An assessment of maturity from anthropometric measurements

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ABSTRACT

MIRWALD, R. L., A. D. G. BAXTER-JONES, D. A. BAILEY, and G. P. BEUNEN. An assessment of maturity from anthropometric measurements. *Med. Sci. Sports Exerc.*, Vol. 34, No. 4, pp. 689–694, 2002. **Purpose:** The range of variability between individuals of the same chronological age (CA) in somatic and biological maturity is large and especially accentuated around the adolescent growth spurt. Maturity assessment is an important consideration when dealing with adolescents, from both a research perspective and youth sports stratification. A noninvasive, practical method predicting years from peak height velocity (a maturity offset value) by using anthropometric variables is developed in one sample and cross-validated in two different samples. **Methods:** Gender specific multiple regression equations were calculated on a sample of 152 Canadian children aged 8–16 yr (79 boys; 73 girls) who were followed through adolescence from 1991 to 1997. The equations included three somatic dimensions (height, sitting height, and leg length), CA, and their interactions. The equations were cross-validated on a combined sample of Canadian (71 boys, 40 girls measured from 1964 through 1973) and Flemish children (50 boys, 48 girls measured from 1985 through 1999). **Results:** The coefficient of determination (R^2) for the boys' model was 0.92 and for the girls' model 0.91; the SEEs were 0.49 and 0.50, respectively. Mean difference between actual and predicted maturity offset for the verification samples was 0.24 (SD 0.65) yr in boys and 0.001 (SD 0.68) yr in girls. **Conclusion:** Although the cross-validation meets statistical standards for acceptance, caution is warranted with regard to implementation. It is recommended that maturity offset be considered as a categorical rather than a continuous assessment. Nevertheless, the equations presented are a reliable, noninvasive and a practical solution for the measure of biological maturity for matching adolescent athletes
Key Words: CHILDREN, ADOLESCENCE, GROWTH SPURT, PUBERTY, MATURITY, LONGITUDINAL STUDY

It is essential that all prospective studies in children, both in context of youth sport classification and research investigations, attempt to control for maturity. Matching children to equalize competition, enhance chance for success, and reduce injury is an objective that many coaches and health professionals have emphasized (3,15). Maturity assessment has specific application in the classification of children for sport during the adolescent period. The range of variability between individuals of the same chronological age in somatic and biological growth is large and especially accentuated around the adolescent growth spurt (13,17,18,26). The formal methodologies to assess maturation are beyond the resources of sport-governing bodies or youth sport organizations and, therefore, the need to revert to chronological age as the classification criteria. Despite the major maturity-related differences in height, weight, strength, speed, and endurance of children at identical chronological age classifications (16,19), chronological age remains the only accepted classification criterion. To date, maturity status has rarely been a factor used in participant classification into youth sports.

Chronological age is of limited utility in the assessment of growth and maturation (14). The need to assess maturation, the tempo and timing of the progress toward the mature state, is imperative in the study of child growth. Although existing methodology provides the required mechanism to assess maturation, there are limitations to the available methodologies (4). Skeletal age assessment, the single best maturational index, is costly, requires specialized equipment and interpretation and incurs radiation safety issues. Although the methodology covers the entire period of growth from birth to maturity, it does not lend itself to fieldwork. Dental age and morphological age are broader measurement techniques with limited applicability. The assessment of secondary sex characteristics is limited to the adolescent period and in a nonclinical situation is considered to be personally intrusive by adolescent children and their parents. In addition to a limited application period, secondary sex characteristics do not reflect the timing of growth. Somatic methods like age of peak height velocity (PHV) or the differential growth associated with regional growth require serial measurements for a number of years surrounding the

