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Bio-Banding in Youth Sports:

Background, Concept and Application

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Abstract

Background. Inter-individual differences in size, maturity status, function and behavior among youth of the same chronological age (CA) have long been a concern in grouping for sport. Bio-banding is a recent attempt to accommodate maturity-associated variation among youth in sport.

Objective. To review the historical basis of the concept of maturity-matching and its relevance to youth sport, and to provide an overview of bio-banding as currently applied.

Methods. Historical studies of CA as the criterion for work, school and sport among children and early methods of maturity assessment are reviewed. Currently used methods for maturity assessment and age-grouping in sport and related concerns are summarized, followed by consideration of the details of bio-banding, results of recent studies and variation within and between maturity bands.

Results. Maturity-matching in sport has often been noted but has not been systematically applied. Bio-banding is a recent iteration of maturity-matching for grouping youth athletes into "bands" or groups based on a characteristic(s) other than CA. Percentage of predicted young adult height at the time of observation is the estimate of maturity status of choice. Several applications of bio-banding in youth soccer have indicated positive responses from players and coaches.

Conclusions. Application of bio-banding has increased in youth soccer and other sports. The potential utility of bio-banding for appropriate training loads, injury prevention, and fitness assessment merits closer attention, specifically during the interval of pubertal growth. The currently used height prediction equation requires further evaluation.

KEY POINTS

- Bio-banding is a recent iteration of the maturity-matching concept.
- Percentage of predicted adult height at the time of observation is a valid indicator of maturity status.
- Both youth and their coaches have responded favorably to bio-banded soccer tournaments and to training in bio-banded groups.
- Bio-banding in soccer appears to benefit both early and late maturing youth by presenting new opportunities and challenges.
- Bio-banding reduces, but does not eliminate, maturity-association variation.

1.0 Introduction

Bio-banding is a recent effort at grouping youth athletes within a chronological age (CA) range, thus far 11 to 15 years, into "bands" or groups based on a characteristic(s) other than CA for specific competitions and training. Percentage of predicted adult height attained at the time of observation, is the maturity indicator used for bio-banding [1].

Bio-banding serves as an adjunct to and is not a replacement for CA-based groups. It attempts to address inter-individual differences in biological maturity status during adolescence. Maturity-associated variation among youth, including athletes, is well-documented [2-7], but has received more attention among boys than girls [8-9]. Sport is selective and exclusive during adolescence, and selectivity in many sports is based, in part, on maturity status [10].

Given current interest in bio-banding, this review has several objectives: first, to place the concept of bio-banding into a historical context; second, to briefly summarize methods of maturity assessment, CA grouping for sport and associated factors; third, to review current applications of bio-banding; and fourth, to address biological variation within bio-bands.

2.0 Historical Background

Concern for inter-individual differences associated with CA *per se* and biological maturity status has deep historical roots. This surfaced during the industrial revolution in the mid-19th century when the utility of CA as an indicator of the readiness of youth for factory work was questioned. The Factory Act of 1833 in the United Kingdom set CA limits for youth workers [11]. Two laws of the act are relevant. First, it was unlawful for a child to work in mills or factories (except silk mills) unless he/she completed their ninth year of age, and second, it was unlawful for youth to work more than nine hours per day until he/she completed their 13th year (though in silk mills, children under 13 years of age were permitted to work 10 hours per day).

Lack of birth certificates, especially among the poor was a problem, and the utility of CA estimates based on physical appearance was questioned. In 1837, Edwin Saunders [12-13] proposed the permanent dentition as an indicator of CA among children in the context of readiness for work. Using observations of about 1000 children and youth, age-related variation in the eruption of the permanent dentition between 9 and 13 years was emphasized. Eruption of the central and lateral incisors and the first molars was proposed as indicative of the 9th year, and eruption of the canines (cuspids) and second molars as indicative of the 13th year. It was not clear whether the interval between initial (piercing the gum line) and complete eruption of the specific teeth was considered.

About 70 years later in 1904, C. Ward Crampton [14-17], a physician in the New York City public schools, proposed stage of pubic hair as an indicator of "*physiological age*" in boys. Based on a survey of about 1200 first year high school boys 11-18 years of age (majority 13-15 years), three stages were proposed: (1) pre-pubescent – no pubic hair is present; (2) pubescent – pubic hair is present, initially fine and not pigmented and gradually becoming pigmented and changing in texture; and (3) post-pubescent – pubic hair is kinked or twisted (curled). The stages were also labeled, respectively, immature, maturing and mature [16]. Based on further study of body size, muscular strength and school performance of boys 12-18 years, "*physiological age*" was proposed as an indicator of *readiness for work*: "the attempt to establish an age - in the child labor movement - above which a child may safely work and under which he may not, may well take this fundamental fact into consideration" [17, p 142, see note 1].

Although Crampton was the Assistant Director of Physical Training of the New York Public Schools, sport *per se* was not specifically mentioned, but application of the method in medical, educational, social and ethical contexts was indicated. Crampton [17] did not apply the pubic hair criteria to girls, but noted height and weight differences between immature (pre-menarcheal) and mature (post-menarcheal) high school girls 13-16 years.

