAB v.13.0.0.b, a MATLAB-based open toolbox (Delorme and Makeig, 2004). Segments with a duration of 1 min (from 30 to 90 s of the collected 120 s data) were selected from the EC and EO resting-state EEG, respectively, and all data associated with the CR task were imported for preprocessing. Raw data were re-referenced to the common average reference and filtered to a frequency range of 0.5–30 Hz. After running eye blink recognition, artifacts associated with eye movements and blinks were removed by using the AAR1.3 toolbox plugin, which performed automatic electrooculogram (EOG) artifact correction using blind source separation (BSS) and identified the EOG components using fractal analysis (Gomez-Herrero et al., 2006). After that, the resting states and CR task data were all segmented into epochs with a duration of 2 s each. Subsequently, the epochs with abnormal values beyond the upper limit of 75 μV were rejected (Collin et al., 2012). Overall, 10.1% epochs from the resting states and 16.2% from the CR task were excluded due to artifact contaminations.

It's well-known that the alpha blocking phenomenon appears during relax wakefulness and conceptualized as desynchronized neural population activity during active stimuli. Previous study has demonstrated that the alpha blocking phenomena could reflect wakefulness-to-sleepiness levels (Jiao and Lu, 2017). They estimated the degree of falling in sleepiness from drivers' wakefulness by calculating the alpha blocking rate from EEG wave. In present study, we calculated the alpha blocking rate ($\alpha_{blockingrate}$) to reflect a subject's switch from eye-close (EC) to eye-open (EO) states as an estimate of degree of wakefulness as well as stability of subjects during experiment. We used the rate of change of the alpha blocking rate ($\alpha_{blockingrate}$) effect of the EC and EO resting states before and after the CR task to monitor the stability of the experimental recording process and verify the validity of EEG data after preprocessing (Zheng et al., 2018). We set 20% as the stability threshold of the rate of change of the alpha blocking rate based on our long-term observations in experimental study. We observed that once subject's $\alpha_{blockingrate}$ decreased its value above 20% change, it was very likely that the subject became sleepy in long-term experiment. On the contrary, if it increased its value above 20% change, it was very likely the intrinsic brain behavior state had changed, which introduced some unexpected noise to the experiment, and affected the interpretability of the data. After the CR task, the $\alpha_{blockingrate}$ values of the 2 groups were both reduced by <20% in comparison to those before the CR task (**Table 1**, **Supplementary Figure 1**, and **Supplementary Method 1**).

TABLE 1 | Descriptive statistics for the variables of interest.

	ES Mean ± *SD*	CG Mean ± *SD*	*P*-value
Complex Reaction (CR)			
CR reaction time	15.85 ± 4.19 s*	19.06 ± 5.13 s*	0.033
CR accuracy	94.86% ± 2.51%*	87.79% ± 8.99%*	0.005
CR speed	4.08 ± 0.8 trials/min*	3.47 ± 0.92 trials/min*	0.049
$\alpha_{blocking\ rate}$			
Before CR tasks	78.55% ± 22.83%	71.92% ± 16.71%	0.356
After CR tasks	73.54% ± 26.2%	61.85% ± 20.2%	0.168
Lateralization Index (LI)			
EC $LI_{frontal}$	−0.011 ± 0.156	−0.050 ± 0.198	0.552
EC $LI_{parietal}$	−0.092 ± 0.225	0.009 ± 0.212	0.200
EO $LI_{frontal}$	0.008 ± 0.150	−0.066 ± 0.117	0.128
EO $LI_{parietal}$	0.029 ± 0.203	−0.048 ± 0.181	0.269
CR $LI_{frontal}$	0.058 ± 0.169	0.012 ± 0.095	0.351
CR $LI_{parietal}$	0.027 ± 0.080*	−0.069 ± 0.118*	0.012
Wiring Connections (W_{NC})			
1–4 Hz	6.31 ± 3.54	5.69 ± 3.11	0.600
4–8 Hz	13.00 ± 5.74	10.31 ± 4.42	0.148
8–13 Hz	9.38 ± 3.69	7.69 ± 3.99	0.224
13–20 Hz	8.38 ± 4.43	8.63 ± 4.37	0.873
20–30 Hz	6.38 ± 4.73*	9.88 ± 4.47*	0.040

$p < 0.05$, significantly different between elite swimmers and the control group.

Network Wiring Connections Based on Phase Lag Index

EEG network connectivity such as functional connectivity generally refers to the statistical relationship of EEG signals between electrodes (or brain areas) (Fingelkurts et al., 2005). To avoid the effect of volume conduction and the field diffusion on multiple-recording channels, we used the phase lag index (PLI) based on phase synchronization to evaluate the brain EEG functional connectivity (Stam et al., 2007). The PLI value was calculated with the open source toolbox HERMES based on MATLAB (Niso et al., 2013). The range of PLI values is generally between 0 and 1, where a value of 1 means that the 2 EEG signals have strict phase locking at a constant non-zero phase lag and a value of 0 means no coupling (or coupling with a relative phase that encircles 0 modπ, which is likely to result from volume conduction) (Zheng et al., 2018). Thus, the larger the PLI value indicates the stronger the non-zero phase synchronization and the stronger the connectivity (Stam et al., 2007). We first applied an approach called network-based statistics (NBS) (Zalesky et al., 2010) to analysis brain functional connectivity based on PLI and to find the significant connectivity edge (SCE). In terms of the energy related to the wiring cost. The weaker or less extensive the connectivity is, the less active synaptic connections there are. The less active synaptic connections will cost less energy. That is, network wiring cost (C_w) is proportional to the wiring number of connections (W_{NC}) (Achard and Bullmore, 2007; Zheng et al., 2021). There were up to 28 edges among the 8 electrodes. Some PLI values were very low which were around noise level. There should be an optimal baseline and threshold to reduce the noise interference. Hence, we set different thresholds e.g., from 1/10, 1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/2–1 maximum of PLI value of 32 participants (Max) in order to compare those relatively stronger functional connections for both ES and CG in the CR task state. There was a significance between 2 groups for some threshold (1/4 Max, 1/8 Max, and 1/9 Max) (**Figure 2C** and **Supplementary Figure 10**). Here, as an example case, $\frac{1}{4}$ Max was used as the threshold for distinguishing the talented swimmer group from the control. Absolute threshold was better than the relative threshold of each subject for the comparability between ES and CG. Therefore, we set 1/4 of the maximum PLI value of 32 participants in 2 groups as the threshold in each frequency band. If the PLI of two channels was greater than the threshold value, one W_{NC} was calculated. The W_{NC} of all participants were calculated and analyzed during the CR task.