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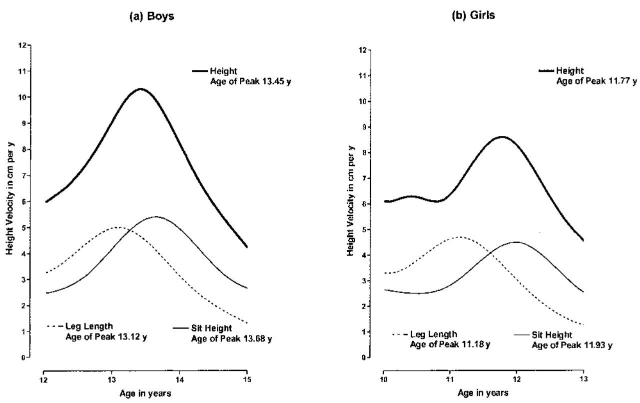

FIGURE 1—Timing of peak velocities in (a) boys' and (b) girls' height, sitting height, and leg length.

occurrence of peak velocity and thus are unusable in a one-off measurement in time.

Age of PHV is the most commonly used indicator of maturity in longitudinal studies of adolescence (16). It provides an accurate benchmark of the maximum growth during adolescence and provides a common landmark to reflect the occurrence of other body dimension velocities within and between individuals. Using the known differential timings of growth of height, sitting height and leg length (Fig. 1) we hypothesized that the changing relationship between leg length and sitting height with growth may provide an indication of maturational status.

The purpose of the present study was to develop a simple, nonintrusive method to assess maturity status in children, years from peak height velocity, using anthropometric variables. The availability of data from three longitudinal studies provided a unique opportunity to develop predictive equations and verification samples to apply and test the equations.

METHODS

Subjects. Data were selected on children who were between 4 yr from PHV and 3 yr after PHV. The predictive equations were developed using data from the Saskatchewan Pediatric Bone Mineral Accrual Study (BMAS). The study was a mixed longitudinal study designed to assess the factors associated with bone mineral accrual in growing children. The study was conducted from 1991 to 1997 and consisted of 113 boys and 115 girls. A full complement of anthropometric measurements was taken on a semiannual basis; a complete description of the study including details with regard to ethical consent can be found elsewhere (1,2).

The verification samples were children taken from the Saskatchewan Growth and Development Study (SGDS) and the Leuven Longitudinal Twin Study (LLTS). The SGDS consisted of 207 7-yr-old boys who were randomly selected on a stratified socioeconomic basis from the elementary school system in Saskatoon, SK, and who were measured annually from 1964 to 1973. The girls' sample was drawn in a similar fashion as the boys' sample. However, the boys' sample was a pure longitudinal design whereas the girls' sample followed a mixed longitudinal design, with smaller groups of subjects added each year and followed longitudinally. A complete description of the study's testing protocol, sampling, analytical techniques, and ethical consent is available elsewhere (20). The LLTS measured 95 twin pairs at semiannual intervals between 10 and 16 yr and at 18 yr. This study ran from 1985 through to 1999 with the intake spread over several years; again, details of the study including ethical consent can be found elsewhere (5). To be included in the present analysis, subjects required an age of peak height velocity. The number of subjects from each study meeting this criterion are shown in Table 1.

Measurements. For both Canadian studies, identical anthropometric measurements were taken. Height and sitting height were measured to the nearest mm, body mass to the nearest 0.1 kg. Two measurements were taken for each anthropometric variable. A third measurement was required if the first two differed by more than 4 mm for height and sitting height and 0.4 g for weight (20,1). The two measurements for each anthropometric measure were averaged. If three measures were taken, the median value was used (1). The anthropometric techniques for LLTS are described elsewhere (5).

Both the BMAS and the SGDS used the age of PHV as the maturity measurement. Each subject's distance data were used to calculate whole-year velocities. Peak height velocity was determined for each individual with a cubic spline fitted to the velocity data (21). The age of PHV was individually determined and not derived from group data. In the LLTS, age of PHV was determined by the application of the Preece-Baines model I to individual data (23). Table 2 provides a comparison of the age of PHV between the three studies. By using the age of PHV as the maturational benchmark, each measurement occasion was described as years from PHV by subtracting the age of PHV from the chronological age at each measurement occasion. The difference in years was defined as a value of maturity offset.

