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Measuring Physical Status and Timing in Early Adolescence: A Developmental Perspective

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Recently, the timing-of-events model typically used for exploring adult development has been proposed for studying early adolescence and the pubertal processes occurring then. As a consequence, new interest has been generated about the psychological effects of being early, on time, or late in sexual maturation during early adolescence. A major issue has to do with the choice of maturational events to study, since puberty is a process involving numerous events, all of which have a different developmental course. This paper reviews some of the maturational events that are applicable in studying psychological effects of pubertal status and timing. Nine changes are reviewed (bone, height, weight, body fat, breast, body hair, penile, testicular, and menarcheal changes) in terms of measurement techniques, psychometric properties, and intercorrelations with other pubertal events. In addition, the usefulness of each measure for psychological research on maturational timing and status is discussed. Finally, how pubertal measures may be incorporated into a developmental perspective is considered, especially with regard to rate, duration, and asynchrony of pubertal changes.

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INTRODUCTION

The renewed interest in the psychological effects of maturational status and timing is quite evident in these two special issues of the *Journal of Youth and Adolescence.* One critical question in the interpretation of the results presented in these issues is how measure dependent they are. We know that maturation is not a unitary event, but is comprised of a set of interrelated processes. Thus, maturation may not be accurately represented by one event alone nor is a measurement at any particular point in time reflective of the rate, duration, or timing of maturation. In the following review, issues about the measurement of physical growth will be raised, especially as they relate to studying psychological effects of maturational timing and pubertal status.

The distinction between maturational timing and status is important. In the former case, the effects of one's maturation relative to a referent group or a norm is of interest; in the latter case, the psychological effect of physical growth or the psychological significance of a physical event, independent of when it occurs, is studied. Most of the literature focuses on maturational timing rather than maturational status, as is evident in the following papers. An argument for studying both may be made, but since the following papers discuss the relevance of timing research, only the case for status research will be made here.

Examining status allows for the examination of the psychological significance of physical growth to an individual (Brooks-Gunn, 1984). The current psychological research on pubertal status has focused on perhaps the most salient physical event and certainly the most discontinuous one—menarche—in part probably because school administrators are more likely to allow studies to be conducted on menarche than other maturational events and because adults vividly remember their own menarche, which is *prima facie* evidence of the salience. This reliance on menarche may have limited our knowledge about the psychological meaning of puberty more generally or other maturational indices more specifically (Greif and Ulman, 1982). The lack of information on pubertal status effects is even more glaring for the pubescent boy. With the exception of a few studies (Gaddis and Brooks-Gunn, 1985), all research on boys has focused on timing of puberty rather than on maturational status.[4]

The study of status may take a more developmental perspective, focusing on psychological effects of rate, duration, and asynchrony of

[4]The lack of research is one of the few examples of a topic being studied more in girls than boys. Other reproductive-related topics, such as early parenting, infertility, and cessation of reproductive ability, also concentrate on females.

events. Not all individuals proceed through maturation at the same rate: One individual may take five years to complete breast growth, while another may take only two years. Certain clinical groups may show especially deviant rate changes; the very late maturer, for example, may proceed through the secondary sexual maturation sequence very rapidly. How rate changes may affect the individual's perception of herself, her behavior, or the behavior of others is not known. In addition, asynchrony in the sequences of different pubertal events may be relevant to psychological functioning (Eichorn, 1975). We know little about the effects of asynchronies upon individuals or on the differential salience of events to individuals. For example, being relatively more advanced in breast than pubic hair development may have a different meaning than the opposite case (Brooks-Gunn, 1984, 1986). The study of actual as well as relative status allows for a fine-grained look at maturation: Timing, rate, asynchrony, and different salience of maturational events all may relate to psychosocial functioning in different ways.

CHOICE OF MATURATIONAL STATUS MEASURES

One of the difficulties in studying the relationships between psychosocial behaviors and physical changes during early adolescence has to do with the choice of maturational status measures.[5] Physical changes have been described in great detail in the medical literature, especially for body hair, breast, and penis development (Marshall and Tanner, 1969; Tanner, 1974), growth velocity (Faust, 1977; Bock *et al.*, 1973; Thissen *et al.*, 1976), bone age on X ray (Cheek, 1974; Forbes, 1975), and hormonal changes (Styne and Grumbach, 1978; Grumbach *et al.*, 1974, 1977; Grumbach and Sizonemko, 1982). Five longitudinal studies, four in the United States and one in England, have provided the bulk of information on growth and maturation (Malina, 1978). From a psychosocial perspective, multiple indices of physical growth have not been studied as extensively. This is due in part to the difficulties inherent in studying measures of physical status outside medical settings, the necessity for prospective studies, and the reluctance of parents and teachers to allow pubertal studies to be conducted in school systems.