Soon after the discovery of x-rays by Wilhelm Röentgen in 1895-1896, Thomas M. Rotch [18,19], a contemporary of Crampton, proposed in 1908 the use of "*anatomic age*" based on a radiograph of the carpals and epiphyses of the wrist, to account for individual differences in the context of school, child labor and athletics and in both boys and girls. Noting the dissociation of chronological and "*anatomic*" ages in children <14 years, Rotch [19, p 619) emphasized: "…it does not…mean that…(because a child)…is 10 or 12 chronological years of age, (he/she) should…be grouped in athletics with boys or girls of that chronological age…" *Thus, early in the 20th century Rotch essentially questioned CA grouping in sport!*

Subsequently, the concepts of physiologic and anatomic age were applied in several contexts. The importance of "*physiological age*" in three aspects of the lives of adolescent boys which were significantly influenced by body size and maturity status: *work, social affairs and athletics* were highlighted in 1910 [20], and the distributions of pubic hair stages among boys and the physiological maturity status of girls 10 to 21 years participating in the Baltimore Public Athletic League were described in 1916 [21]. The criteria for girls included menstrual flow, enlargement the breasts, "appearance of subcutaneous fat," and axillary hair. Application of *physiological age* to physical training in both sexes was also noted: "It would be justifiable to arrange physical training schedules in schools on the basis of physiological age, giving boys or girls of the same physiological age similar types of exercise" [22, p 196]. Applications to "mental maturation," school progress and promotion, industrial work, social adjustment, and "moral and religious awakenings" were also noted.

Pubertal assessments were used in studies of physical activity, body size and performance of adolescent boys 12 through 16 years in the 1930s [23,24]. Of interest, the focus was variation in height, weight, strength and motor ability associated with pubertal status *within single year CA groups*, which contrasted earlier efforts and also the reasonably common current practice of grouping youth by stage of pubertal development *without* considering potentially independent effects of CA.

The use of hand-wrist radiographs was extended to studies of epiphyseal union in 1910 [25], and was applied to adolescents in the context of physical immaturity among youth on entry into the United States Naval Academy: "It is common knowledge that a boy of 16 may be so immature that he shows no signs of puberty; yet it is possible, and has indeed happened, that such a youth is admitted to a class in which some of his fellows are completely matured men, and he undertakes necessarily to equal their accomplishments in work and athletics" (26, p 7-8). It was also suggested that admission to the Academy should be standardized by "*anatomic age*".

Application of the principles of skeletal maturity of the hand and wrist on a wider basis, including sport, did not occur until publication of T. Wingate Todd's *Atlas of Skeletal Maturation* in 1937 [27]. Maturity-associated variation in competitive sports for youth was noted in a 1952 report on Desirable Athletic Competition for Children [28]. The report included a comment from Wilton M. Krogman, professor of physical anthropology in the Graduate School of Medicine at the University of Pennsylvania and Director of the Philadelphia Center for Research in Child Growth, which highlighted a comparison of the skeletal maturation of high school boys in Cleveland (n=1028) classified as athletes and non-athletes; the former were biologically advanced by about two years (see note 2).

Implications of maturity-associated variation among younger sport participants were highlighted among participants in youth baseball in the 1950s. Little League baseball was founded by Carl Stotz in 1939, and expanded rapidly with economic prosperity and expansion of urban populations into the suburbs after the World War II [29]. Among 112 players 10-12 years in the 1955 Little League World Series [30], 42 (37%) were pre-pubescent, 19 (17%) pubescent and 51 (46%) post-pubescent. Among 55 players 11-13 years in the 1957 World Series [31], skeletal ages [27] were average (within ±1.0 year of CA) in 25 (45%) and advanced by more than +1.0 year in 25 (45%) players, but were delayed by more than -1.0 year in only 5 (10%) players. The distribution prompted the following: "The successful Little League ball player is old for his age … biologically advanced. This boy succeeds, it may be argued, because he is more mature, biologically more stable, and structurally and functionally more advanced…" [31, p 55]. This observation has been replicated in many studies of male youth athletes in several sports - American football, soccer, ice hockey, basketball, swimming, track and field (except for distance runners); the maturity-related advantage generally emerges circa 12-13 years of age [10,32,33].

3.0 Maturation and Maturity Assessment

Three processes - growth, maturation and development, characterize the lives of children and youth between birth and adulthood. *Growth* refers to the increase in body size, changes in proportions and body composition, and changes in specific systems associated with body size. *Maturation* refers to progress towards the biologically mature stature which varies among systems - skeletal, reproductive, somatic, neuromuscular, neuroendocrine, dental, etc. *Development* refers to the acquisition and refinement of the cognitive, social, emotional, moral, motor and other behaviors expected of the culture within which the individual is reared. The three processes occur concurrently and interact. Interactions are especially prominent during adolescence, influence self-concept, self-esteem, perceived competence, etc., and play a significant role in the development of sport talent. Inter-individual differences in biological maturation also play a central role in the latter as they impact body size, strength, power and motor performances, and influence behaviors, especially during adolescence [7]. Awareness of methods for the assessment of *maturity status* – state of maturation at the time of observation, and *maturity timing* – age at which specific maturational events occur, is thus essential. A related factor is *tempo* or rate of maturation.

3.1 Maturity Status

Two indicators have been traditionally used to assess maturity status, skeletal age (SA) and secondary sex characteristics. Methods of assessment, variation among methods and limitations of SA [7,10,34-36] and methods, specific criteria, reliability and limitations of pubertal status assessments [3,7,36-38] have been previously described. The dentition is another indicator [7], although the teeth have not been used as a maturity indicator in studies of youth athletes. Percentage of predicted near adult height attained at the time of observation [39] is an indicator of maturity status that is increasingly used in studies of youth athletes [40]. The protocol is the indicator of maturity status in applications of bio-banding (see below).

3.2 Tempo of Maturation

Tempo refers to the rate at which the process of maturation progresses in different systems. Longitudinal data are required. Limited evidence suggests that progress in SA (gains in SA relative to CA) and in each secondary sex characteristic (intervals between stages of puberty) varies considerably within and among individuals [36].