Activity Cost Based on Mean Frequency

Brain signaling activity involves not only a wiring cost for network connectivity but also an activity cost for neuronal discharge. Studies have shown that a higher mean frequency (MF) of EEG reflected higher levels of cerebral blood flow and metabolism (Ingvar, 1971; Hyder et al., 2013), and MF was confirmed to have a positive correlation with these physiological variables (Ingvar et al., 1976; Zheng et al., 2021). That is, the high MF suggests higher frequency of brain electronic activity that will cost more metabolic energy (Hyder et al., 2013; Yu et al., 2018). Since the MF can indirectly reflect the energy cost of neural electrical activity in the brain, we used the MF of the CR task state as the index for the energy cost of brain activity ($C_{activity}$). MF will be higher or lower when the condition is changed. In the present study, we calculated and compared the MF of ES and CG groups at the same condition.

Calculation of MF: Each subject was selected 50 s signals of EC state, 50 s signals of EO state, and 70 s signals of CR task (selection from the beginning recording signals of the CR task) to be preprocessed. The mean frequency of 25 segments or 35 segments EEG data from 8 channels were calculated in 2 s. It is known that electromyogram (EMG) artifacts have a higher amplitude than the EEG signals and can be removed by using independent component analysis (ICA) technique (Chen et al., 2014; Frolich and Dowding, 2018). But in our present study, there were only 8 electrodes and they were not enough for using ICA to detect the EMG artifacts. According to the characteristics of EMG, such as distributing relatively higher frequency with a higher amplitude, we used the ratio in the formula (1) for the evaluation of the muscular content. The electromyography (EMG) artifacts were removed according to the ratio of high-frequency bands power over low-frequency bands power due to the relatively higher frequency of myoelectric. The calculation formula of the ratio was as follows:

$$\text{Ratio} = \frac{\sum_{i=13}^{30} P(f_i)}{\sum_{i=1}^{13} P(f_i)} \tag{1}$$

Where *i* represents an integer frequency ranging from 1 to 30 Hz, and *P(fi)* means the power value at a certain integer frequency. When the value of Ratio of one segment from one channel of a subject was >1, this segment was removed because it belongs very likely to the EMG artifacts (**Supplementary Figure 14** and **Supplementary Method 4**). According to the above methods, about 2.81‰ segments of EC, 8.59‰ segments of EO, and 7.03‰ segments of the CR task were removed before calculating the mean frequency of each channel of every participant in 3 conditions (EO, EC, and the CR task).

Spectrum Power and Activation Rate

Averaged power spectra were computed across segments of different states in each participant. The power values were calculated for 5 frequency bands (δ: 1–4 Hz; θ: 4–8 Hz; α: 8–13 Hz; β_{lower}: 13–20 Hz; β_{upper}: 20–30 Hz). It has been well-established that low-frequency signaling activities, such as δ or θ, are related to sleep or the resting state of the brain, while high-frequency signaling activities, such as α and β, are related to the cognitive function (Kumar and Bhuvaneswari, 2012). The power ratio of the high-frequency band to the low-frequency band can reflect the degree of brain activation (Cheron et al., 2016). Therefore, we calculated the power ratio of the upper β frequency band to the θ frequency band of each channel (upper beta/theta ratio, or UBTR), to represent the activation rate of eight brain areas (Arns et al., 2013; Vollebregt et al., 2015). The formula of UBTR was as follows:

$$\text{UBTR} (\%) = \frac{Power_{upper\ beta}}{Power_{theta}} \times 100 \tag{2}$$

Note: In our study, there were no electrodes in the temporal or occipital areas of the brain. When we drew the spectrum power and mean frequency topologic maps, we added an additional 18 electrodes and set the values to 0 to avoid the influence of the frontal and parietal signals on the periphery. The added electrodes were Fp1, Fp2, F5, F6, C5, C6, P5, P6, Po3, Po4, F7, F8, O1, O2, T7, T8, Po1, and Po2.

Blink Recognition

The electrical potential of eye blinks is required along with the brain rhythm signals by the electrodes in EEG and shows a higher intensity in the frontal electrodes and possesses higher amplitude than the brain rhythms (Sovierzoski et al., 2008; Al-gawwam and Benaissa, 2018). In present study, blink recognition was performed based on the EEG data of each participant after high- and low-pass filtering. The processes of algorithm identification were: (1) to find all the peaks that may be blinks in the Fpz channel using the function *findpeak* in Matlab (seen **Supplementary Method 3**); (2) to select 250 ms time series before and after each peak and calculate the amplitude of the peak to the trough on the left and right sides, respectively, and then to compare the averaged left and right amplitudes with the peak threshold. It would be kept when the averaged amplitude was larger than the peak threshold; (3) to meet the condition that there were at least in 3 other channels the amplitudes of the trough were greater than the trough threshold at the same period; (4) to remove the local maximum peak with the amplitude difference between 2 consecutive peaks less than one third of the maximum peak in the Fpz channel. The peak threshold was set to

