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Bio-banding in Sport: Applications to Competition, Talent Identification, and Strength and Conditioning of Youth Athletes

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ABSTRACT

BIO-BANDING IS THE PROCESS OF GROUPING ATHLETES ON THE BASIS OF ATTRIBUTES ASSOCIATED WITH GROWTH AND MATURATION RATHER THAN CHRONOLOGICAL AGE. CHILDREN OF THE SAME AGE VARY CONSIDERABLY IN BIOLOGICAL MATURATION WITH SOME INDIVIDUALS MATURING IN ADVANCE OR DELAY OF THEIR PEERS. THE TIMING OF MATURATION HAS IMPORTANT IMPLICATIONS FOR COMPETITION, TALENT IDENTIFICATION, AND TRAINING. INCREASED AWARENESS AND INTEREST IN THE SUBJECT OF MATURATION HAS SPARKED A RENEWED INTEREST IN THE STUDY AND APPLICATION OF BIO-BANDING. THIS OVERVIEW DESCRIBES THE PURPOSE AND PROCESS OF BIO-BANDING, POTENTIAL BENEFITS AND LIMITATIONS, AND DESCRIBES SOME RECENT ADVANCES IN ITS APPLICATION IN YOUTH SPORTS.

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INTRODUCTION

Young athletes are traditionally grouped by chronological age (i.e., age based on the calendar date on which an individual was born) for the purpose of competition and training. Children of the same chronological age may, however, vary in biological maturity with some individuals maturing in advance or delay relative to their peers. Maturation refers to progress toward the adult or mature state and can be defined in terms of status, timing, and tempo (54,56,61). Whereas status refers to the state of maturation at the time of observation (e.g., prepubertal, pubertal, postpubertal), timing refers to the age at which specific maturational events occur, such as age at menarche and age at peak height velocity (PHV). Tempo refers to the rate at which maturation progresses. Children of the same age can vary in rate, with some individuals reaching adulthood in advance of others.

Individual differences in the timing of maturation impact both physical and

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psychosocial development (6,56,77). Boys who mature in advance of their peers are, on average, taller and heavier from late childhood. Early maturing boys also tend to experience a more intense adolescent growth spurt (i.e., greater PHV), resulting in greater pubertal gains in height, weight, and lean mass (56). This affords the early maturing male potential athletic advantages, i.e., greater size, strength, speed, and power, especially between the ages of 11 and 14 years when maturity-associated differences in size and function are at their greatest (61). Height differences among early, average (on time), and late maturing youth are, however, negligible in late adolescence/early adulthood. From a psychological perspective, early maturing boys present a more adaptive motivational profile with higher perceptions of the physical self, i.e., strength, attractiveness, physical fitness, and sport competence, and greater self-esteem (24,48). Consequently, early maturing boys are more likely to be attracted toward, and selected into, sports where greater size, strength, and power are desirable attributes, for example, ice hockey, American football, soccer, rugby, basketball, and swimming (61).

The physical and psychological consequences of maturity timing in females are not directly equivalent to those observed in males. Like boys, girls who mature in advance of their peers are taller, heavier, and experience a more intense pubertal growth spurt (56). Pubertal gains in mass in females are, however, largely attributable to body fat, with comparatively smaller gains in lean mass relative to males. As a consequence, early maturing girls tend to outperform their later maturing peers on tests of absolute strength, whereas differences in performances of girls of contrasting maturity status in tests of speed, agility, and power are negligible (9,56). Early maturing females are often overrepresented in sports that emphasize size or strength, such as tennis and swimming, and underrepresented in sports that emphasize aesthetic qualities and/or relative strength and endurance, such as gymnastics, diving, distance running, figure skating, and cycling. Girls advanced in maturation also present a less adaptive psychological profile with lower levels of self-esteem (68) and more negative perceptions of physical attractiveness, fitness, and sport competence (25,38). The associations may, however, vary with cultural and societal expectations and ideals pertaining to female attractiveness (24).

Individual differences in growth and maturation may contribute to competitive inequity and increased risk of injury, especially for athletes who are constitutionally small and/or delayed in maturation (44,52). In this context, proposals to match athletes on the basis of physical attributes rather than chronological age have a long tradition (5,30,55). This strategy is currently labeled "bio-banding" and involves the grouping and/or evaluating athletes on the basis of size and/or maturity status rather than chronological age. Although bio-banding places athletes into groups on the basis of physical characteristics, it does not preclude the consideration of psychological and/or technical skills. An early maturing boy, for example, might be discouraged from competing against or training with older youth if they lacked the technical competence and/or psychological maturity to ensure a safe and positive experience (50,51). Similarly, a late maturing boy who is already thriving within his age group is unlikely to benefit from competing against peers who are younger but of similar maturity. Bio-banding does not preclude the consideration of technical and psychological development. These attributes should be taken into consideration when grouping athletes by size and/or maturation for the purpose of training and competition.

BIO-BANDING: A HISTORY OF THE CONCEPT

The concept of grouping children on the basis of physical rather than chronological age was first advocated in the early 20th century. With reference to child labor, Crampton (21) proposed the use of "physiological age," based on the development of pubic hair (PH; i.e., a secondary sex characteristic), as a more suitable determinant of readiness to work. A year later, Rotch (75) proposed the use of "anatomic age," based on the radiographic assessment of the carpal bones, for grouping children in both school and sports. Commenting on the overrepresentation of early maturing boys competing in the 1957 Baseball Little League World Series, Krogman (45) suggested that assessments of maturation should be considered when determining player eligibility and evaluating athletic potential.