Leg length to sitting height ratio was used as a method to predict maturational status. Table 3 illustrates the pattern of this ratio variable and its sensitivity to the occurrence of PHV. The

TABLE 1. Subject numbers, number of observations, and test occasions.

	Boys			Girls		
Study	Subjects	Observations	Tests	Subjects	Observations	Tests
BMAS	79	659	5–13	73	599	6–12
SGDS	71	433	4–7	40	225	4–7
LLTS	50	588	9–13	48	378	7–13
Total	200	1680		161	1202	

BMAS, Saskatchewan Pediatric Bone Mineral Accrual Study; SGDS, Saskatchewan Growth and Development Study; LLTS, Leuven Longitudinal Twin Study.

TABLE 2. Age of peak height velocity (yr) in the three studies.

Study	Boys				Girls			
	Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum
BMAS	13.4	0.7	11.1	15.6	11.9	0.7	10.3	13.6
SGDS	14.0	1.0	11.4	16.5	11.6	0.7	10.5	13.1
LLTS	14.2	0.8	12.6	15.8	12.5	0.8	10.9	14.6

ratio of leg length to sitting height increases steadily before PHV and then decreases at and after PHV. As a single measurement on two occasions, approximately 1 yr apart, it provides a broad categorization of maturity: if the ratio is increasing, the individual is pre-PHV; if the ratio is decreasing, the individual is post-PHV. Measurements less than 1 yr apart may reflect seasonal variation in linear growth and result in some variability in the ratio (21). However, measurements minimally 1 yr apart do not demonstrate this variability and on an individual basis consistently follow an increasing ratio to PHV and declining ratio after PHV. In the BMAS, 72 of the 79 male subjects and 67 of the 71 subjects followed this pattern. In fact, in the 11 cases where the pattern was broken, a review of the data indicated possible measurement variability. The ratio requires serial measurements, 1 yr apart. A single measurement occasion is a major limitation in the application of this ratio. Therefore, the development of gender-specific multiple regression equation incorporating this ratio from a single measurement occasion provided a viable alternative.

Statistical analysis. Maturity offset was used as the dependent variable in multiple regression analysis. Independent variables included chronological age, height, sitting height, subischial leg length, and weight. Interaction variables were included to reflect the interaction between specific anthropometric variables and age: age and height, age and sitting height, age and leg length, age and weight, and the interaction between leg length and sitting height. Five ratio variables were calculated: weight divided by height, body mass index (weight divided by height squared), sitting height divided by height, leg length divided by height, and leg length divided by sitting height.

From these 15 independent variables, gender-specific multiple regression equations were developed through a hierarchical entry with consideration given to both biological and statistical significance of potential entry variables to predict maturity offset. Based on significant changes in R and the decrease in SEE, variables were accepted if they made a statistical significance contribution (alpha = 0.05) to the predictive equation.

The accuracy of the predictive equations developed from BMAS data was assessed by predicting maturity offset in data from SGDS and LLTS and then comparing the accuracy of the predicated maturity offset to actual maturity offset according to the procedure described by Bland and Altman (8). All calculations were made using SPSS procedures (SPSS for Windows release 10.0).

RESULTS

In boys the predictive equation was as follows: (Eq. 1) Maturity Offset = −29.769 + 0.0003007·Leg Length and Sitting Height interaction −0.01177·Age and Leg Length interaction + 0.01639·Age and Sitting Height interaction + 0.445·Leg by Height ratio, where R = 0.96, $R^2 = 0.915$, and SEE = 0.490.

In girls, the predictive equation was: (Eq. 2) Maturity Offset = −16.364 + 0.0002309·Leg Length and Sitting Height interaction + 0.006277·Age and Sitting Height interaction + 0.179·Leg by Height ratio + 0.0009428·Age and Weight interaction, where R = 0.95, $R^2 = 0.910$, and SEE = 0.499.