3.3 Maturity Timing

The two commonly used indicators of maturity timing are age at peak height velocity (PHV) and age at menarche [7,36]. Both require longitudinal data spanning adolescence Ages at peak velocity of growth in specific body dimensions, and ages at attaining a specific SA, stage of puberty and/or percentage of adult height can also be estimated provided longitudinal data are available [7,41-43]. Ages at PHV for youth athletes are limited due in large part to the selectivity of samples which results in longitudinal height records that do not span the interval of the growth spurt [44]. Many of the studies started too late and/or concluded too early.

More recently, equations for predicting maturity offset defined as time before PHV, and in turn predicted age at PHV, CA minus offset [45], are increasingly used in studies of youth athletes [40]. The sex-specific equations require CA, height, sitting height, estimated leg length and weight. Modified equations limited to CA and height or CA and sitting height in boys and CA and height in girls are also available [46]. Validation studies of the prediction equations in longitudinal samples of Polish [47-49] and U.S. [50] youth have indicated significant intra-individual variation in predicted ages at PHV depending upon CA at prediction, and major limitations with early and late maturing youth of both sexes. Ages at PHV were later than observed in early maturing and earlier than observed in late maturing individuals; the equations had utility within a narrow CA range in average maturing boys close to the time of observed age at PHV.

4.0 Chronological Age in Youth Sports

Youth sports are largely organized by CA within sex. Chronological age at registration for a sport or a specific competition is a function of date of birth and the prescribed cut-off date for age groups and seasons. In addition to CA, other groupings include skill (novice, experienced, select, pre-Olympic, etc.), weight categories (judo, wrestling), and weight and position limitations (American football).

Cut-off dates vary among sports and have varied over time. For example, the upper CA limit was 12 years of age (i.e., not yet 13) at the start of the Little League baseball season (April 30 in 2017). Among teams who progressed through the play-offs, many boys were 13 years of age by the time of the Little League World Series in August. The cut-off date for the 2018 season was thus changed to August 31 so that all players would be 12 years or under at the time of the World Series [51].

In European soccer, the competitive season generally begins in September and CA of youth players as of December 31st of the competitive season defines specific age groups. Thus, a player classified as U12 will not have attained his 13th birthday by January 1st or a player classified as U14 will not have attained his 15th birthday by January 1st of the competitive season. Since the season continues through the spring, some 12 year old players will be 13 years and some 14 year old players will be 15 years during the second half of the season.

Grouping youth by maturity status for a sport, often labeled maturity-matching, has been often mentioned but has not been systematically applied [8,9]. Primary objectives of maturity grouping include equalizing competition, enhancing opportunity for success, injury prevention as in size-mismatches, individualization of training and talent development. The latter are apparent in efforts to "protect" talented later maturing youth by "holding them back" to avoid mismatches in size and athleticism in their competitive CA group. This challenge is explicit in the comments of Sir Alex Ferguson [52, p 260]:

> "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."

Individual differences in maturity status and timing are also implicit in discussions of injury prevention. Status implies size-mismatches, while timing implies susceptibility to certain injuries associated with differential timing of growth. A survey of injuries in youth players from 38 soccer academies indicated no clear association with the adolescent years, with two exceptions [53]. Sever's disease (heel, calcaneal apophysitis) and Osgood-Schlatter's disease (knee, inflammation of patellar tendon of the anterior quadriceps muscle at the tibial tuberosity) accounted for only 5% of all injuries, but the former occurred most often among U10 to U14 players (peak U11 players), while the latter occurred most often among players U12 to U16 years (peak U13- U14 players) [53]. In the general population, CAs of boys with Sever's disease ranged from 9 to 15 years with a median of 12 years [54], while CAs of boys with Osgood-Schlatter's disease ranged from 12 to 15 years [55]. Both conditions were also more prevalent among youth active in sport, and may be related to the differential timing of growth in segments of the lower extremity. The adolescent spurt occurs first in the distal segments (foot and ankle, followed by the lower leg (tibia), and the proximal segment (femur); the growth spurt of the trunk follows that of the lower extremities [7].

"Playing up" a grade in school sport in the U.S. is a related issue, especially in middle or junior high school (7^{th} and 8^{th} grades). The New York State Public High School Athletic Association includes maturity status among several criteria for an athlete in the 7^{th} or 8^{th} grade, to "move up" and compete with those in higher grades in interscholastic sport [56,57]. In addition to approval of parents and local board of education, the protocol calls for evaluation of general medical status, pubertal status (boys - pubic hairs, girls - menarcheal status), height and weight, prior experience in the sport, physical fitness, coach rating of proficiency in skills, and a try out for the team. Guidelines for other states, in contrast, focus on CA. Some permit a 7th or 8th grader who is "old for his grade" to play up according to his CA [58], while some do not permit 7th and 8th graders to play up [59]. As the population in some rural areas of the U.S. declines, the number of students in school districts also declines so that the issue of "playing up" may increase in significance in an effort to field teams in some sports.

Two issues merit attention is addressing the potential utility of grouping youth by maturity status for sport, training and/or specific competitions: variation in maturity status within a competitive age group, and variation in CA and other characteristics among individuals of the same biological maturity status. The first is illustrated in Table 1 among soccer players in two competitive age groups, while the second is illustrated in Table 2 for the total sample of players grouped by stages of pubic hair. Variation in CA, body size, current height as a percentage of predicted adult height, skeletal maturity status, functional capacities and sport-specific skills within competitive age groups and among players of the same pubertal status is considerable.

Behavioral implications of maturity-matching strategies should not be overlooked. Youth athletes should be viewed in a holistic perspective, recognizing variation in psychosocial and technical/tactical characteristics, in size and maturity-related characteristics, and their potential interactions. Strategies should be in place to prepare and support players who are "playing up" or "playing down" a CA group to increase the likelihood that they possess the necessary skills to adapt to the challenges. Asking a player to compete against younger, physically matched peers, may create a perception that the athlete is less able or does not have the potential to succeed at the adult level. Such concerns can be allayed through education and by highlighting the fact that several successful late developing soccer players have played down an age group at various stages of their development, for example, Alex Oxlade-Chamberlain, Jesse Lingaard, Danny Welbeck.