The process of grouping young athletes on the basis of age and weight-based criteria is common in combat sports (e.g., boxing, judo, taekwondo, and wrestling), in which extreme size mismatches are considered to have implications for competitive equity and athlete safety (2). Similar size-based grouping strategies have been implemented in collision sports, such as rugby and American football at younger ages, although they tend to be the exception rather than the rule. Concerns regarding the larger size of some children, particularly those of Polynesian and Maori descent, have prompted a number of youth rugby programs in New Zealand to use weight-based criteria to group children within age groups and/or move players between age groups (86). Weight restricted divisions in rugby are limited to children of a specific age at or below a specific weight criterion (e.g., under 11s $\leq$ 43 kg). For similar reasons, some junior American football programs have used weight criteria to permit children to play down an age band and designate which individuals are allowed to play specific positions and/or advance the ball (86). Adopting a similar, yet more holistic approach, the New York State Public High School Association employ an athlete dispensation rule whereby seventh and eighth graders wishing to participate in interscholastic high schools sports are assessed on a combination of physical, psychological, and technical attributes including medical and sexual maturity status, physical size, fitness, and skill proficiency (81).

Although bio-banding strategies have been designed and implemented in good faith, there is limited evidence that they are effective in reducing injury risk, increasing competitive equity and/or optimizing athletic development. This criticism is, however, more representative of an absence of scientific inquiry into the potential benefits of bio-banding rather than the presence of contrary evidence. Nevertheless, growing concerns regarding the impact of mismatches in size and maturity upon athlete development, welfare, and safety have led to a renewed interest in this subject. Across a range of sports, researchers and practitioners are beginning to explore the broader application of bio-banding strategies with particular interest in how assessments of biological maturation may be used to inform talent identification and development, including the provision of strength and conditioning. In this context, the purpose of this review is to describe some of the novel ways in which bio-banding is being reconsidered and introduced in youth sports, and how it might be used to optimize athletic development and reduce the relative risk of injury (Figure 1).

BIO-BANDING FOR MATURITY

Bio-banding strategies have traditionally grouped athletes on the basis of physical size. In recent years, however, researchers and practitioners have begun to explore the potential benefits of grouping players by maturity status, which raises the question of how to best assess biological maturity status. Assessments of secondary sex characteristics and skeletal age and estimates of age at PHV are impractical for use in youth sports. However, 2 noninvasive and feasible anthropometric methods for estimating maturation have been advanced for use with young athletes–the percentage of predicted adult stature and the maturity offset. The former is an estimate of maturity status, whereas the latter is an estimate of maturing timing, specifically time before PHV, which can be used as an estimate of status, that is, pre- or post-PHV.

Using percentage of predicted adult stature at the time of observation (41,58,64,74), it is possible to group athletes into maturity categories. The distribution of stages of pubic hair (PH) relative to four bands for percentages of predicted mature height attained at the time of observation illustrates the potential utility of this approach (Table and Figure 1). The data are for soccer players 11.0–15.25 years of age at observation. Although numbers are limited, the majority of players with percentages of predicted adult height (PAH) <85.00% and ≥85.00 to <90.00% are, respectively, prepubertal (PH 1) and early pubertal (PH 2). The majority of players with percentages of PAH ≥90.00 to <95.00% and ≥95.00% are, respectively, mid-pubertal (PH 3) and late pubertal (PH 4). Similarly, PHV tends to occur between 88 and 96% of adult height, peaking at approximately 92% (7).

Percentage of predicted mature height is not an indicator of growth velocity, although it can be used to indicate whether a youngster may be progressing through the adolescent growth spurt. As noted, evidence collected from longitudinal data indicate that PHV occurs at approximately 91–92% of adult stature (7,80), with the linear growth spurt lasting approximately 24–26 months (i.e., ±1 year from PHV) (78). Applying a band of 1 year before and after PHV to longitudinal reference data (80), the onset of the adolescent growth spurt (i.e., point of inflection from minimal growth velocity in childhood) would be expected to occur at approximately 88–89% of adult stature before returning to pre-growth spurt velocity (i.e., rate at take-off) at 95–96%. Applying these criteria, it is possible to group athletes as being pre-, circa-, and post-growth spurt. Estimates of percentage of PAH and group assignment should, nevertheless, be cross-referenced with concurrent measures of growth velocity. Growth velocities during the adolescent growth spurt range between 5 and 11 cm in males and 5 and 9 cm in girls. If, for example, a male athlete is at 91% of their PAH and presents a growth velocity of 8 cm per year, it is likely that they are currently experiencing their adolescent growth spurt. In contrast, an athlete at 98% of PAH and presenting a growth velocity of 1 cm per year would be considered post-growth spurt.

The accurate measurement of chronological age, height, and weight of the youth players and of biological mid-parent height is central to the protocol for estimating predicted adult stature. As such, it is important that those responsible for taking such assessments are appropriately trained and qualified. Reported parental heights, adjusted for the tendency for overestimation, have been used in several research studies, although the suitability of this method needs further evaluation. There is also

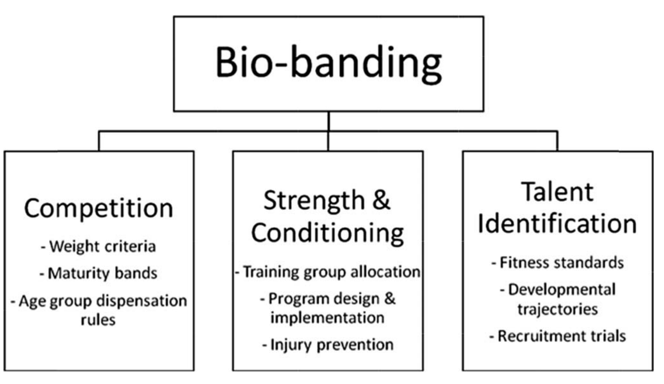

Figure 1. A contemporary model of bio-banding for youth sports.