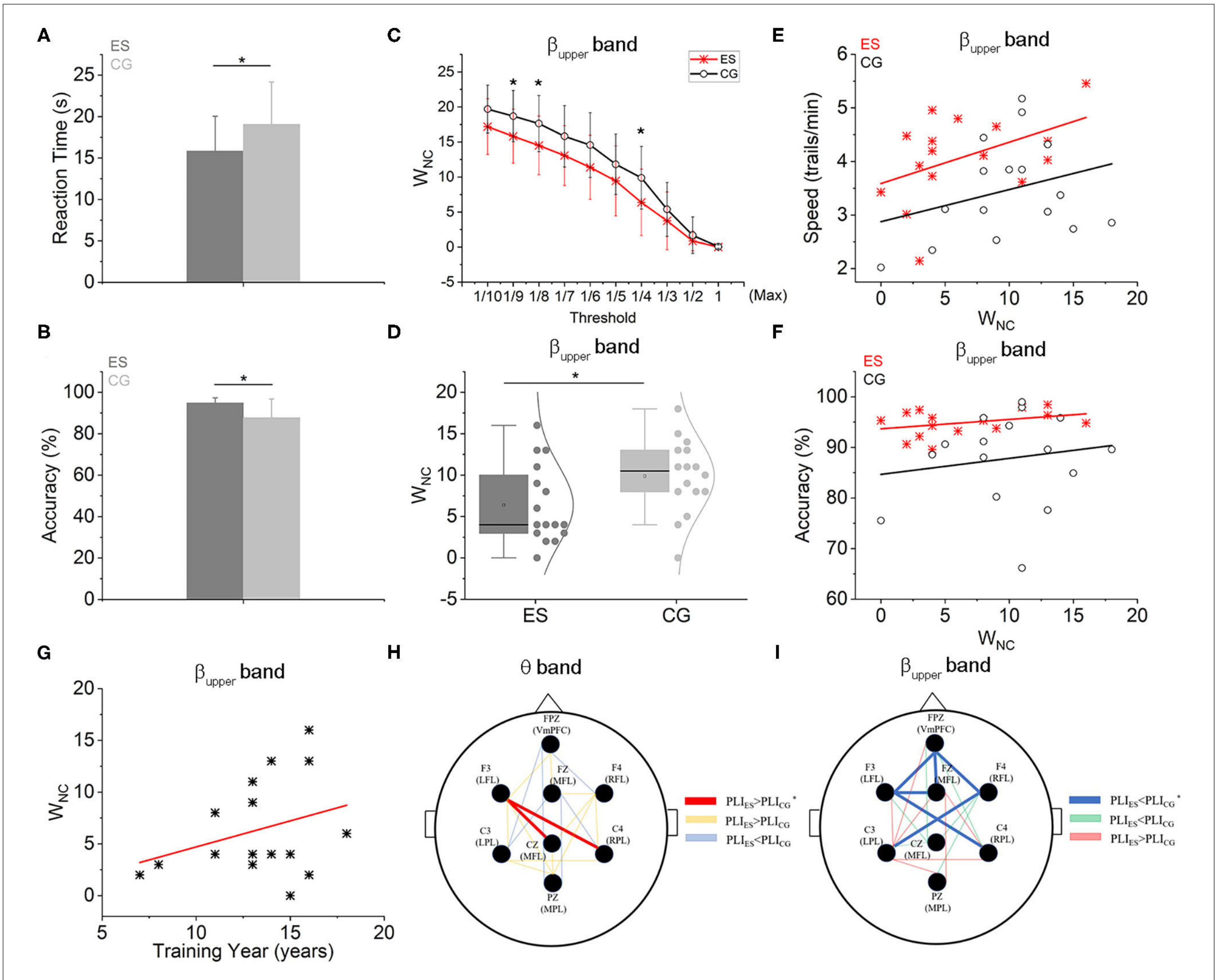

FIGURE 2 | Functional connectivity and network wiring cost-efficiency characteristics based on PLI. **(A)** The CR responding time of ES was significantly shorter than controls. **(B)** The CR accuracy of ES was also significantly higher than CG. **(C)** The relationship between WNC of two groups and different threshold settings. When the threshold was set as the 1/4Max, 1/8Max, and 1/9Max, the WNC of ES was significantly less than that of CG in the upper beta frequency band. **(D)** The W_{NC} of ES was significantly less than controls in the upper beta frequency band when the threshold was set as the 1/4 Max. **(E)** Both in the ES and CG groups, W_{NC} was positively correlated with the CR speed (S) in the upper beta frequency band. But in the ES, the intercept was greater [$S_{ES} = 3.588 + 0.077 \times W_{NC}$, $r(16) = 0.458$; $S_{CG} = 2.876 + 0.06 \times W_{NC}$, $r(16) = 0.292$]. **(F)** There were positive linear relations between W_{NC} and CR accuracy (AC) both in the ES and CG group in the upper beta frequency band [$AC_{ES} = 93.677 + 0.185 \times W_{NC}$, $r(16) = 0.349$; $AC_{CG} = 84.668 + 0.316 \times W_{NC}$, $r(16) = 0.157$]. **(G)** In the ES group, there was a positive linear relation between W_{NC} and swimming training year (T) in the upper beta frequency band [$W_{NC} = -0.323 + 0.503 \times T$, $r(16) = 0.312$]. **(H)** In the θ frequency band, there were 2 SCEs between ES and CG, connecting F3 to Cz and C4 (red lines indicate that the PLI values of ES were significantly higher than those of CG in the SCE topologic map, yellow lines indicate that the PLI values of ES were higher than CG but no significance, blue lines indicate the PLI values of ES were lower than CG but no significance). **(I)** Six SCEs were shown at the upper β frequency band between the 2 groups: Fpz-Fz, Fpz-F3, Fpz-F4, Fz-F3, F4-C3, and F3-C4 (blue lines represent that the PLI values of ES were significantly lower than those of CG in the topological map of SCEs, green lines represent the PLI values of ES were lower than CG but no significance, red lines represent the PLI values of ES were higher than CG but no significance). *$p < 0.05$, compared with the control group.

2/5 of the maximum peak amplitude of the subject and the trough threshold was set to one third of the lowest trough amplitude of the subject in the Fpz channel during the complex reaction task. One blink was recognized after the above 4 conditions were all met.

According to the above-mentioned blink recognition algorithm, all the blinks of each subject were identified during the complex reaction task. The peaks of blinks were aligned to 0 ms. The mean amplitude from 250 to 150 ms before the blink peak was set as the baseline amplitude. Task-evoked blink potentials of each subjects were plotted after normalized by the Z-score method.

Blink rate or the frequency at which the eyelids open and close has been proposed and used to study cognitive control, learning, working memory, and decision making (Eckstein et al., 2017). In the manuscript, the instantaneous blink rate of each subject was calculated over time from the beginning to 60 ms of the complex reaction task, and was normalized with the average blink frequency of his/her group in 60 s. In the calculation process, subjects who blinked <3 times in the first 60 s should be removed.

Previous study noticed that the interblink intervals were quite variable between subjects (Ponder and Kennedy, 1928). According to the percentages of different blink intervals to the total number of blink intervals of each participant, the interblink interval histogram (IBIH) of each person in the process of CR tasks was calculated for his/her total CR tasks continuous time sequence s selected from each subject in the 2 groups. The total number of blink intervals of all subjects in each group was calculated with the time bin of 1 s. Most interblink interval durations of these subjects were distributed in <20 s while a very few interval durations (>20 s) distributed sparsely with maximal value reaching 91 s.

Statistical Analysis

Brain functional connectivity based on PLI was analyzed mainly by an approach called network-based statistics using the NBS v1.2 toolbox, based on MATLAB (Zalesky et al., 2010). After 5,000 permutation tests, if there was a significant difference ($p < 0.05$) between ES and CG groups, it was marked with a line as a SCE in the topology diagram (**Figures 2H,I**). Other index data were analyzed by SPSS 20.0. An independent t-test was used between the 2 groups in one state such as the speed and accuracy of the CR task, WNC at different frequency bands or different threshold, the lateralization index in the resting or task state, mean frequency in the resting or task state, spectrum power at different frequency bands etc. A paired t-test was used between 2 states within the same group, e.g., mean frequency of ES between EC and EO state or between EO and the CR task state; the significance threshold was set at $p < 0.05$. Pearson correlation analysis was used for individual EEG and CR task performance.

RESULTS

Complex Reaction Task Performance

The averaged reaction time and accuracy values of the CR task were shown in **Table 1**. The ES responded significantly faster (**Figure 2A**) and more accurate (**Figure 2B**) than the CG. This result is consistent with reports from other sports (Mori et al., 2002; Williams et al., 2002; Kida et al., 2005).