5.0 Bio-Banding

Bio-banding refers to the grouping of youth athletes within a given CA range, 11 to 15 years, into “bands” or groups based upon estimated biological maturity status for specific competitions and/or training. Percentage of predicted adult height attained at the time of observation is the maturity indicator presently used in bio-banding. It is a recent application and extension of the concept of “maturity matching” [8,9].

5.1 Height Prediction

Height prediction equations used clinically include SA among predictors [60-66], although a height prediction protocol without SA was recommended as a non-invasive indicator of maturity status [39]. The suggestion was based on the common clinical premise that mid-parent height (average of the heights of the biological mother and father) provides a target range within which the adult height of a youngster will likely fall. Sex-specific prediction equations without SA were subsequently developed [67] and are used in current applications of bio-banding. The equations were developed on participants in the Fels Longitudinal Study, all of whom were of European ancestry (White) and from families of middle and upper socioeconomic status in southwest Ohio, U.S.; families of low socioeconomic status were under-represented in the sample [68].

The sex-specific prediction equations [67], commonly called the Khamis-Roche method, include age-specific constants from 4.0 to 17.5 years for height, weight and mid-parent height. The protocol requires CA, height and weight of the youngster and mid-parent height. The height of the youngster at the time of observation is then expressed as a percentage of his predicted adult height. *This is the indicator of maturity status at the time of observation*. Youth are grouped into specific bands based on percentage of predicted adult height, e.g., ≥85.0% and <90.0%, or ≥90.0% and <95.0% [69-73]. The bands are assumed to span the adolescent spurt, but bands are not fixed and may be modified as needed. Nevertheless, a major source of error in height predictions "…is the inability to predict the timing or the intensity of the adolescent growth spurt" [74, p 4].

Measurement variation in height and weight (inter- and intra-observer technical errors of measurement) should be noted; it may influence predictions. This also applies to parental heights, although reported parental heights adjusted for the tendency to overestimate height have been generally used.

Across the age range of the Khamis-Roche prediction equations for males, mean error and standard deviation at the 50th percentile was 2.2±0.6 cm; the corresponding error at the 90th percentile was 5.3±1.4 cm [67]. Focusing on the age range in which bio-banding has been applied, 11-15 years, median age group specific errors at the 50th percentiles ranged from 2.4 cm to 2.8 cm, while corresponding errors at the 90th percentiles ranged from 5.5 cm to 7.3 cm. The median and 90th percentile errors translate to approximately 1.5% and 3.0 % of predicted height for the average male. Given errors associated with height predictions, some players may be in or out of a band due to error associated with predictions.

Nevertheless, the bio-banding grouping strategy apparently reduces maturity-associated variation compared to that observed in competitive CA groups and in competitive bands. The latter is suggested in a box plot analysis of percentage of predicted adult height for players in four US Soccer developmental academies (Figure 1). In addition to single year CA groups, two methods were used to bio-band male players by percentage of predicted adult height. The first, Quartile Bio-banding (QBB), involved transferring players in the most and least mature quartiles within a CA group, up or down an age group, respectively, i.e., the most mature U13s were grouped with the U14s and the least mature U14s were grouped with the U13s, and so on. The second strategy grouped players within a maturity band which restricted percentage of predicted adult height to a specific range, ≥85.0% and <90.0%. For each CA group, the bio-banding strategy reduced the range of variation in maturity status and also reduced differences at the extremes of the maturity continuum. Although variation was reduced, the inclusive medians were very similar across the CA and bio-banded groups.

5.2 Predicted Height and Other Indicators of Maturity Status

The relationship between estimated maturity status based on percentage of predicted adult height at the time of observation and an established indicator of maturity status is relevant. Among American football players 9-14 years, concordance between maturity status (late, average, early) based on SA (Fels method [75]) and percentage of predicted adult height was moderate, <11 years, 69%, 11-12 years, 52%, ≥13 years, 67% [76]. Similar moderate concordance was noted between the two maturity indicators in soccer players 11-12 years (57%) and 13-14 years (63%), while Spearman rank order correlations between stage of PH and maturity status based on percentage of predicted adult height were significant,11-12 years (rho=0.34) and 13-14 years (rho=0.36), but at the low end of the moderate range [77].

5.3 Applications of Bio-Banding

Several studies have considered responses of youth soccer players to bio-banded competitions. Players 11 through 14 years from four English Premier League (EPL) academies with current heights ≥85.0% and <90.0% of their predicted adult heights participated in three, 11-a-side games (25 minute halves) on a regular size field [69,70]. Sixteen players participated in focus groups which emphasized player perceptions of their experiences competing in bio-banded groups, i.e., competing with players of similar maturity status. Perceptions of coaches were also considered.

Overall, the experiences were positive for all players. Early maturing (younger boys "playing up" with older boys of the same maturity status) and late maturing (older boys "playing down" with younger boys of the same maturity status) players presented contrasting but favorable views of the bio-banded games. Early maturing players viewed the games as not as challenging physically compared to age group competitions, but had to adapt their style of play to a faster game and had to place more emphasis on tactics and techniques. Late maturing players also viewed the games as less challenging but liked the opportunity to demonstrate and develop their technical, tactical and physical skills, and often adopted leadership and mentoring roles in the games.