Figures 2a and 2b illustrate the Bland-Altman procedure for BMAS boys and girls. The mean difference between the predicted and actual maturity offset values are plotted against the average of the two maturity offset values. The mean difference between the two measurements is −0.010 yr with a standard deviation of 0.489 yr in boys and −0.021 yr with a standard deviation of 0.497 yr in girls.

To verify and cross-validate the predictive equations, boys and girls from SGDS and LLTS were utilized. Figures 3a and 3b illustrate the Bland-Altman procedure applied to the boys and girls of the combined verification samples. The mean difference between the two measurements is 0.243 yr with a standard deviation of 0.650 yr in boys and 0.001 yr with a standard deviation of 0.678 yr in girls.

When the three studies were combined, the following gender-specific predictive equations were developed. In boys, the predictive equation was: (Eq. 3) Maturity Offset = −9.236 + 0.0002708·Leg Length and Sitting Height interaction −0.001663·Age and Leg Length interaction + 0.007216·Age

Table 3. Ratio of leg length to sitting height (%) in BMAS male and female subjects.

Years from PHV	N	Boys	N	Girls
−4	24	87.9 ± 3.1	9	87.1 ± 3.0
−3	68	89.6 ± 3.4	46	89.1 ± 3.9
−2	98	91.1 ± 3.4	73	90.3 ± 3.8
−1	125	92.5 ± 3.9	96	91.2 ± 3.7
0	141	93.2 ± 4.0	124	91.4 ± 3.9
1	110	92.3 ± 4.2	121	90.3 ± 3.5
2	68	90.4 ± 3.9	97	89.3 ± 4.2
3	25	89.6 ± 3.0	33	88.5 ± 3.9

Mean ± SD; PHV, peak height velocity.

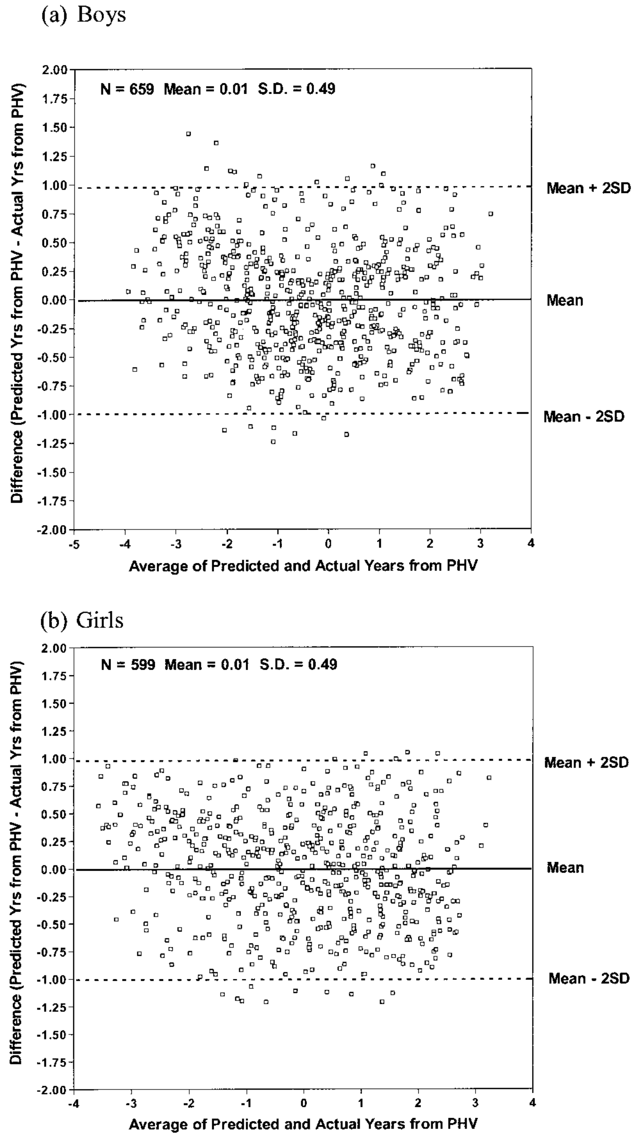

FIGURE 2—Bland Altman procedure for BMAS in (a) boys and (b) girls.