Alpha Blocking Rate

Alpha activity is greatly reduced by the increase in light input from the resting EC state to the EO state or blocked by other attention-related signals. The alpha-blocking phenomenon is conceptualized as desynchronized neural population activity during active stimuli, and alpha blocking rate ($\alpha_{blockingrate}$) between the EC and EO states is used to monitor the stability of the experimental recording process (Method seen **Supplementary Method 1**). It is generally believed that a data recording process is relatively stable if the $\alpha_{blockingrate}$ is <20% before and after the tasks (Bazanova and Vernon, 2014). In the current study, the mean $\alpha_{blockingrate}$ of the elite swimmers after the CR tasks was 6.4% lower than the rate before the tasks. In the control group, the $\alpha_{blockingrate}$ after the CR task was reduced about 15% (**Table 1** and **Supplementary Figure 1**). This relatively higher and stable $\alpha_{blockingrate}$ values in elite athletes might reflect that they could maintain sustained attention for relatively longer period than controls.

Network Wiring Connections

Based on network-based statistical analysis, there were 2 strengthened functional connectivity edges in the θ frequency band (4–8 Hz) in the ES compared with the CG during the CR task (**Figure 2G**). These edges were distributed in the left frontal area, connecting the left frontal area (F3) to the central parietal area (Cz) and to the right side of the parietal area (C4). In the upper β frequency band (20–30 Hz), compared to the college student controls, master swimmers had 6 less correlated functional connectivity edges (**Figure 2H**), which were mainly distributed in the frontal, temporal and parietal regions of the brain. The connection strengths of all recording sites for other frequency bands were not significantly different between the 2 groups.

In the upper β frequency band, the frontoparietal network W_{NC} of ES was significantly lower than that of CG ($p < 0.05$; **Figure 2D**) and was positively correlated with swimming training years within the ES group (**Figure 2G**). As shown in the **Supplementary Figure 2**, there were positive linear relations between training years and CR accuracy or speed. However, in the other 4 frequency bands, W_{NC} was not different between ES and CG (**Supplementary Figure 3**). Within the group either ES or CG, W_{NC} was also positively correlated with CR speed (**Figure 2E**) or accuracy (**Figure 2F**). However, the 2 intercepts of linear relations of ES were both greater than controls.

Activity Cost Based on Mean Activity Frequency

A gradual decrease was shown in the mean frequency of the frontoparietal area from the EC state to the EO state and then to the CR task (**Figures 3A,D,E** and **Supplementary Figure 4**). This result was consistent with our group's previous findings on the mean frequency of the normal population in the frontoparietal area (**Supplementary Figure 5**). However, during the CR task, there was no difference in the mean frequencies between ES and CG ($p > 0.05$; **Figure 3B**), nor was the change rate of the mean frequency from the EO state to the CR task ($p > 0.05$; **Figure 3C**).

Spectrum Power Analysis and Activation Rate

Although the absolute power values of ES in the 5 frequency bands were not significantly different from those of CG during the CR task ($p > 0.05$), there was an upward trend in the ES in the frontoparietal region of the left hemisphere while it was absent in the CG (**Supplementary Figure 6**).

Comparing to the EO state, ES showed increased activities in the prefrontal region at each frequency band during the CR task state, while CG showed more spatially distributed across multiple