Coaches noted that many early maturing players (younger boys playing up) were getting by on their size and strength alone, and were forced to modify their game to different challenges, adopting a more technical, tactical and team-oriented style of play. In contrast, coaches of late maturing players (older boys playing down) noted aspects of play not ordinarily seen due to their dependence on their size/strength advantage; from another perspective, coaches noted that the late maturing boys could demonstrate their skills instead of being physically dominated in age-group competitions [69,70]. Older late maturing boys were also more likely to step into leadership roles, instructing, motivating and mentoring their younger yet physically matched peers. Consistent with the players, the coaches agreed that the process of restricting maturity-related variation in body size and athleticism results in a game that emphasized technical and tactical aptitude over physicality.

Game demands of 13 EPL academy players 13-15 years (14.0±0.4 years) with current heights ≥90.0 and <95.0% of their predicted adult heights were compared in CA-based and bio-banded 11-a-side matches (40 minute halves) [71,72]. Percentage of time in different heart rate intensity zones (via telemetry) based on percentage of maximal heart rate did not differ between CA-based (85.4±4%) and bio-banded (84.8±4%) matches. Match performance analysis, adjusted for playing time, suggested more passes and touches, and slightly more shots on goal in the bio-banded match.

Round robin bio-banded tournaments for four boys' teams (CA 12.5-15.4 years) and four girls' teams (CA 12.3 to 15.2 years) were recently hosted by US Soccer; each team competed in three games (40-minute halves). Results paralleled observations in the EPL tournaments and were generally similar among males and females [78]. Early maturing players of both sexes reported greater levels of physical challenge and described the process of playing up as a superior learning experience. While late maturing players described the experience as less physically and technically challenging, they reported more opportunity to utilize and demonstrate their physical and technical attributes and to assume positions of leadership. Both early and late maturing boys and girls described the games as placing a greater emphasis upon creativity and technical competence over physicality, and also described the tournament as beneficial to their development, more enjoyable and less stressful. The participants also enjoyed the opportunity to play and compete with new players.

6.0 Related Issues

Although the studies of bio-banded matches are promising, questions regarding percentage of predicted adult height as a maturity indicator and variation within bands merit attention.

6.1 Changes in Percentage Adult Height with Age

Data for three longitudinal studies of the general population and two cross-sectional studies of American football and soccer players are summarized in Table 3. The former have a measure of near adult or young adult height, while the latter are based on percentage of predicted adult height. The data were reasonably concordant across the CA range and those for athletes 13-14 years were generally consistent with advanced skeletal maturity status observed at these ages [79,80]

6.2 Bands and the Adolescent Spurt

Applications of bio-banding [69-72,78] have used bands described as spanning the adolescent spurt – percentages of predicted adult height ≥85.0% and <90.0%, and ≥90.0% and <95.0%. How do the bands relate to the adolescent spurt, specifically percentage of adult height attained at take-off (TO) and at PHV in longitudinal studies? Among Polish boys [42], 80% of adult height was attained at 11.0±0.8 years, while TO occurred at 11.8±1.2 years. PHV was attained at about the same age as 90% of adult height in Polish boys, 14.0±1.2 years and 13.9±1.0 years, respectively [42], and in U.S. boys, 13.8±1.2 years and 13.7±1.0 years, respectively [41]. Recent analyses of two early longitudinal series (Brush Foundation, Cleveland; University of California Berkeley) also noted occurrence of PHV at about 90% of adult height in boys [81].

The preceding focused on central tendencies. Among boys in the Zurich longitudinal study, median percentages of adult height attained at TO and PHV and respective 10th and 90th percentiles were reported [82]. Median percentage of adult height at TO (11.2±1.1 years) was 81.5% (10th and 90th percentiles, 78.3% and 84.5%) and at PHV (14.0±0.9 years) was 91.5% (10th and 90th percentiles 89.8% and 92.9%). Using the 10th and 90th percentiles for percentages of adult height attained at TO and at PHV, percentages of adult height ≤85.0% but >90.0% would appear to approximate the interval between TO and PHV.

6.3 Variation within Different Bands

Using the observations for Swiss boys [82], American football players, 11.0-14.2 years [76] and club soccer players 11.0-15.2 years [80] were grouped into four bands based on percentages of predicted adult height at the time of observation using the Khamis-Roche method [67]: ≥78.0% but <85.0% - about Take-Off (at-TO); ≥85.0% but <90.0% - interval between TO and PHV (TO-to-PHV); ≥90.0% but <93.0% - about the time of PHV (at-PHV); and ≥93.0% - post-PHV.

Distributions of the youth athletes in each sport and associated variation in CA, SA (Fels), height, weight, and maturity status within the respective bands are summarized in Table 4. Variation within and among bands should be noted. Among youth American football and soccer players within three of the four bands, CA was similar; soccer players in the post-PHV band were older. Proportionally more American football players were advanced in skeletal maturity in each band, while late maturing players were absent in the at-PHV and post-PHV bands. Among soccer players, the proportion of late maturing youth based on SA declined across the four bands, while three stages of pubic hair were represented in three bands and four stages were represented in the post-PHV band. The range of heights within each band was reasonably similar except for American football players in the group at-TO. The range of weights, however, was considerably greater among American football compared to soccer players in each of the bands, and increased across bands.

6.4 Predicted Height with and without SA

Predictions of adult height which include SA among the predictors are generally viewed as more accurate than predictions without SA. In this context, the concordance of bio-banded groups based on two height prediction equations developed on the Fels longitudinal sample, one using CA, height, weight and mid-parent height [67] and the other using CA, height, weight, mid-parent height and SA [64], were compared in the American football and soccer players (Table 5). Bio-banded groups with the two equations were concordant in 71% (70 of 98) of American football players and in 82% (131 of 159) of soccer players. Concordance of classifications was highest in the post-PHV band in both sports; each had only one misclassification. Concordance was generally the same in the other three bands among American football players, about 67%. Among soccer players, however, concordance declined systematically across bands, from 80% (at-TO), to 75% (TO-to-PHV) and to 65% (at-PHV).