Table
Correspondence between pubertal status (stage of pubic hair) and somatic maturation as assessed by percentage of adult stature in Portuguese youth soccer players aged 11–15 years

Pubic hair stage	Percentage of PAH bands				Total no. of players
	<85% PAH	85–90% PAH	90–95% PAH	95–100% PAH	
1	40	7	0	0	47
2	15	23	4	1	43
3	1	6	20	8	35
4	0	0	7	25	32
5	0	0	0	2	2
Total	56	36	31	36	159

PAH = predicted adult height.

Calculated by Robert M. Malina with permission from data reported in the study by Figueiredo et al. (31). The analyses presented in this table are based upon data provided by Dr Antonio J Figueiredo, University of Coimbra, Portugal.

a need for further refinement of height prediction equations.

Predicted age at maturity offset (time before or after PHV) and in turn age at PHV (age at prediction minus offset) provides an indicator of maturity timing (65). This method is based on the premise that youth who are advanced or delayed in maturation will experience PHV at an earlier or later than expected age, respectively. Mean age of PHV is, on average, about 13.8 years in boys and 11.9 years in girls (8). Although predicted maturity offset was suggested as a categorical variable, that is, an indicator of maturity status: pre-PHV (>1 year before PHV), circa-PHV (±1 year from PHV), or post-PHV (>1 year after PHV), it is often used as an indicator of maturity timing. The accuracy and reliability of the method has been questioned (57,59,60). Predictions are dependent on age and body size at prediction and have reduced variation compared with actual ages at PHV. They are also influenced by individual differences in actual ages of PHV, especially among early and late maturing youth. Among early maturing boys and girls, predicted ages at PHV are later than actual age at PHV, whereas among late maturing boys and girls, predicted ages are earlier than actual ages at PHV (57,59,60). Intraindividual variation in predicted ages at PHV is also considerable. Similar limitations have been noted for the modified prediction equations (67) in an independent longitudinal sample of boys (42).

Accordingly, practitioners using the maturity offset method should interpret their findings with caution and recognize the limitations of the protocol. Validation studies to date suggest that predicted age at PHV or classifications of pre-, circa-, or post-PHV status may be useful near the time of actual PHV in average maturing boys within a relatively narrow age range, circa 14.0 ± 1.0 years (57,59). Of note, many early- and mid-adolescent male athletes are advanced in skeletal and pubertal maturation (61). Corresponding data for girls are less clear. Predicted age at PHV seems to be useful among some average and some late maturing girls (54,60). A more complete and critical discussion of both invasive and noninvasive methods of maturity assessment is beyond the scope of this discussion (54).

BIO-BANDING AND COMPETITION

Competition is an integral component of youth sports programs and is inherently neither good nor bad (36). Competitive inequity arising from mismatches in size and/or maturity can, however, serve to impede the development of both early and late maturing boys (61). Athletes who mature in advance of their peers experience a competitive advantage in some sports because of their superior size and athleticism (56). Although early developers initially experience more success, it can also be argued that they simultaneously experience less challenge. As a consequence, the early developing athlete is often ill prepared for future competition against physically matched and/or more mature opponents. The competitive and selective nature of many youth sports programs may also encourage the early developer to play to their physical strengths at the neglect of his or her technical and tactical skills (61). A failure to use or develop these skills during a developmental stage (i.e., childhood and adolescence), in which neural pathways are strengthened or removed, may have important implications for learning and future performance (13,14). The consequences of such actions may be most evident in late adolescence and early adulthood, when maturity-associated differences in size and function are either attenuated or in some cases, reversed (47). Collectively, these factors may help explain why those athletes identified as the most able in childhood often fail to meet expectations for success as adults.

Athletes who mature in delay of their peers are at a distinct disadvantage in sports that demands size, speed, strength, and power (56). As a consequence, late maturing players are less likely to experience success and/or be identified as talented. Even if the later developers are selected, they are less likely to play key roles or positions and impact the game (61). It can be argued that the greater challenge associated with being the youngest and/or least mature serves as a stimulus toward superior long-term development. This argument was first advanced by Krogman (45) and is embedded in the "underdog hypothesis" of Gibbs et al. (34), which states that those youth who experience the greatest physical challenges are more likely to develop the technical and psychological attributes necessary for success at the adult professional level. The argument only holds, however, if the challenge is manageable and if the athlete is recruited into and/or retained by the system. At the elite level, the level of challenge associated with being the youngest and/or least mature within an age group is significant. In a sample of academy soccer players at a professional club, players who were late maturing and born in the fourth quarter of the competitive age group (i.e., youngest) were 20 times more likely to be deselected (39). This observation is particularly concerning when one considers the fact that neither date of birth nor maturity timing are an attribute over which the athlete has control.