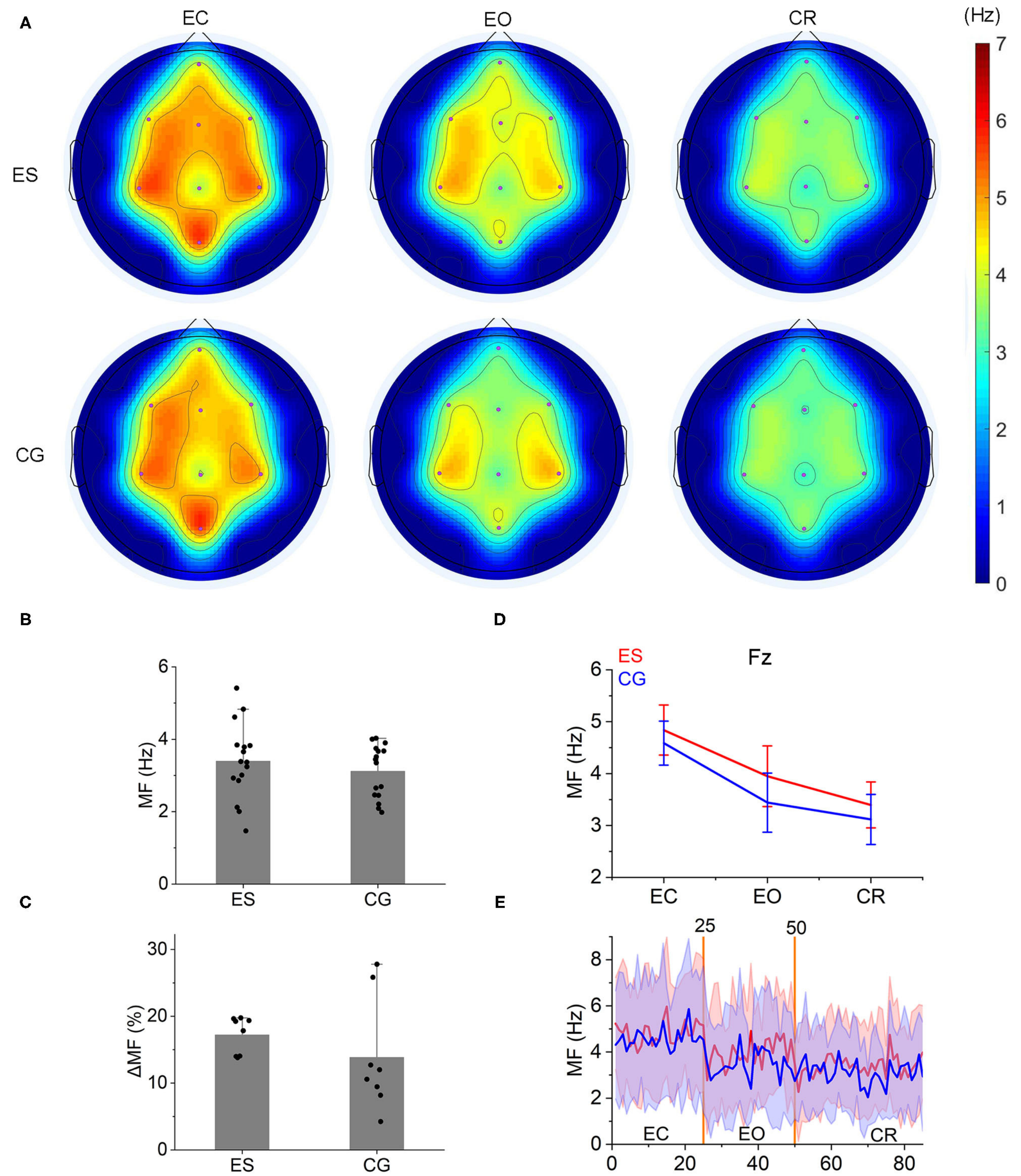

FIGURE 3 | Mean frequency topology and characteristics in the 2 groups. **(A)** From the EC state to the EO state and then to the CR task state, a gradual decrease was shown in the MF topology both in ES and CG. **(B)** During the CR task, the MF of ES was slightly higher than that of CG, but there were no significant differences between the 2 groups ($P > 0.05$). **(C)** The change rate of the MF [$(MF_{eo} - MF_{cr})/MF_{eo} \times 100$] from the EO condition to the CR task did not show significant differences between ES and CG. **(D)** The MF of the 2 groups in the Fz channel decreased from the resting state (EC and EO condition) to the CR task state. **(E)** The change trend of MF at the Fz channel from the resting state to the CR task state.

regions (**Figures 4A–E** and **Supplementary Figures 6, 7**). In terms of the absolute value of the power change, at the δ frequency band (1–4 Hz), ES had significantly smaller power changes in the left frontal area (F3) than CG (**Figure 4A**); in the θ frequency band (4–8 Hz), there was a significant difference in the center of the parietal area (Cz), and the power change of the ES was significantly smaller than that of the CG (**Figure 4B**); at the lower β frequency band (13–20 Hz), ES had a significantly smaller change in the right frontal area (F4) (**Figure 4D**); and in the upper β frequency band (20–30 Hz), an increased power change was found in the left parietal lobe (C3) of ES (**Figure 4E**).

From the EO state to the CR task state, the UBTR of ES decreased significantly less than that of CG in the frontal Fz channel (**Figure 5**). There were 5 channels (F3, F4, Cz, C3, and C4) in which the UBTR changes of the 2 groups interacted. That is, there was an increasing trend in the UBTR change of the ES, while there was a decreasing trend in that of the CG. However, only in the Cz channel was there a significant difference (**Figure 5**).

Supplementary Table 2 and **Supplementary Figure 8A** showed the frontal lateralization index (LI_f) (Method seen **Supplementary Method 2**). There were no significant differences between ES and CG either in the resting state (EC and EO) or in the CR task state ($p < 0.05$). However, the parietal lateralization index (LI_p) of ES was significantly different from that of CG in the CR task state ($p < 0.05$). During the CR task, the LIp value of ES was positive and close to zero, while that of CG was negative and far from 0. This result suggested that top swimming athletes had more balanced left and right cerebral hemisphere activities and more strengthened activation in the right hemisphere than college students (**Table 1** and **Supplementary Figure 8B**).

Blinks and Burst Blinks

The EEG-based blink amplitude and blink frequency of ES were both lower than those of CG, although the absolute values of the 2 groups were not significantly different during the CR task (**Figures 6A–C**). The interblink interval histogram (IBIH) also revealed that the blink frequency of ES in the short interval group was lower than that of CG (**Figure 6E**). From the beginning of the tasks to the following 60 s, the task-related blink rate of ES showed a regular periodic concentrated blink pattern with an interval of ∼15–16 s. However, in the CG, there were continuous blinks in short periods but no obvious concentration pattern. Meanwhile, the blink frequency of CG was almost higher at each time point than that of ES during the first 1 min (**Figure 6D**). Interestingly, there were some burst blinks (more than or equal to 2 blinks in 1 min) in the 2 groups during the CR task. However, ES had more burst blinks than CG in both the burst blink rate (**Figure 6F**) and the proportion of subjects (**Figure 6I**).

To test whether the performance of the CR task was affected by the blinks, we computed Pearson correlation coefficients to evaluate the relationships between the complex reaction accuracy or speed and blink frequency. As shown in **Figure 6G**, there was a negative correlation between $\log_{10}$ blink frequency and complex reaction accuracy in both groups. However, a smaller slope was displayed in the ES than in the CG, which indicated that the task performance of master swimmers was less influenced by the blinks. Consistent with the reaction accuracy, the complex reaction speed also exhibited a negative linear relationship with log blink frequency but was less affected than the reaction accuracy in terms of the slope difference (**Figure 6H**).

DISCUSSION

Our findings showed that elite swimmers were significantly better in performing the eye-hand-foot reaction task while showed less energy-cost wiring connections than age-matched college students. Elite athletes also had highly stabilized eye blinking rate. These results suggest that long-term professional training of arm-leg coordination may facilitate formation of necessary direct wire connections whose number is significantly less than controls. This may be an energy saving for the brain and would enhance the reaction time and keep the brain focus on the task in hand.

Due to long-term professional skill training, athletes are expected to have some phenotypic characteristics (Simonek, 2011). Here, our study showed that elite swimmers had significantly faster reaction speed and more accurate responses to complex reactions than age-matched college students with no professional swimming training. It was consistent with many previous studies (Mori et al., 2002; Williams et al., 2002; Kida et al., 2005). As the number of choices increases, the probability of differences between individuals also increases (Hick, 1952). Complex reaction tasks require not only attention and exercise execution but also the ability to discriminate stimulus's features and to make response selection in a fast way (Miller and Low, 2001). The performance is determined by many factors, such as age, gender, physical activity, and training (Spirduso, 1975; Morehouse and Miller, 1976; Davranche et al., 2006; Enel and Erog, 2006). A 6-week training program could significantly reduce the reaction time of the peroneal muscles of healthy subjects, which might be related to the improvement of reaction inhibition ability by exercise training (Linford et al., 2006). When a selection error occurred in the complex reaction, the individual would spend more time in response suppression to limit the recurrence of the error (Welford, 1988; Koehn et al., 2008). Due to the long-term cooperative training of hands and feet for underwater resistance, the inhibition and control capabilities of swimmers might be improved. Therefore, complex reaction performance is regarded as a behavior characteristic for the selection and cultivation of elite swimmers (Guang et al., 2013).