6.5 Maturity Variation within Bands

Characteristics of soccer players classified as late, average or early maturing (based on SA minus CA) within each of the four bands spanning adolescence are compared in Table 6. Maturity-related differences in height and weight in each band were consistent with the gradient noted in the literature, i.e., early > average > late [7]. The counter movement jump (CMJ), an indicator of power, showed a similar gradient in the TO-to-PHV, at-PHV and post-PHV bands. In contrast, endurance (yoyo shuttle run) in the bands at-TO and TO-to-PHV showed, on average, a gradient of late > average > early, although differences were rather small. A similar trend was suggested for the sprint and agility, but differences in endurance, sprinting and agility were not consistent between average and early maturing players in the at-PHV and post-PHV bands. In contrast, two soccer-specific skills, task and ego orientation, and coach evaluations of potential did not vary by maturity status within the four bands.

6.6 Other Considerations

As applications of the bio-banding concept increase, many academies systematically measure heights at quarterly and perhaps shorter intervals to monitor changes in height and weight for the purpose of estimating changes in predicted maturity status. Of relevance, changes in height and weight during the course of the day (diurnal variation) and differential growth during the year (seasonal variation) require attention. Youngsters are tallest upon arising and "lose" height, especially in the first three hours [83], while weight tends to increase during the day. Youth also should not be measured soon after training. Seasonally, youth also grow more in height during the spring and summer, and more in weight during the fall and winter [84].

While it is possible to consider technical and psychological skills in banding, the latter more likely follow variation in CA and experience rather than maturity status. Maturity-related contrasts in size, strength and power are more significant between 11 and 15 years [7] and often attract the attention of coaches, while technical and psychological skills are likely more relevant in later adolescence. For example, adolescent soccer players 13-14 years selected by trainers for regional teams were taller and heavier, advanced in skeletal maturation, and performed better in power and speed tests than unselected teammates [85]. In contrast, body size did not differ between selected and not-selected late adolescent professional players 16-18 years, while the former performed better in functional (shuttle sprint), technical (dribbling) and tactical (positioning, deciding) tasks [86].

Bio-banding is often mentioned in the context of the relative age effect (RAE), the over-representation of players born early within a competitive year. While it appears logical to assume that the oldest players within a CA group would be the most physically mature, evidence indicates that the RAE and biological maturity status are independent [87,88]. The RAE is present during childhood and generally maintained through adolescence, whereas the maturity-related bias emerges with the onset of puberty and increases with CA and level of competition [89]. The RAE and maturity status are functions of different factors, respectively, the calendar (birth and cut-off dates) and genotype [7]. It is entirely possible for a young athlete to be the oldest within a CA cohort and also the least biologically mature, and vice versa. Solutions to counter the RAE during youth should be considered, including attributes associated with older CA and experience within competitive groups. Other potential considerations include competitions based on mean CA and rotating cut off dates, 4th quarter trial days, and use of visual cues to help coaches/scouts account for differences in CA among players [90].

7.0 Conclusions: What Bio-banding Is and Is Not

Bio-banding attempts to accommodate individual differences in size, strength and power associated with variation in maturity status by grouping youth athletes into specific bands defined by percentage of predicted adult height at the time of observation. It is neither a complete solution nor panacea; variation in maturity and its correlates, size and power, is reduced but not entirely eliminated.

Bands are biologic constructs applied in specific contexts. They are not fixed and can be modified in terms of absolute values and widths. Applications of specific bands may also be varied to provide experiences for all players to periodically play up or play down.

Bio-banding is an adjunct to and not a replacement for CA groups. It has been applied only in the short term, e.g., experimental tournaments, training matches, training activities, etc.

Bio-banding is potentially useful for both identifying and developing talent. It may facilitate the accommodation of maturity variation when evaluating an individual’s talent and also provide an appropriate environment and challenges in which individuals varying in maturity status can optimally develop.

Bio-banding has been applied in samples of varying backgrounds and perhaps mixed-ancestry. The height prediction equations used in the bio-banding protocol were developed on better-off American children and adolescents of European ancestry. The issue of potential ethnic variation in height prediction merits attention.

Research is required to better understand the potential benefits and risks of bio-banding and how coaches, sport psychologists and parents can better support players to ensure that such strategies contribute positively towards youth development.

Note 1

Although Crampton is given credit for coining the term "physiological age," he indicated that the credit "…properly belongs to … Franz Boas, who, with G. Stanley Hall and Luther H. Gulick, gave the author (Crampton) the encouragement of their approval and interest" [90, p 52]. Boas was an anthropologist with a primary interest in the study of growth and especially adolescence, Hall was a psychologist who focused on adolescence, and Gulick was a physician active in school physical education and physical training.

Note 2

Krogman worked under the direction of T.W. Todd at Western Reserve University in Cleveland in the 1930s; skeletal maturity was likely assessed with the atlas method of Todd [27] which was in the process of development at this time.

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Sean Cumming has worked in research and consultancy roles with the Premier League, the English Football Association, the lawn Tennis Association, and British Gymnastics.

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Caption for Figure

Figure 1. Percentage of predicted adult height attained at observation by chronological age groups (U13, U14, U15) and bio-banded groups based on quartiles and percentage of predicted adult height.