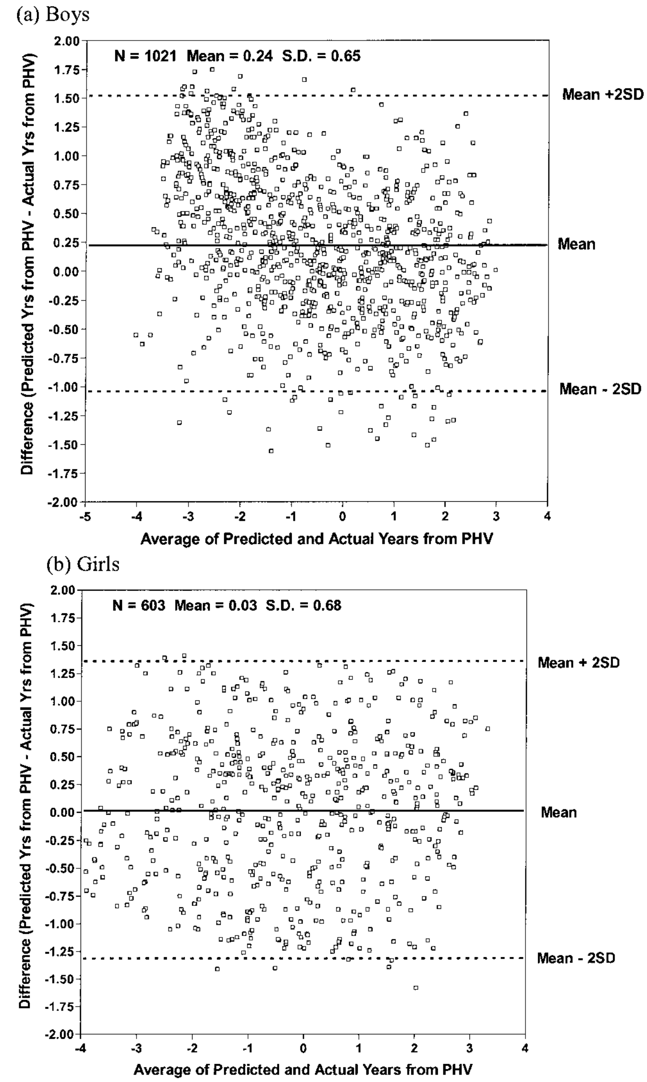

FIGURE 3—Bland Altman procedure for SGDS and LLTS in (a) boys and (b) girls.

and Sitting Height interaction + 0.02292·Weight by Height ratio, where R = 0.94, R^2 = 0.891, and SEE = 0.592.

In girls, the predictive equation was: (Eq. 4) Maturity Offset = −9.376 + 0.0001882·Leg Length and Sitting Height interaction + 0.0022·Age and Leg Length interaction + 0.005841·Age and Sitting Height interaction − 0.002658·Age and Weight interaction + 0.07693·Weight by Height ratio, where R = 0.94, R^2 = 0.890, and SEE = 0.569.

Figures 4a and 4b illustrate the Bland-Altman procedure applied to the three study prediction model for male and female subjects, respectively.

DISCUSSION

During adolescence, it is essential that the effects of maturation be controlled for both in context of youth sport classification and research investigations. All prospective studies that evaluate the physiological process in children must attempt to control for maturity. Equitable classification of participants in youth sport remains an important but unresolved issue. The purpose of this investigation was to establish a noninvasive and practical method to assess maturity status during adolescence. We have shown that age from peak height velocity, a maturational benchmark, can be predicted with a reasonable degree of accuracy by measuring height, sitting height, body mass, and chronological age.