Research pertaining to the potential benefits of bio-banding is limited and largely restricted to sports in which grouping athletes by age and weight-based criteria is an established practice. Evidence from combat sports suggests that weight-based criteria can eliminate potential selection and performance biases toward older and/or more mature athletes. The absence of a relative age effect in junior boxing has been attributed to the grouping of athletes for competition by a combination of both age and weight-based criteria (26). The relative age effect is also absent in other combat sports that use age and weight-based criteria, for example, Olympic taekwondo and judo (1), with the exception of the "heavy" category in judo where a slight overrepresentation of athletes born in the first half of the competitive year is noted. Although the results of these studies are suggestive, it should be noted that relative age is not an indicator of maturation. It reflects, on average, age differences among youth in the same chronological age year (e.g., 13.50–14.49 or 14.00–14.99 years of age). Accordingly, selection biases toward early maturing athletes may still exist within these sports, especially at the more elite levels. The impact of weight categories on player selection/development and safety in contact sports such as American football and rugby is largely unknown, although observations for Australian rugby suggest that discrepancies in player size do not serve as a risk factor for injury (43).

A CASE STUDY EXAMPLE OF BIO-BANDING FROM THE PREMIER LEAGUE ACADEMY SYSTEM

The English Premier League has been a front-runner with regards to the recent interest in the application of growth and maturation to long-term athlete development. As part of the Elite Player Performance Plan (EPPP) in English soccer, the league recently trialled a bio-banded soccer tournament, in which players were grouped on the basis of biological maturity status rather than age (Bengsch VA. Step forward? Kids in British Premier League academy train based on physical maturity. Available at: https://www.researchgate.net/blog/post/a-step-forward-kids-in-british-premier-league-academy-train-based-on-physical-maturity. Accessed: September 15, 2016) (22). Using percentage of predicted adult stature as the index of maturity status, teams participating in the tournament were restricted to fielding players aged between 11 and 14 years and whose percentage of predicted adult stature fell between ≥85.0 and <90.0%. This band represents the transition from late-childhood to adolescence, that is, early puberty (Table and Figure 2). It is important to note that clubs were advised to consider both the psychological and the technical development of players when selecting their teams.

Players' experiences and perceptions of competing in the bio-banded tournament were captured in a series of focus groups (Bengsch VA. Step forward? Kids in British Premier League academy train based on physical maturity. Available at: https://www.researchgate.net/

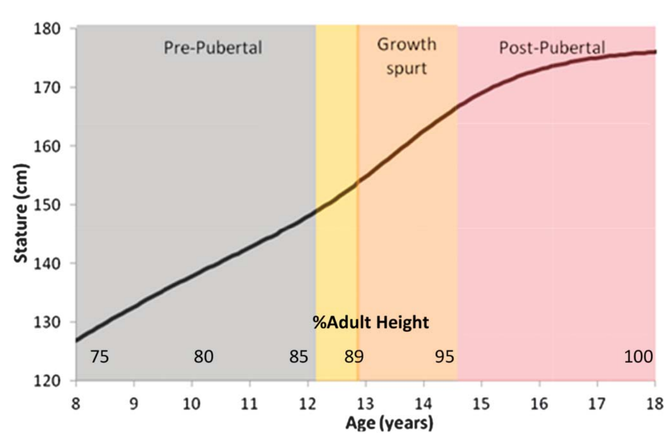

Figure 2. Bio-bands of maturity for an individual male based on cumulative growth and percentage of adult height.

blog/post/a-step-forward-kids-in-british-premier-league-academy-train-based-on-physical-maturity. Accessed: September 15, 2016) (22). Early and late maturing players described their experiences as positive and agreed that the bio-banded games presented them with unique challenges and a more diverse learning experience. They also recommended that the Premier League should integrate bio-banded games within the existing games program and continue to support this initiative. Their reason for supporting the initiative varied, however, relative to their maturational status. Early maturing players described the games as physically more challenging and found that they had to adjust their game emphasizing technique, teamwork, and tactics over physicality. They also described the games as ideal preparation for competing at the adult level and as an opportunity to learn from, and be mentored by, older players.

As expected, late maturing players described their experience as less physically challenging. They did, however, see benefits from having more opportunity to use and demonstrate their complete skills set (i.e., physical technical and tactical), impact and take control of the game, and adopt positions of leadership. It should be noted that while the early and late maturing players unanimously supported the introduction of bio-banded games, they also believed that bio-banding should serve as an adjunct to, and not as replacement for, age-group competition. Coaches also described their experiences as positive and encouraged the Premier League to include more opportunities for bio-banding within the existing games program (Bengsch VA. Step forward? Kids in British Premier League academy train based on physical maturity. Available at: https://www.researchgate.net/blog/post/a-step-forward-kids-in-british-premier-league-academy-train-based-on-physical-maturity. Accessed: September 15, 2016) (22). More specifically, bio-banding was viewed as providing players with a more varied training program and a more diverse set of challenges and learning experiences, contributing to the holistic development of the athlete. Coaches also noted that the tournaments challenged them to "think differently about our players" and gave them an opportunity to evaluate the players' skills and attributes in a more evenly matched environment (22).

Although the results of this initial bio-banding venture show promise, further research is required to fully understand the potential benefits and limitations of such initiatives. The impact of bio-banded competitions on player performance and evaluation is of particular interest. Application of new technologies such as GPS and performance analysis software will permit the examination of the impact of bio-banding upon in-game indicators of performance, for example, peak speed, distance covered at speed, and involvement in singular and repeated high-intensity activities, among others. It should also be noted that while the Premier League has the financial and logistical resources to introduce and potentially benefit from bio-banding, these strategies may be more challenging to implement at the grass roots or local levels. Nevertheless, there is no reason that strategies aligned with the principles of bio-banding could not be considered. In many youth sports programs, for example, it is common for early and late maturing athletes to be encouraged to play up or, to a lesser extent, play down an age group if it is felt that this will aid in the athlete's development and if the athlete is psychologically and socially prepared for such a transition. It should be noted, however, that athletes playing up or down an age group will still have to contend with the significant variances in athlete size and maturity that exist with chronological age groups.

