

Pubertal Status: Assessment, Interpretation, Analysis

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Inter-individual variation in biological maturation is a common theme in research pediatric exercise sciences, in general, and also in research with young athletes. This is evident in the relative success of boys advanced in maturation in several sports, e.g., soccer, ice hockey, American football, among others, and of girls later in maturation in artistic gymnastics and figure skating, especially as level of competition increases [1-3]. There is also a need to control for variation in biological maturation in studies of the growth and performance characteristics of youth athletes.

Biological maturation can be viewed from two perspectives, status and timing. The former refers to the state of maturation at the time (chronological age, CA) of observation, while the latter refers to the CA at which specific maturational landmarks are attained. The two most commonly used indicators of maturity status are Skeletal Age (SA) and stage of development of secondary sex characteristics. Two commonly used indicators of maturity timing are age at menarche and age at Peak Height Velocity (PHV); both, however, require longitudinal data to obtain estimates for individuals [4].

This commentary focuses on secondary sex characteristics - Breast (B) and Pubic Hair (PH) in girls and Genital (G) and PH in boys - as they are widely used, and at times misused, in studies of young athletes. Each characteristic is most often evaluated at clinical examination on a five stage scale using the criteria described by Tanner [5]; 1=no development, 2=initial appearance or development, ... 5=mature state. Note, however, self-assessments using the criteria of Tanner are increasingly used as are several other modified scales of pubertal development. Given the sensitivity of evaluating pubertal status, the issue of the reproducibility of assessments and potential error has not received sufficient attention.

Overt manifestation of Breast (B2) and Genital (G2) development marks the transition into puberty in girls and boys, respectively. Timing and sequence are variable among individuals; Pubic Hair (PH2) may precede B2 and G2 in some youth. Stages 3 and 4 reflect maturity progress on the path towards stage 5 (the mature state), and are more difficult to differentiate than stages 2 and 5. Testicular volume is an additional indicator of sexual maturation in boys but it requires direct palpation of the testes.

Allowing for potential error in assessment, stages of puberty have several limitations which should be noted [4,6]:

1. Stages are discrete categories imposed on a continuous process of maturation. A youngster is either in a stage or not in a stage; there are no intermediate stages.
2. Assessments indicate stage at time of observation and provide no information on the age at which the stage was entered or how long the youngster has been in the stage.
3. Stages are not equivalent within sex (B3≠PH3 in girls, G3≠PH3 in boys) and between sexes (B3≠G3; PH3 in girls≠PH3 in boys).
4. Duration of a stage and age at transition from one to another are difficult to estimate. To do so requires longitudinal observations at relatively short intervals.

5. Rate of transition from pubertal onset to maturity is highly variable among individuals and is not extensively documented.

In addition to stages *per se* and sampling strategies, pubertal status of youth is variably reported among studies, which limits comparability. Some studies simply note pubertal status (pre-pubertal, pubertal, and post-pubertal) of subjects based on B and/or PH or G and/or PH. At times, this is done without specifying the characteristic (s) that was (were) assessed [7]. Note that pre-pubertal children of the same CA are not uniform in maturity status; they can vary by as much as four or five years in SA [4]. Stages of B and PH or G and PH are occasionally combined into a single score, e.g., 1.8 or 2.6, or reported as means and standard deviations [8,9]. As noted, stages are discrete categories. There are no intermediate stages equivalent to 1.8 or 2.6.

Youth are also often grouped by stage of PH, B or G independent of CA. Variation in CA among youth at the same stage of puberty is problematic. Assume two girls in B3 or two boys in G3, respectively, one 11 and the other 14 years; the older youngster at the same stage of puberty has had three more years of growth. Older youth within a stage are, on average, taller and heavier.

It is also difficult to assume variation in maturity timing (i.e., early or late) based on CA within a specific stage. For example, a study addressing the relationship between overweight and sexual maturation among youth 10-15 years used quartiles of CA adjusted for pubertal stage to differentiate youth by maturity timing [10]. Within each sex and statistically adjusting for stage of puberty (girls B, boys G), youth in the first quartile (youngest) of CA were considered "early maturers" while those in the fourth quartile (oldest) of CA were considered "late maturers". As noted, stages indicate only status at the time of observation and provide no information on how long the youngster has been in a particular stage. Unfortunately, distributions of stages of puberty by CA group or variation in CA within pubertal stage were not reported.

The tempo of maturation - the rate of progress through puberty, is a related concept. Observations from two longitudinal studies indicate that progress from G and PH stages 2 (onset) to 5 (maturity) can take less than 2 years in some boys, and 5 years and perhaps more in others [11,12]. Similar variation for B and PH is apparent in longitudinal observations of girls [13,14]. Moreover, there is little relationship between the age at which a secondary sex characteristic begins and the length of time required to pass through the stage.

Coelho-e-Silva et al. [15] examined 80 basketball players aged 12-

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Received January 27, 2013; **Accepted** January 27, 2013; **Published** January 31, 2013

Citation: Coelho-e-Silva MJ, Valente-dos-Santos J, Figueiredo AJ, Sherar LB, Malina RM (2013) Pubertal Status: Assessment, Interpretation, Analysis. J Sports Med Doping Stud 3: e134. doi:10.4172/2161-0673.1000e134

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13 years of age and after testing differences between participants in stages PH2, PH3 and PH4 basketball in functional capacities (strength, aerobic fitness) and sport-specific skills. The analysis was repeated using chronological age as covariate. In parallel, another study with young soccer players aged 11-14 years [16] examined inter-individual variability in physical performance associated with skeletal maturity given by the discrepancy between SA and CA (delayed, on-time, advanced). Evidences of maturity related variation of performance in the soccer and basketball studies are not comparable, since stage of puberty used in youth basketball did not inform about the tempo and, not surprisingly, demonstrated a different influence on functional capacities compared to the study of young soccer players who were examined by age group based on categories derived from the discrepancies between CA and SA.

In summary, stages of puberty provide an indication of maturity status at the time of observation. Youth of the same CA can vary considerably in pubertal status, just as youth of the same pubertal status can vary considerably in CA. Both realities need to be recognized in studies of pubertal development of young athletes. Information on the age of transition from one stage to the next, or on the duration of a stage is limited.

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