Although the Bland-Altman procedure (8) provides the appropriate methodology to assess the prediction equations, the acceptance of the prediction equations requires the researcher to establish reasonable and practical limits for the prediction. For the purposes of the present investigation, the authors suggest acceptable limits to approximate the mean plus or minus 1 yr (assuming a mean of zero and an SD of 0.5 yr).

Within the limitations stated above, the cross-validation of the prediction equations meets statistical standards for acceptance. Ideally, further verification on different samples would provide additional support. The cross-validation allows the prediction equations to be tested for generalizabil-

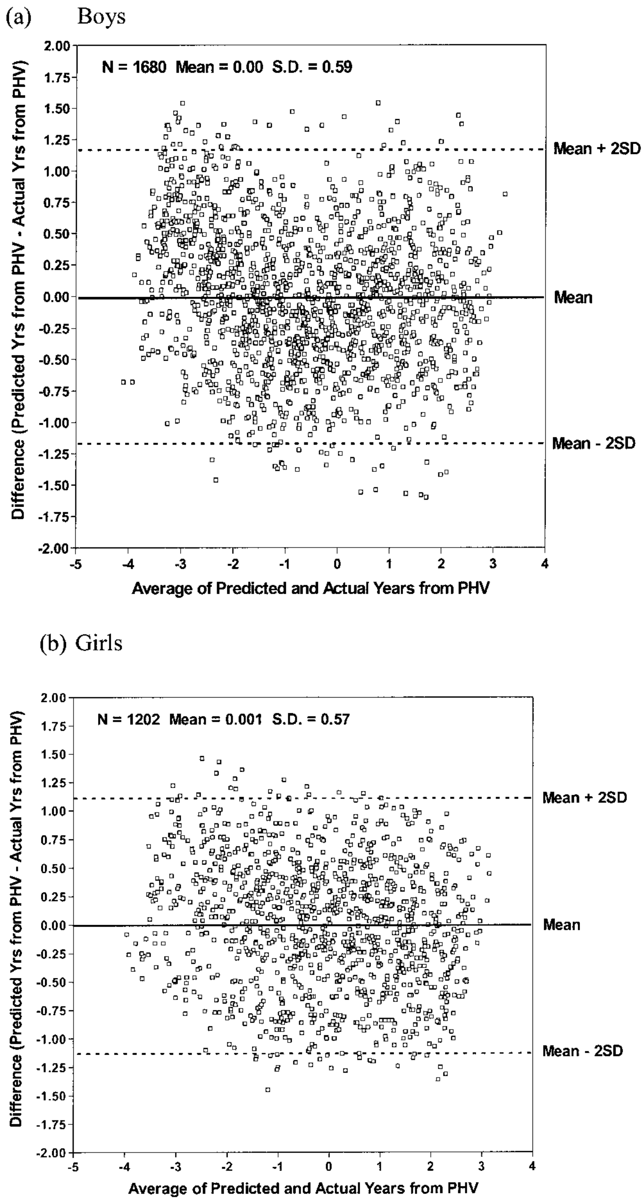

FIGURE 4—Bland Altman procedure for BMAS, SGDS, and LLTS in (a) boys and (b) girls.

ity. When population specific equations are applied to other samples, there may be a loss in the accuracy of the prediction or shrinkage reflected in the reduction of the R^2 value (27). The R^2 values for the boys and girls in the BMAS were 0.92 and 0.91. When the prediction equations were applied to the verification samples, the R^2 values were 0.89 and 0.88 for male and female subjects, respectively. This difference would indicate a small amount of shrinkage from the development sample to the prediction sample. However, the increase in the standard deviation of the difference between predicted and actual maturity offset values 0.49 in boys and 0.50 in girls from the development sample (BMAS) to 0.65 in boys and 0.68 in girls in the verification samples (SGDS and LLTS) is a more critical evaluation of the prediction equations.