BIO-BANDING AND TALENT IDENTIFICATION

The identification and confirmation (i.e., validation) of talented young athletes is a primary objective of most professional sports clubs, national governing bodies, and many intercollegiate sport programs in the United States. Talent is commonly defined on the basis of success and/or athletic aptitude within competitive age groups (83). However, the entire process of identification and development is superimposed on the demands of physical growth, biological maturation, and behavioral development and their various interactions.

Individual differences in biological maturation directly and indirectly impact the process of talent identification (24). Direct effects reflect the immediate impact of variance in physical and functional attributes upon athletic success, whereas indirect effects reflect the psycho-social interpretation and management of growth and maturation, by the individual athlete and the adults (e.g., coaches, managers) who direct specific sports programs. The body and functional characteristics hold significant social stimulus value for those involved in the identification and development of young athletes (23,66). More to the point, youth with the physical and functional attributes deemed most appropriate for success in a given sport are more likely to be encouraged and rewarded for their participation, obtain more playing time and opportunity to play important positions (i.e., captain), and receive greater access to specialized coaching and training resources (17). Conversely, youth who may be equally talented yet physically less gifted, due to delayed maturation, are less likely to experience success and more likely to be overlooked or excluded (20).

Talent identification strategies that favor youth on the basis of attributes not fully realized until adulthood (i.e., mature size and build, technical and tactical skills) may be counterproductive in the long term. There is a risk in overinvesting in youth who are physically most capable at the expense of those who may have the most potential as adults. As previously noted, maturity-associated differences in size and function observed in adolescence are often attenuated or reversed in adulthood (47). Selection gradients toward the selection of youth of specific maturity status have been documented in a number of sports and tend to increase with age and competitive level (52,53). There is, however, limited evidence to suggest that ability or success in late childhood and adolescence is predictive of success at the adult level. A 7-year follow-up of German athletes across 7 Olympic sports found that only 15 of 4,972 (0.3%) of those selected at the youngest level in each sport eventually ranked among the 10 best international senior athletes (35). Furthermore, a 3-year follow-up analysis noted that only 192 of 11,287 athletes in elite sport schools (1.7%) attained a medal in an international championship as adults. These findings highlight the importance of encouraging multiple sports participation in youth and providing a varied/sampling training stimulus that teaches a broad range of movement skills and prepares athletes for success across a range of activities.

The biggest risk was that we had erred in our assessment of a particular boy and could have used his slot to work with a more talented youngster. We had to wait a little longer to see the real potential in some boys, because not everyone's physique develops at the same rate.

—Sir Alex Ferguson, former manager of Manchester United Football Club (29, p. 260) author

Observations from studies of the relative age effect provide some additional insights. Youth soccer players enrolled in the talent development program of the German Football Association who were born in the first quarter of the competitive year (January–March) presented the highest absolute mean values on a composite index of athletic aptitude (85). However, the scores fell below the median value for age when compared against the developmental curve for age, that is, the oldest players performed the best within their age group but were the weakest when evaluated relative to the developmental curve. Conversely, players born late in the competitive year (October–December) presented the lowest mean scores within their competitive age groups, yet scored well above the median when considered relative to the developmental curve. The largest differences in absolute athletic aptitude scores were observed between those players born at the start of the competitive year and the players born a month earlier (i.e., December) in their next oldest age group. The observation is seemingly consistent with the "underdog hypothesis," which suggests that younger and/or later maturing athletes need to be physically, technically, and psychologically "ahead of the curve" to remain competitive within such programs (34). The results also suggest that older and/or early maturing males get by on their physical prowess rather than their technical or tactical abilities.

CASE STUDY EXAMPLES OF BIO-BANDING FOR TALENT EVALUATION

As part of the EPPP for U.K. soccer, all Premier League and category 1 academies conduct a standardized series of fitness tests on a tri-annual basis (22). The data from each club is entered into the Premier League's Player Management Application and used to generate league-wide age- and maturity-specific reference. On a similar basis, the British Lawn Tennis Association (LTA) (Science could help search for the next Andy Murray. Available at: http://www.bath.ac.uk/news/2016/07/04/tennis-biobanding/. Accessed: September 15, 2016) and Bath Rugby Football Club (Atkinson M. Bio-banding in the academy. Available at: http://www.bathrugby.com/academy-news/bio-banding-in-the-academy/. Accessed: September 15, 2016) combine maturation and fitness data to generate age- and maturity-specific references. Use of these references permits the banding and/or consideration of athletes by both chronological age and maturity status when assessing fitness. The strategy should also enable coaches and practitioners to better account for individual differences in maturation when evaluating athletic ability and potential, and help to identify previously unseen strengths and weaknesses in their athletes. The benefits of considering athletic performance and/or fitness relative to both age- and maturity-specific standards are illustrated in Figures 3 and 4. In Figure 3, the performances of an early maturing 12-year-old male soccer player (player A) on a series of physical fitness tests are plotted relative to reference standards derived from players of the same chronological age. Considering the athletic advantages associated with advanced maturation in males, it is not surprising that player A scores consistently above the mean on tests of speed, power, agility, and aerobic capacity when compared with his same-age peers. When player A's performance is compared against standards derived from youth of the same biological maturation, however, we see a much different pattern of results (Figure 4). In this instance, player A's fitness scores only approximate and, in some instances, fall below the mean (i.e., agility and aerobic capacity), revealing previously unidentified weaknesses. Conversely, a late maturing athlete, who may not appear exceptionally fast or strong compared with same age peers, may present a much more favorable performance compared against their maturational peers.