Developmentalists have not concentrated upon pubertal events for other reasons. In an attempt to move away from biological deterministic models, they have concentrated upon social and psychological events. And

[5]The choice of psychological measures as well as physical measures needs to be carefully specified, as do the models chosen to explore interrelationships among variables. These issues are discussed in several recent reviews (Adelson, 1980; Petersen and Taylor, 1980; Hill, 1983; Brooks-Gunn and Petersen, 1983, as well as these two special issues).

their focus often has been on interrelationships across rather than within life phases (Simmons *et al.*, 1983; Baltes and Nesselroade, 1973). Even when physical status is included as a measure in early adolescent psychological research, it is often conceptualized either as a time-bounded variable or as a unidimensional one. Rate changes, asynchronies, or changes in status or timing have not been explored across the adolescent period.

In order to understand the effects of puberty, it is necessary to examine some of the physical parameters related to maturation. In the present paper, nine physical parameters associated with puberty will be reviewed—anthropomorphic measures (height, weight, body fat, bone age) and secondary sexual characteristics (breast, body and pubic hair, penile, testicular, and menarcheal development). The usefulness of each parameter for psychological research will be discussed as well as current methods for measuring each. Emphasis will be placed on measures that are suitable for studies conducted outside medical settings and that are believed to be psychologically salient to the child.

Three topics will be discussed for each pubertal event. The first has to do with measurement techniques, psychometric properties of techniques, and interrelationships of various pubertal measures to one another. It is beyond the scope and is not the purpose of this review to provide a comprehensive look at growth and maturation; the reader is referred to several excellent reviews for such information (Malina, 1978; Grumbach *et al.*, 1974; Tanner, 1975; Eveleth and Tanner, 1976; Petersen and Taylor, 1980). Our aim is to discuss techniques that have been or may be used by researchers interested in psychological correlates of maturation, not to document the maturational process itself. The second topic has to do with the possible significance of the event to the adolescent and to others as well as the relevance of the measure for timing and status research. Third, the usefulness of the measure for psychological research will be summarized.

Several caveats must be mentioned. First, only measures used in psychological pubertal studies of timing or status are reviewed. Thus, a number of potentially important measures are omitted, such as foot, leg, hand, and trunk length, age at peak velocity of sitting height, leg length, biacromial breadth, and bicristal breadth (Tanner *et al.*, 1976). Such measures, however, could be obtained easily in psychologically oriented studies and may be salient to the adolescent. With regard to skeletal age, a number of changes in certain bones are not reviewed, even though data exist for the fibula, femur, tibia, and cranial base lengths (cf. Roche, 1974; Roche *et al.*, 1977).

Second, the measures selected may not necessarily be the best predictors of later development. For example, the skeletal maturation of the knee may predict adult stature better than maturation of the hand and wrist, which are more commonly used (Roche *et al.*, 1975).

Third, discrepancies within a class of measures may exist; examples include maturation as assessed by knee and hand skeletal growth or by pubic and axillary hair growth. Thus, discussions of specific events may not be generalized to other events within a class.

Fourth, while we discuss hormonal changes, they are not presented in great detail. It is important to remember that they precede the pubertal events to be discussed as well as occurring simultaneously with them. Hormonal levels may be linked to behavior, as Susman and colleagues (this issue) suggest.

ANTHROPOMORPHIC MEASURES

Bone Age

Skeletal maturation is typically measured by an X ray of the bones, typically the wrist and hand and less commonly the knee and long bones. Based on epiphyseal fusion of different bone centers and osseous maturation, bone status has been extensively studied (Styne and Grumbach, 1978). During the course of sexual maturation and as a direct result of the secretion of gonadal hormónes, the epiphyseal cartilage plates become progressively obliterated. There is resultant fusion of the shafts and epiphyseal ossification centers, at which time linear growth ceases. Radiographs are made of the hand and wrist and compared to norms published in the Greulich and Pyle (1959) atlas or the more recent norms of Tanner and Whitehouse (1975; Tanner *et al.*, 1975). Reproductions enable the skeletal age of the child to be identified and compared to his or her chronological age. Height predictions can also be made with this data using tables from a variety of sources (Acheson *et al.*, 1963; Bayley and Pinneau, 1952; Tanner *et al.*, 1975; Roche *et al.*, 1971a, 1971b, 1975).