In addition, a highly efficient mammalian brain is generally shaped with optimal wiring connections of cortical units to support high-profile cognitive functions (Laughlin and Sejnowski, 2003). Such economical wiring networks are developed from long-term learning and shaped by energetically costly spatially distributed spiking and synaptic activities (Alle et al., 2009; Carter and Bean, 2009; Yu et al., 2012) that could be captured by EEG recordings on the scalp. We observed that with almost equal EEG activity levels, the brains of elite swimmers exhibited more decorrelated network connectivity than the control group in the frontoparietal region at the specific upper β frequency band (20–30 Hz). Interestingly, within ES group,

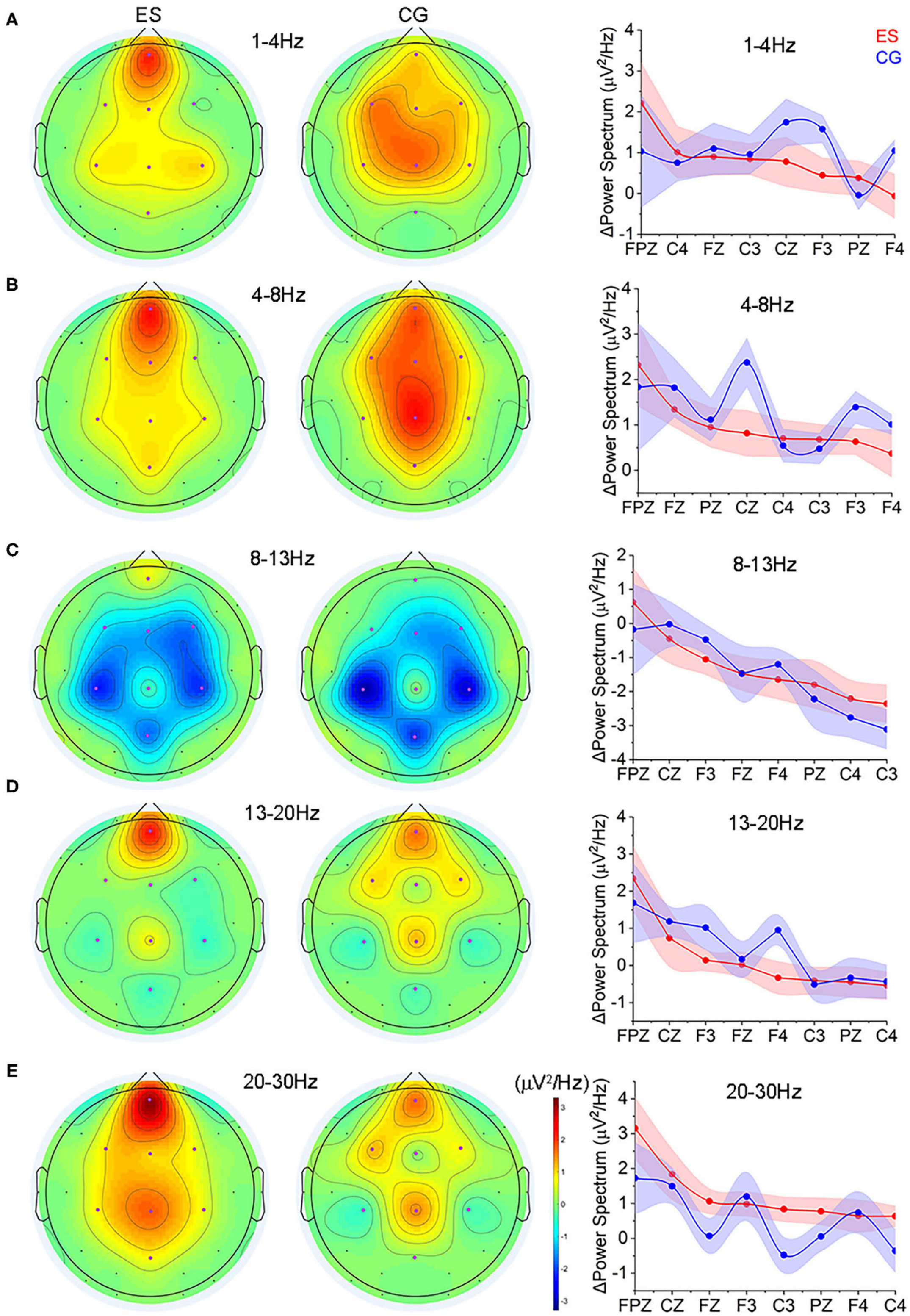

FIGURE 4 | The changes of spectrum power from the resting EO condition to the CR task state. **(A)** Topology of the power changes in the frontoparietal region at the δ (1–4 Hz) frequency band and the differences in the change in each channel at this frequency band between ES and CG. **(B)** Topology of the power changes in the frontoparietal region at the θ (4–8 Hz) frequency band and the differences in the change in each channel at this frequency band between the 2 groups. **(C)** Topology of the power changes in the frontoparietal region at the α (8–13 Hz) frequency band and the differences in the change in each channel at this frequency band between

(Continued)

FIGURE 4 | the 2 groups. **(D)** Topology of the power changes in the frontoparietal region at the lower β (13–20 Hz) frequency band and the differences in the change in each channel at this frequency band between the 2 groups. **(E)** Topology of the power changes in the frontoparietal region at the upper β (20–30 Hz) frequency band and the differences in the change in each channel at this frequency band between the 2 groups.