To better monitor long-term changes in the functional capacity of junior tennis players, the LTA is currently working with the Institute for Mathematical Innovation at the University of Bath to generate age- and maturity specific developmental trajectories for fitness (Science could help search for the next Andy Murray. Available at:

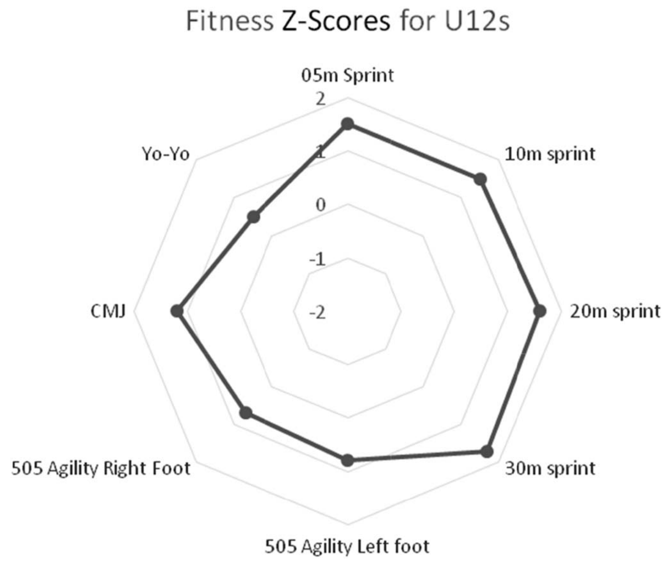

Figure 3. Player A's fitness attributes represented as Z-scores relative to players of the same chronological age.

http://www.bath.ac.uk/news/2016/07/04/tennis-biobanding/. Accessed: September 15, 2016). Developmental trajectories for fitness should enable practitioners to better monitor athlete development while taking individual differences in maturation into account. The trajectories may also help identify periods of acceleration and stagnation and in the partitioning of training-related gains from those that occur as a result of normal growth and maturation. Although the development of age- and maturity-specific references against which a young athlete can be compared represent a step in the right direction, it is important to recognize that functional capacities (peak $\dot{V}O_2$, static strength, power, and speed) also have adolescent growth spurts that vary, on average, relative to the timing of PHV in boys and girls (10,11,56,69).

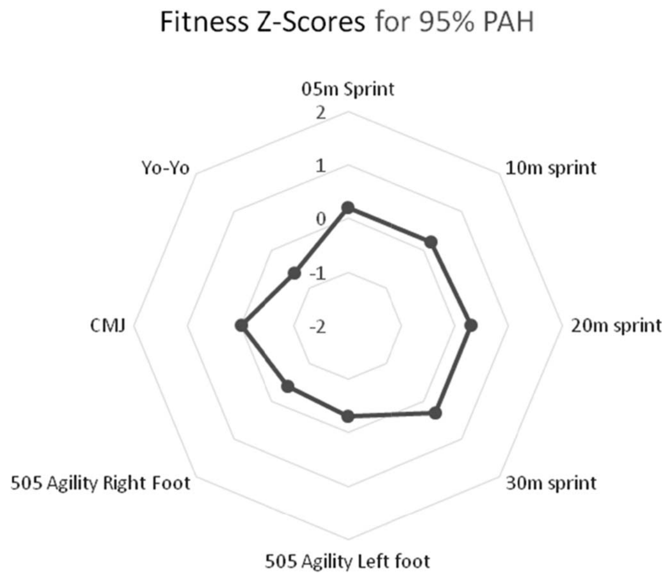

Figure 4. Player A's fitness attributes represented as Z-scores relative to players of the same maturity status.

Recognizing that a selection bias toward older and/or more mature soccer players exists as part of the scouting process, a number of English and Scottish professional soccer clubs have hosted trials restricted to youth born in the last quarter of the competitive year (15). Similarly, a study conducted with the PSV Eindhoven's soccer Academy demonstrated that scouting biases towards relatively older players can be mitigated through the use of age-ordered shirt numbers (62). These strategies and perhaps others attempt to address the relative age bias in athlete recruitment. The overall effectiveness of such strategies may be limited, however, as they do not account for variation in maturity status, as noted in the report (62).

Individual differences in maturity status are not dependent on the calendar. Within a single chronological year, for example, 11.0–11.99 years or 13.0–13.99 years, late, average, and early maturing players are observed within each birth quarter. A player born late in the year, yet who is advanced in maturation, may not be expected to struggle in a competition within their own age group; whereas a player born early in the year who is late in maturation may not be expected to possess an athletic or size advantage over his same age peers. It should be also noted that the relative age effect is a population-based phenomenon reflecting appropriation of athletes of various ages across an organization and, as noted earlier, should not be considered a proxy for maturity status in individual athletes. Nevertheless, organizations and practitioners need to consider how some of these aforementioned strategies could be used to counter selection biases toward older and/or more mature players in the scouting process.