When the three studies are combined, the predictive Equations 3 and 4 provided a more complete and balanced sample. Note that measurements were taken once a year in SGDS and twice a year in the BMAS and LLTS. It is recommended that the three study prediction equations be used to predict maturity offset. With more extensive observations on either side of PHV and the increase in observations, these latter prediction equations are more robust and possibly afford greater generalizability given the combination of three different samples.

Both the age range and variability of the predicted value should be considered in the application of the predictive equations. Although it is possible to predict a continuous maturity measure, years from PHV, an alternative may be the application of categorical maturity offset values (6). For example, any negative maturity offset prediction should classify the individual as pre-PHV and any positive prediction as post-PHV. Used in this manner, a common benchmark maturity classification can be constructed for both boys and girls. This would be similar to a pre- and post-menarcheal categorization, which is only available in girls.

To assure the best estimate of maturity from these prediction equations, care and attention must be paid to standardized measurement procedures, especially in the measurement of sitting height. The magnification of measurement error by prediction equations is a major limitation to any method but especially where one measurement, sitting height, has a direct relationship with a number of independent variables.

The quest to develop a noninvasive measurement of maturity is not a new issue (7,24). For nearly 100 years, there have been advocates for various classification indexes to account for size and maturity in elementary, junior, and senior high school and college men and women (9–12,19,22,25,28). The purpose of these classifications was to improve instruction and to place students into equitable groups according to "their capacities and their achievements on which they are likely to succeed" (19). The earlier approaches predict adult stature and calculate maturity as a percentage of adult stature. The current investigation attempts to assess maturation by predicting the tempo of growth or where the individual is in relation to a maturational benchmark, PHV. The test of any approach is the generalizability to other populations and other maturity assessment methods. Skeletal age is another common and important method of assessing maturity. Is there a relationship between skeletal age assessment and maturity offset? The male subjects in the SGDS had skeletal hand-wrist x-rays assessed at age 11 yr. The correlation coefficient between skeletal age offset from chronological age and PHV maturity offset from chronological age was 0.83. Although the methods are different, the direction and strength of the relationship indicate a maturational commonality between the two methodologies.

Although it is feasible and possible to seek a biologically based classification system, the practical application of this outcome rests with the acceptance by sport-governing body authorities and youth sport organizers. An application of these predictive equations is illustrated in the following example: two male individuals, A and B, were first tested at chronological ages 11.4 and 11.3. The difference in their height and weight was 4.7 cm and 6.2 kg. The application of the maturity offset prediction equation categorized each individual as pre-peak height velocity. When both individuals were 14 yr of age, the difference in their height was 25.8 cm and in their weight was 13.7 kg. The maturity offset prediction categorized the taller and heavier individual as post-peak height velocity and the other individual as pre-peak height velocity. At 17 yr of age, there was less than a 1-cm difference in height and a 2-kg difference in weight, and both individuals were predicted as post-peak height velocity. The age of PHV for the two individuals was 13.09 and 15.09 yr. This example illustrates the effect of tempo of growth in two individuals of the same chronological age who were relatively the same size before and after adolescence. However, the path to maturity is variable and an individual one.

All studies of adolescent children need to control for the confounding effects of maturation. Current assessment methodologies are invasive, intrusive, and/or gender specific. Gender-specific equations are presented that predict age from peak height velocity (a measure of maturity offset) by using four anthropometric variables (chronological age, stature, sitting height, and body mass). The use of stature and sitting height in the prediction takes into consideration the differential timing of the adolescent spurt in body dimensions and also their interactions with chronological age. The present results indicate that maturity offset can be estimated within an error of $\pm$ 1 yr 95% of the time. We believe this level of accuracy is sufficient for adolescence to be assigned a maturational classification. A classification that can be applied to various research designs. In a sporting context, matching adolescence sports groups biologically rather than chronologically may equalize competition, enhance chances for success, and possibly reduce incidence of injury.

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