Table 1. Variation (minimum, maximum) in chronological age, maturity status, body size functional capacity and sport-specific skills among youth soccer players in two competitive age groups*

	U12 soccer, n=87	U14 soccer, n=72
Chronological age, yrs	11.0-12.9	13.3-15.2
Skeletal age (Fels), yrs	8.3-14.6	12.0-17.7
Pubic hair	stages 1-3	stages 2-5
Height, cm	132.2-160.7	142.8-182.9
Height, % Pr Ad Ht#	77.2-92.4	87.1-100
Weight, kg	26.5-55.0	34.0-77.5
Sprint, sec†	9.96-7.45	8.91-7.02
Agility, sec†	24.6-18.4	20.9-15.9
CMJ, cm	6.7-38.3	22.4-46.1
Yoyo endurance run, m	240-2880	320-3960
Dribbling, sec†	23.1-13.1	16.7-11.7
Passing, pts	8-23	11-30

*Calculated from data reported in Figueiredo et al. [80]. Observations were made early in the season for U12 and late in the season for U14 players; several thus attained their 15th birthday. Functional and skill tests: sprint – fastest of 7 sprints (35 m with a slalom), agility – 10 x 5 shuttle run, CMJ - counter movement jump (ergo-jump protocol), yoyo – intermittent endurance test level 1, dribbling – slalom dribble, passing – wall pass

#current height as a percentage of predicted adult height

†times inverted as a better performance is a lower time

Table 2. Variation (minimum, maximum) in chronological age (CA), skeletal age (SA), body size, functional capacities and sport-specific skills among U12 and U14 soccer players grouped by stage of pubic hair (PH) development*

	Stages of Pubic Hair			
	PH 1	PH 2	PH 3	PH 4/5
N	47	43	35	32/2
CA, yrs	11.0-12.8	11.0-14.1	11.3-15.2	13.5-15.2
SA (Fels), yrs	8.3-14.3	11.1-14.4	10.7-16.5	13.1-17.7
Height, cm	132.2-152.6	136.1-165.4	143.0-177.1	151.1-182.9
Height, %#	77.2-87.0	82.3-95.7	84.8-98.2	91.0-100
Weight, kg	26.5-41.0	31.0-61.0	35.5-70.0	45.0-77.5
Sprint, sec†	9.09-7.45	9.96-7.41	8.91-7.15	8.56-7.02
Agility, sec†	24.1-18.4	24.6-17.9	20.9-15.9	20.2-17.3
CMJ, cm	6.7-37.2	10.1-44.0	18.3-46.1	22.9-42.7
Yoyo, m	400-2880	240-3720	320-3840	480-3960
Dribbling, sec†	19.5-13.3	23.1-12.6	17.3-11.7	16.3-12.1
Passing, pts	8-23	10-23	14-16	11-30

*Calculated from data reported in Figueiredo et al. [80]. Observations were made early in the season for U12 and late in the season for U14 players; several thus attained their 15th birthday. Functional and skill tests: sprint – fastest of 7 sprints (35 m with a slalom), agility – 10 x 5 shuttle run, CMJ - counter movement jump (ergo-jump protocol), yoyo – intermittent endurance test level 1, dribbling – slalom dribble, passing – wall pass

#height as a percentage of predicted adult height

†times inverted as a better performance is a lower time

Table 3. Percentage of adult height attained at different chronological ages (CA) in three longitudinal studies (Fels, University of California, Berkeley – UCB, Wroclaw Growth Study - WGS) and percentage of predicted adult height at the time of observation in two cross-sectional studies of youth American football and soccer players*

	% Adult Height			% Predicted Adult Height	
CA	FELS	UCB	WGS	AmFB	Soccer
9.0	75.6%	75.6%	74.8%	75.4%	
9.5		77.2		77.2	
10.0	78.6	78.4	78.2	79.3	
10.5		79.8		80.3	
11.0	81.6	81.3	80.6	82.3	82.4%
11.5		82.5		83.5	83.6
12.0	84.9	84.0	83.4	85.1	84.9
12.5	85.4			87.4	85.8
13.0	88.7	87.3	87.4	88.9	90.0
13.5		89.2		91.3	91.2
14.0	92.7	91.0	91.4	94.1	93.9

*Percentage of measured young adult height in the Fels [39], UCB [61] and WGS (Kozieł, unpublished) studies and percentage of predicted adult height in American football [79] and soccer [80]) players

Table 4. Chronological age (CA) and skeletal age (SA, Fels), body size and maturity status based on SA of American football players 11.0-14.2 years and soccer players 11.0-15.2 years within several bands of percentage of predicted adult height at the time of observation*

	Bands based on Percentage of Predicted Adult Height			
	at Take-off	TO to PHV	at PHV	Post-PHV
	≥78.0 <85%	≥85% <90%	≥90% <93%	≥93%
American Football	n=29	n=36	n=18	n=15
CA, yrs	11.0-12.7	11.2-14.0	12.0-14.2	12.4-14.2
SA, yrs	9.6-14.3	10.7-15.0	13.2-16.1	14.4-17.5
SA-CA, yrs	-2.7 +2.7	-1.7 +2.8	-0.3 +2.8	-0.5 +3.3
Height, cm	131.8-163.7	148.5-168.0	154.2-177.8	159.9-181.7
Weight, kg	27.4-63.6	42.4-92.6	40.0-102.8	53.4-108.0
Maturity status				
SA Late	9	2	0	0
SA Average	8	11	3	3
SA Early	12	23	15	12
Soccer	n=55	n=36	n=20	n=47
CA, yrs	11.0-12.6	11.0-14.0	12.8-14.2	13.4-15.2
SA, yrs	8.3-13.9	9.3-14.5	12.4-16.5	13.4-17.7
SA-CA, yrs	-4.2 +2.7	-3.1 +3.4	-1.7 +2.8	-0.9 +2.7
Height, cm	132.2-153.2	140.8-160.7	143.0-169.3	157.3-182.9
Weight, kg	26.5-50.5	31.0-55.0	37.0-63.0	45.0-77.5
Maturity Status				
SA Late	12	6	2	0
SA Average	31	19	12	28
SA Early	12	11	6	19
PH 1	39	7		
PH 2	15	23	4	1
PH 3	1	6	14	14
PH 4			2	30
PH 5				2

*Calculated from data for American football reported in Malina et al. [76] and for soccer years of age reported in Figueiredo et al. [80]. No football player and one soccer player had a % predicted adult height <78.0%. Stage of pubic hair (PH) was available only for soccer players.