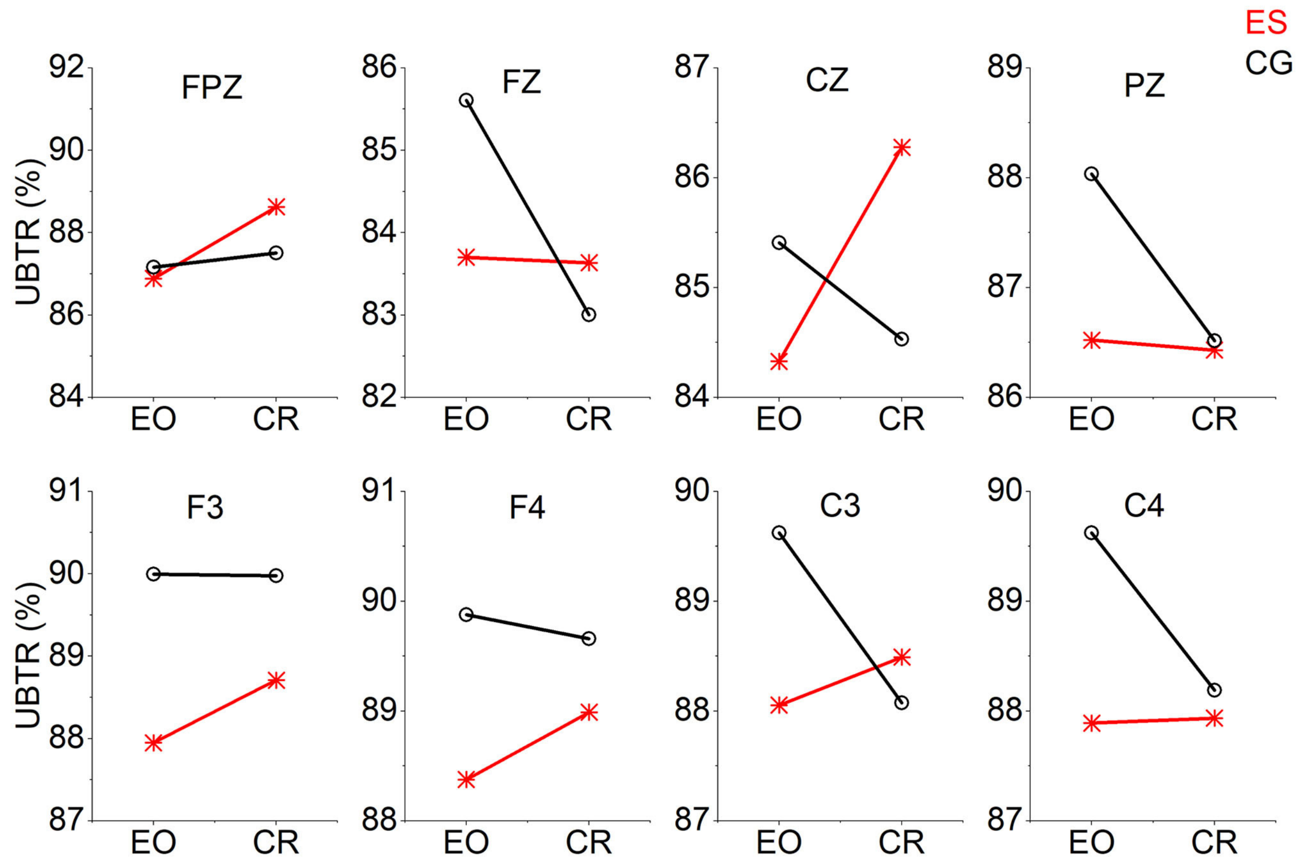

FIGURE 5 | The trend graph of UBTR changes at 8 channels from the EO condition to the CR task condition in the 2 groups. The UBTR changes of the 2 groups interacted with 5 channels (F3, F4, Cz, C3, and C4).

the more wiring connections, the longer training years which positively correlated with CR performance. It indicated that the least wiring connections didn't mean the best performance. There was a balance between them and existing the preferred wiring number of connections during the given task. Previous study has shown that wiring number of connections is highly correlated with the energy cost (Tomasi et al., 2013). The frontoparietal network is observed to be a "fingerprint" that can predict cognitive efficiency or intelligence level (Finn et al., 2015). Thus, functional connectivity with lower intensity and variance in athlete frontoparietal brain may suggest the underlying energy-efficient wirings.

In the other low-frequency EEG bands, the wiring connections and activity cost of elite swimmers were not significantly different from those of the control group. These results indicated that the β frequency band played a key role for the master swimmers. Previous studies have found that the β frequency band is important in sensorimotor integration (Vukelic et al., 2014), attention processing (Chung et al., 2017), or sensory functions such as somatosensory input (Pfurtscheller et al., 2001). The suppression of the β frequency band was significantly related to the reduction in reaction time (Pollok et al., 2014) and response error (Chung et al., 2017). In our research, however, we found that only when the β frequency band was subdivided into lower (13–20 Hz) and higher (20–30 Hz) β frequency bands did the functional connectivity of elite swimmers appear to be significantly different from that of the control group. This result suggested that top swimming athletes might apply different frequency selective strategies when performing complex reaction task.

In addition, in the β frequency band, top swimming athletes were more inclined to focus on the upper β frequency band with greater power changes and less correlated functional connectivity. In the control group, both the lower and upper β frequency bands had wide-ranging power changes with relatively small amplitudes and strong functional connectivity. The pattern