BIO-BANDING AND STRENGTH AND CONDITIONING

Although bio-banding was initially proposed for matching athletes in competition, it also has potential relevance in the context of strength and conditioning. Practitioners have long been encouraged to accommodate individual differences in growth and maturation when designing, implementing, and evaluating training and conditioning programs for young athletes (76). In childhood, for example, gains in strength, speed, and power are best achieved through activities that encourage adaptations of the neuromuscular systems, whereas postpubertal youth are more able to become stronger, faster, and powerful through muscle fiber hypertrophy and increases in the cross-sectional area of muscle (50). It has also been suggested that the adolescent growth spurt is a period of increased risk for overuse injuries and that training and recovery should be more carefully monitored and adjusted during this phase of rapid growth (28,63,70). It remains unclear, however, whether the growth spurt, per se, or the cumulative effect of a range factors related to age, size, and maturity–behavioral changes, training volume, changes in the nature of competition, and perhaps others–contributes to the increased risk of injury. Further research is clearly warranted.

To optimize training effects and ensure athlete safety and well-being, practitioners should consider individual differences in maturity status (51). The Long Term Athlete Development (LTAD) Model was the first model of athlete development to gain worldwide recognition and was adopted and implemented by numerous organizations working with young athletes (4). The LTAD model proposed that the development of young athletes could be accelerated and optimized by implementing the most appropriate training stimuli at specific phases of maturational development known as "windows of opportunity." The authors proposed that through the assessment and monitoring of the pubertal growth spurt, it was possible to adapt training programs relative to their stage of development of individual athletes, thereby maximizing potential benefits. Although the concept of matching training relative to maturity status is intuitively appealing, the LTAD model has been criticized on several accounts (32). Key criticisms included the use of chronological age groups and not maturational bands for defining key phases of development, limited evidence to suggest that a failure to exploit windows of opportunity inhibits athletic development, and too late of an emphasis upon muscular strength development (50). A further limitation of the LTAD model was the lack of consideration of growth spurts in other dimensions and functions, in addition to overemphasis on the importance of the adolescent growth spurt.

Addressing the limitations of the LTAD model, an alternative paradigm named the Youth Physical Development (YPD) model has been advanced (50). The YPD model offers a more comprehensive and detailed framework for understanding athlete development in youth and the impact of maturation on trainability in children and adolescents. A key tenet of the YPD model is that all fitness attributes are responsive to training throughout childhood and adolescence. The most efficacious training modes are, however, those that complement physiological adaptations, which occur as a result of growth and maturation. Referred to as "synergistic adaptation," the principal holds that the athletes' training program (assuming technical competence has been achieved) should expose athletes to training stimuli that complement their stage of maturation (49). Before puberty, optimal strength gains in strength and power are achieved through enhanced neural coordination. Maximum gains in strength and power during and after puberty are achieved through a combination of both neural and structural adaptations, with the latter resulting from a combination of factors, including hormonal and metabolic changes, training stimuli, and nutrition (32). From a bio-banding perspective based on PAH, youth <85% would be considered prepubertal (Table) and training programs would be designed to primarily facilitate positive neural adaptations to enhance force, speed, and power. Youth between 89 and 95% of PAH would be in the mid to late stages of puberty and thus programs should be modified to facilitate both neural and structural changes. Youth at 95% PAH and beyond would be postpubertal and more capable of achieving substantial performance gains through hypertrophy.

Through the consideration of individual differences in maturation and the provision of developmentally appropriate training programs, practitioners may be able to reduce the risk of injuries related to growth and training load. The adolescent spurt is often indicated as an interval during which youth are more susceptible to overuse and growth-related injuries (18,19,28,40,63,70). The prevalence of apophyseal injuries, such as Osgood Schlatter's disease and Sever's disease among youth soccer players peaks during and just before the adolescent growth spurt, respectively, following a curve that is very similar to that of growth velocity in stature (70). The earlier increase in the incidence of Sever's disease may reflect the fact that the growth spurt in the foot typically occurs 6 months in advance of the lower and upper segments of the legs. In line with this reasoning, an increased risk of overuse injuries in Dutch Academy soccer players were noted in the year before and during predicted age at PHV (84). Additional risk factors for such injuries include sex (i.e., being male), neuromuscular control, overtraining, and participation in sports that require running, jumping, and sudden changes of direction (73).

Through regular assessment of growth and maturity status, in addition to concomitant risk factors, practitioners can better identify intervals of greater risk of injury and adjust training programs accordingly. Such strategies may be particularly beneficial for the early maturing athlete who may experience a more intense growth spurt and the late maturing athlete who experiences his or her growth spurt at an age when the demands of training and competition are typically greater and in turn may enhance the risk of injury (84). Consistent with this hypothesis, ballet instructors argue that early maturation is favorable for dancers in that it *"gets the growing out of the way"* at an age when training demands are lower and before important phases of evaluation and selection (66). On a similar basis, delayed maturation in female gymnasts has been identified as a potential risk factor for chronic spine injuries as a result of prolonged exposure of the growth plates to unfavorable mechanical factors, such as repetitive pressures, microtrauma, and impacts (79,87). Through the application of bio-banding, it may be possible to accommodate individual differences in the maturity status of young dancers and adjust training and evaluation practices accordingly. Dancers going through the growth spurt might have their training load adjusted to place a greater emphasis on quality and diversity in contrast to quantity while corresponding adjustments and assessments may be delayed until after the growth spurt in later maturing dancers.