Table 5. Concordance of bio-banded groups based on predicted adult height without SA [89] and with SA [87] in American football players 11.0-14.2 years and soccer players 11.0-15.2 years*

Bands based on Predicted Adult Height with SA	**Bands based on Predicted Adult Height without SA**				
	At Take-off ≥78.0 <85%	TO to PHV ≥85% <90%	At PHV ≥90% <93%	Post-PHV ≥93%	Total
American Football					
At TO, ≥78.0 <85%	**20**	2	0	0	22
TO to PHV, ≥85% <90%	9	**24**	0	0	33
At PHV, ≥90% <93%	0	10	**12**	1	23
Post-PHV, ≥93%	0	0	6	**14**	20
Total	29	36	18	15	98
Soccer					
At TO, ≥78.0 <85%	**44**	7	0	0	51
TO to PHV, ≥85% <90%	11	**27**	4	0	42
At PHV, ≥90% <93%	0	2	**13**	1	16
Post-PHV, ≥93%	0	0	3	**46**	49
Total	55	36	20	47	158

*Calculated from data for American football players reported in Malina et al. [76] and for soccer players reported in Figueiredo et al. [80], No football player and one soccer player had a % predicted adult height <78.0%. SA was assessed with the Fels method.

Chi square: American football = 139.78, p<0.000; Soccer = 274.11, p<0.000

Table 6. Characteristics of youth soccer players 11.0-15.2 years classified by skeletal maturity status within bands of percentage of predicted adult height at the time of observation*

		Bands based on Percentage of Predicted Adult Height											
		at Take-off ≥78.0 <85% n=55			TO to PHV ≥85% <90% n=36			at PHV ≥90% <93% n=20			Post-PHV ≥93% n=47		
		n	M	SD	n	M	SD	n	M	SD	n	M	SD
CA, yrs	L	12	11.8	0.5	6	13.0	0.7	2	14.1	-	-		
	A	31	11.6	0.4	19	12.6	0.8	12	13.6	0.4	28	14.5	0.5
	E	12	13.4	0.3	11	11.9	0.5	6	13.3	0.3	19	14.2	0.6
SA, yrs	L		9.9	0.7		11.2	1.0		12.7	-			
	A		11.5	0.7		12.6	0.8		13.8	0.7		14.6	0.4
	E		13.2	0.5		13.9	0.5		14.9	0.9		15.9	0.9
Height, cm	L		138.3	4.0		144.7	3.0		147.1	-			
	A		142.8	5.6		147.9	3.5		156.7	3.8		167.3	6.1
	E		143.4	5.2		152.3	6.1		159.9	5.6		170.7	4.6
Weight, kg	L		33.3	3.8		35.8	2.3		40.0	-			
	A		36.5	4.7		39.9	4.9		47.0	5.0		56.8	7.6
	E		37.2	5.2		46.8	5.6		49.3	7.2		62.1	7.7
Sprint, sec	L		8.3	0.5		8.0	0.5		8.0	-			
	A		8.5	0.6		8.1	0.4		8.0	0.4		7.8	0.4
	E		8.6	0.5		8.4	0.5		7.7	0.1		7.7	0.4
Agility, sec	L		20.3	1.4		19.8	0.6		18.8	-			
	A		20.7	1.3		19.8	1.4		19.4	0.8		18.7	0.8
	E		21.0	1.1		20.7	1.7		18.3	0.7		18.4	1.1
CMJ, cm	L		22.2	6.0		24.6	4.5		27.2	-			
	A		26.5	5.1		26.6	6.9		28.9	6.5		32.0	4.6
	E		25.2	4.7		27.3	5.8		29.8	4.4		33.8	3.8
Yoyo, m	L		1673	721		2473	901		2980	-			
	A		1246	695		1827	809		1877	898		2661	933
	E		987	756		1331	838		2447	529		2591	984
Dribbling, sec	L		15.5	1.4		15.0	2.1		13.2	-			
	A		16.0	2.2		14.6	1.3		13.8	1.1		13.1	0.7
	E		16.4	1.7		15.7	2.0		13.7	0.9		13.5	1.1
Passing, pts	L		18.8	2.1		20.3	2.2		19.0	-			
	A		16.8	3.6		19.8	1.7		20.3	3.3		22.4	3.1
	E		16.8	3.4		18.2	2.9		20.3	2.4		20.6	3.8
Potential	L		3.3	1.2		3.5	1.0		4.0	-			
	A		2.8	1.2		3.4	1.1		2.5	0.9		3.6	1.1
	E		3.1	1.1		3.2	1.4		3.5	1.5		3.3	1.2

Task	L	4.3	0.5	4.5	0.2	4.1	-		
	A	4.2	0.5	4.3	0.5	4.3	0.5	4.1	0.6
	E	4.5	0.3	4.2	0.4	4.1	0.4	4.1	0.7
Ego	L	2.2	0.5	1.8	0.6	2.1	-		
	A	2.2	0.8	1.9	0.6	2.0	0.6	1.8	0.6
	E	2.4	0.7	1.8	0.6	1.4	0.3	1.7	0.6

*Calculated from data reported in Figueiredo et al. [80]; see Table 1 for details of the functional and sport-specific tests