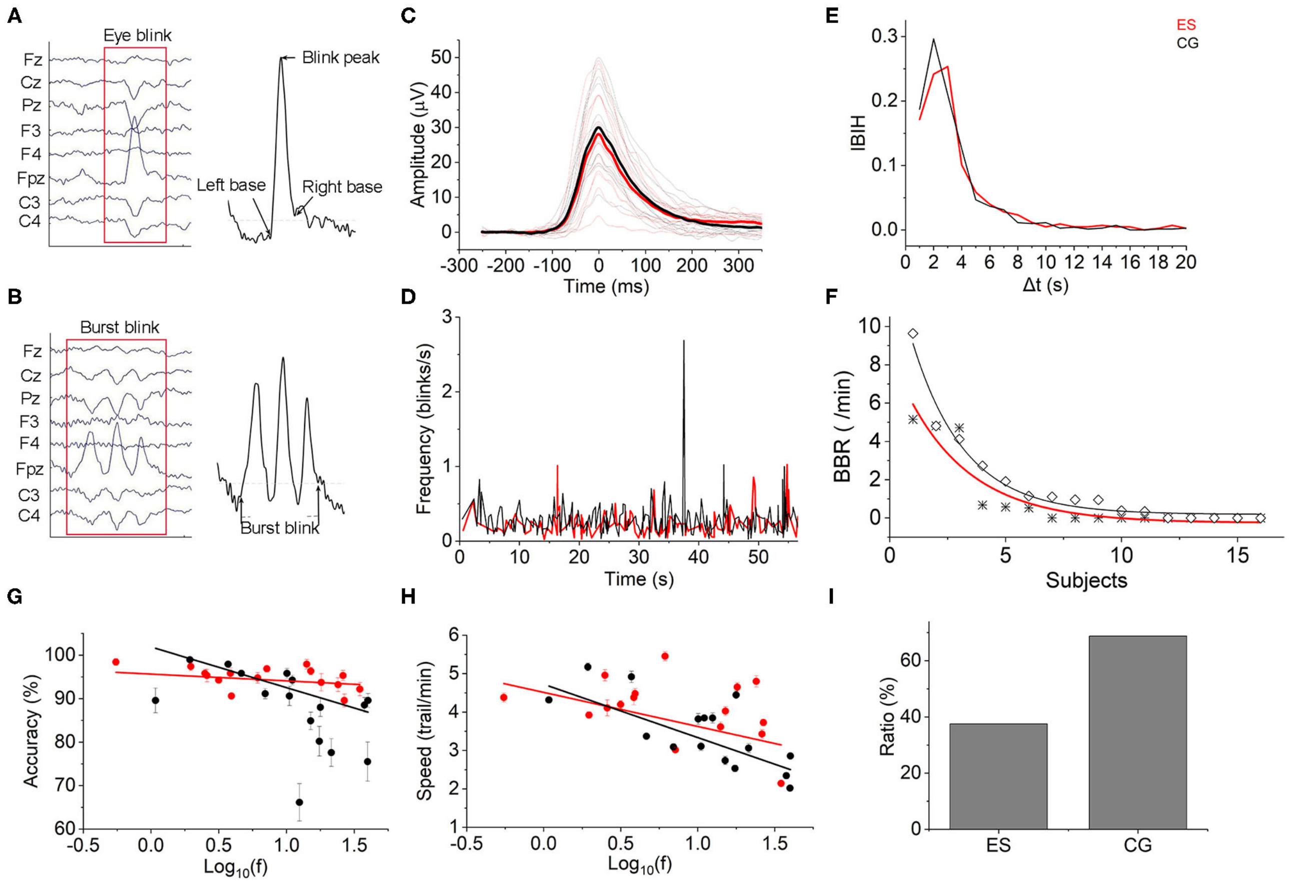

FIGURE 6 | Eye blinks. **(A)** Eye blink diagram from EEG recording data. **(B)** Diagram of burst blink based on EEG data. **(C)** The mean task-evoked blink potentials of ES were lower than those of CG after Z-score normalization. Mean group potential, thick line; individual subjects' potentials, thin lines. **(D)** The mean instantaneous blink frequency of the 2 groups showed different patterns over time from the beginning to 60 ms of the CR task. **(E)** Most interblink interval duration was distributed in <20 s. The IBIH of ES was lower than that of CG, especially at the short interblink interval (≤5 s). **(F)** The BBR of ES (*) was lower than that of the controls (◇). **(G)** Blink frequency and reaction accuracy relationship. There was a negative correlation between them in both the ES and CG [ES: Accuracy= 95.662–1.566 × log10(f), *r*(16) = −0.252; CG: Accuracy = 101.892–9.356 × log10(f), *r*(16) = −0.756]. **(H)** Blink frequency and reaction speed accuracy relationship. Negative correlations were also shown in the 2 groups [ES: Speed = 4.513–0.887 × log10(f), *r*(16) = −0.492; CG: Speed = 4.723–1.386 × log10(f), *r*(16) = −0.77]. **(I)** Burst blinks appeared in 6 elite swimmers (37.5%) and 11 controls (68.75%).

of increasing the power changes of the high-frequency band and reducing the corresponding functional connectivity might be one of the reasons why elite swimmers exhibited higher network wiring cost-efficiency. Moreover, the UBTR changes of the elite swimmers were significantly different from those of the control group in the frontal and central parietal areas. It was mainly manifested in the interactive phenomenon that the UBTR of elite swimmers increased while that of the control group decreased in the left and right frontal and central parietal areas. This further illustrated that the spectrum power changes were different between the elite swimmers and the control group in the low- and high-frequency bands. From the resting state to the task state, top swimming athletes tended to increase spectral power and less correlated functional connectivity to reduce network wiring costs and optimize wiring cost-efficiency.

In the present study, we also found that the parietal lateralization index of the elite swimmers was significantly higher than that of the control group and was closer to 0 during the CR task. The lateralization index reflected the power changes of the left and right hemispheres in the α frequency band (Neubauer et al., 2020). The lower the power of the α frequency band was, the more highly the brain was activated (Bazanova and Vernon, 2014). Therefore, elite swimmers seemed to show more balanced brain activation and higher activation of the right hemisphere. It was demonstrated that leftwards asymmetries were present in the motor control regions and that motor response areas, such as the precentral gyrus, supplementary motor area and several basal ganglia, were initiated in right-handed subjects (Rogers et al., 2004; Dadda et al., 2006; Luders et al., 2006; Toxopeus et al., 2007; Coxon et al., 2010). Our results suggest that the brain activities in the elite swimmers were more bilateral during the complex reaction task, indicating an increased symmetry of 2 hemispheres due to the long-term and regular coordinated movement of arms and legs.

Blink rate was proposed to serve as a non-invasive, indirect measure of dopamine (DA) activity in the central nervous system and has been used to study cognitive control, learning, working memory, and decision making (Eckstein et al., 2017). A previous study observed that higher blink rates predicted better performance on set-shifting and Stroop tasks but worse performance on an updating task (Zhang et al., 2015). Other research revealed that a higher blink rate was related to lower distractibility on tasks that place high demands on working memory (Colzato et al., 2009). In our study, a lower task-related blink rate in elite swimmers showed better performance on complex reaction task, which was different from the Stroop tasks but consistent with the research that blinks affect the performance of visual attention (Cruz et al., 2011). Moreover, the CR task involves many brain regions for vision, motion, planning, cognitive computing, attention, and decision making and may also be closely correlated with DA functions (Westbrook and Braver, 2016). An inverted U-shaped relationship between DA and cognitive control (Goldman-Rakic et al., 2000) indicated that the best cognitive control ability was related to preferred DA activity. That is, a blink rate that is too high might result in worse cognitive control. However, to what extent the blink rate was the best is still open. In light of varying testing- and participant-related affective factors (Eckstein et al., 2017), it is suggested that methods and conditions should be cautiously selected when using blink amplitude or frequency as a biomarker. Moreover, Ponder and Kennedy (1928) noticed that the interblink intervals were quite variable between subjects. Due to the short recording time in our study, there were no significantly different interblink interval distribution patterns between the 2 groups (**Supplementary Figure 9**). Whether the pattern of interblink interval distribution is a biomarker for elite athletes needs to be further cautiously designed and long-term recorded research.

The main limitations of this study were as follows: (1) There were only 8 frontoparietal channels for recording EEG signals, so the brain activities and cost-efficiency of other brain regions are not accessed; (2) the brain cost-efficiency was based on the strength of functional connectivity and mean frequency rather than direct measurement based on blood oxygen or glucose metabolism, which might lack quantitative accuracy. (3) Master-level swimmers were very rare and distributed to 5 main items, so we cannot classify the events in the light of stroke and compared the competition results within the swimmer athlete group.

CONCLUSION

In summary, elite swimmers are faster and more accurate in performing the complex reaction task than controls. By using wiring number of connections between EEG channels to represent wiring cost and mean frequency to index the activity cost of brain, we found that elite swimmer's brain has less and weaker correlations among frontal and parietal regions in upper beta frequency band than controls. This finding suggests that elite swimmers' brains are more energy efficient in wiring connections. However, the mean activity rates of elite swimmers' brains are slightly higher than controls' (although the difference is not significantly), suggesting that they are more actively in response to the task. Meanwhile, athletes showed higher stability and lower eye-blinking rate comparing to controls. A set of distinct physiological features, e.g., energy-efficient wiring connections and stable blinking dynamics, together with behavior performance results, could potentially be used as effective measures, to identify athletes with great potential in achieving competitive performance.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://osf.io/4mzra/.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of the Fudan University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

YY and XP conceptualized and designed the study. XP, XQ, and YC collected data. XP and YJ analyzed data and interpreted results. XP wrote the paper. A-LW commented on the paper. CZ, YY, and XS supervised the research. All authors reviewed and approved the final version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.661632/full#supplementary-material

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