Bio-banding may also be used to better identify and accommodate athletes who experience decreases in movement skills during the adolescent spurt. Commonly referred to as "adolescent awkwardness," some evidence suggests that the rapid changes in size and proportions that accompany the pubertal growth spurt coupled with changes in how the brain processes information about body positioning (12,71) may adversely impact neuromuscular control and proprioceptive ability during the interval of rapid growth. Although empirical evidence remains somewhat limited, it has been argued that decrements in neuromuscular control during the growth spurt result in a decline in motor and functional performances (9), a need to relearn motor skills (18), and an increased potential risk of injury (12,18,19,37,69,72). Similarly, it has been argued that an asynchrony between rates of growth in standing height and bone mass accumulation, occurring between stages 2 and 3 (PH) of puberty, may predispose youth to a high incidence of fractures during this period (3,16,33,46).

To alleviate the potential impact of growth and maturation on skill performance, practitioners should routinely screen athletes to identify any notable deficiencies in fundamental movement skills, especially during the phase of rapid growth. The observation of athletes in training and competition would also help determine the extent to which any such changes impact the performance of sport-specific skills and/or present an increased risk of injury. Note, however, that not all individuals experience decrements in performance during the adolescent growth spurt. Likewise, not all decrements in performance can be attributed to the growth spurt and may arise from training overload, competing interests, lack of motivation, or poor coaching.

Athletes entering phases of rapid development should also be educated on the potential risks to skill performance and their training programs should be adjusted accordingly (18). Both education and implementation should be delivered by individuals (e.g., coaches, sports scientists, or medical staff) who have been trained in the assessment and interpretation of growth and maturity status and who operate as part of a multidisciplinary and integrated athlete support program. A variety of strategies might be implemented to mitigate the effects of growth on skill performance, including the integration of fundamental movement skills in warm-ups and technical sessions, a greater emphasis on movement skills training and a reduced emphasis on performance gains (i.e., quality over quantity), the use of visual and kinesthetic feedback, controlled movement, reaction and motor co-ordination training, and the retraining of functional abilities (i.e., running, lifting, and jump-landing mechanics) (15).

CASE EXAMPLES OF BIO-BANDING FOR TRAINING

When assigning athletes to various bands based on maturity status, it is important to initially consider the resistance training competence and/or psychological maturity (i.e., cognitive and emotional) of the individual athlete. For example, an integrated 3-step process for bio-banding athletes for the purpose of training had been advocated; it includes the assessment of technical, psychological, and maturational development before the athlete is assigned to a specific training group (15). A number of professional soccer clubs in England are already using assessments of biological maturation and technical competence are to group players for the purpose of conditioning (27). Such approaches can also be used to create individualized developmentally appropriate training programs for young athletes.

A progression model (e.g., bronze, silver, gold, platinum), whereby individuals are graded on the basis of their technical, psychological, and maturational attributes, may facilitate the assessment and monitoring of a young athlete's "readiness" to move into and through different stages of a training program (e.g., bronze level = poor technical competency, prepubertal, psychologically immature; platinum = high technical competency, postpubertal, psychologically mature). A stage-based progression model can also help practitioners to monitor and address potential regressions in technical competency in some athletes, which may be related to the adolescent growth spurt (i.e., awkwardness). A coach might, for example, encourage an athlete to revisit a particular stage (e.g., silver to bronze) should they experience a sudden decrement in technical competence. Such models should emphasize the holistic development of the young athlete and any decisions to move an athlete up or down a level should be made on the basis of scientific evidence and input from a specialist practitioner/integrated sports performance team.

SUMMARY

The practice of bio-banding is receiving renewed interest in the context of youth sports and is being applied in a variety of contexts (i.e., competition, training, assessment). Emerging evidence suggests that bio-banding, as an adjunct to age group competition, can benefit both early and late maturing players in academy soccer. Further research is required to replicate the findings and evaluate the extent to which they may generalize to different sports or samples. Some evidence suggests that bio-banding may also have application to the training of young athletes and the processes of talent identification and confirmation. More research is, however, required to substantiate these positions.

Although the process of bio-banding has the potential to contribute positively to the experiences and development of young athletes, it is important to recognize that it is not a panacea and that it should operate as part of a multifaceted and holistic program of development. Bio-banding is one of many tools that can be used to better understand and promote the development and well-being of young athletes. It is not a substitute for age group training or competitions; rather, bio-banding is an adjunct activity that has the potential to challenge the athlete in a unique manner and to create a more diverse and developmentally appropriate learning environment. In line with this reasoning, a more effective athlete development program might include the provision of both age group and bio-banded activities, which offer athletes a more diverse, multifaceted, and developmentally sensitive learning stimulus. A "hybrid approach" (82) might involve monthly or bimonthly bio-banded competitions as part of the existing game program. Such a system would retain the benefits of age group competition while simultaneously addressing its limitations. It would also expose athletes to a broader range of challenges and learning contexts, which may optimize athlete development, skill acquisition, and welfare. A hybrid approach would also permit coaches and scouts to assess abilities and potential of athletes across a wider range of learning environments.

Finally, bio-banding competition, much like age-group competition, has its limitations. Maturity assessments applicable to field conditions need further study and validation. Biological growth and maturation and psychological and social development do not progress in synchrony. Knowing how to best assess and evaluate biological, psychological, and social readiness is essential for improving the effectiveness of bio-banding strategies. Bio-banding, as both a practice and topic of scientific inquiry, is also still in its infancy. Thus, more research is needed to determine its effectiveness and understand its limitations.

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