Problems exist in measurement even of something as seemingly straightforward as bone growth, including which skeletal maturation rating system is used, inter-observer error, and discrepancies between growth rates of different bones (Roche *et al.*, 1975; Malina, 1978)

Skeletal maturity is related to secondary sexual characteristics, peak height velocity, and menarche (Roche *et al.*, 1975; Tanner *et al.*, 1976). However, bone age is of little value in predicting when the secondary sex characteristics will develop. At most stages of sexual development the variations in skeletal and chronological age differed very little from each other (Marshall, 1974). However, in girls who were X rayed shortly before or after menarche, the standard deviation of skeletal age (0–0.39 "years") was significantly less than that of their chronological ages at the time when the

radiography was carried out. Thus, skeletal age was shown to be better than chronological age alone for predicting age at menarche. The relevant prediction equations, with estimates of the error of prediction, in girls of different ages are presented by Marshall and Limogni (1976). Correlations between skeletal age and the pubertal indices are typically higher for girls than boys (Malina, 1978; Marshall, 1974). For example, in one study, the correlations between PHV (peak height velocity) and skeletal age was .34 for boys and .74 for girls (Marshall, 1974).

Bone age has been used as a status and timing measure. The early growth studies all used bone X rays for timing classifications (Jones and Bayley, 1950; Jones and Mussen, 1958; Peskin, 1973). However, it is not particularly salient to the adolescent, who does not directly observe the skeletal growth changes. In brief, skeletal age may not be particularly useful in psychological research, given the risks posed by radiation, the necessity of a trained X ray technician, the scheduling of adolescents in a hospital or clinic setting, and the lack of salience to adolescents themselves.

Height

The most common anthropomorphic measure is standing height. Other measures for which extensive data have been collected include foot, leg, hand, and trunk length (Tanner *et al.*, 1976). Typically, changes in height over age are assessed using curve-fitting techniques (Bock *et al.*, 1973; Thissen *et al.*, 1976). In addition, maximum velocity and age at the peak of the growth spurt are examined (Malina, 1978; Faust, 1977). The interest in velocity changes necessitates charting a child's height from middle childhood onwards—for girls, from age 8 or 9 and for boys, from age 9 or 10. Five or six years of data collection are often not feasible in short-term longitudinal studies. In addition, with the exception of the growth studies (Berkeley, Oakland, and Fels), the 11–15-year-old is the focus of most adolescent research. Thus, information on velocity is more likely to be collected for boys than for girls, as the former reach PHV later than the latter do.

An alternative to measuring height prospectively to estimate PHV is to obtain retrospective data through record review. Schools records may yield fairly complete information in districts where students do not move frequently. Annual prediatric data may be available in communities where annual physical examinations are required for camp, sports, and school and where health care compliance is generally high. However, this method relies on the willingness of prediatricians to abstract data. In one of our studies of college students in New York City, 80% of the pediatricians contacted supplied adolescent height and weight data.

For studies in which current height data are gathered, rather than data for estimating peak height velocities, actualmeasures are preferable to record review or self-report. However, self-report data are fairly accurate (correlations with actual height are in the 90's), even for young adolescents (Brooks-Gunn and Warren, 1985; Brooks-Gunn, Warren, Gorgiulo, and Russo, 1986). A final possibility is to ask parents to measure their children at home. Detailed instructions may make this procedure as accurate as school measures. To our knowledge, no study has attempted to collect such parental data.

Measurement of height is straightforward. In order to minimize measurement errors, it is advisable to take two or three readings and compute an average and to use a T-square and a tape measure. Percentiles are available for age, gender and pubertal status (Tanner and Whitehouse, 1976; Hamill *et al.*, 1973, 1976; National Center for Health Statistics, 1976).

The growth spurt typically occurs between Tanner Stages I and III for girls and Tanner Stages IV and V for boys. The peak of the spurt occurs on the average two years earlier for girls than for boys (Faust, 1977; Tanner, 1962). PHV is moderately related to other pubertal indices.

The psychological significance of height for children has been demonstrated in a variety of ways. First, taller children are expected to act in more socially mature ways than are their shorter same-age peers (Brackbill and Nevill, 1981). In addition, taller young adolescents rate themselves as more socially competent than do their shorter counterparts (Brooks-Gunn and Warren, 1985). Second, a small but consistent correlation between height and intelligence exists in many studies; the relationship is thought to be due in part to the differential treatment and self-perceptions of taller individuals (Feldman, 1975; Tanner, 1966). In addition, PHV may be used to classify subjects as early, on time, and late maturers (Faust, 1977). It is commonly used for boys, in part because studies have concentrated on the middle school ages, when the peak velocity may have passed for girls.

In summary, height is a useful measure for psychological research, is easy to obtain from a variety of sources, and is reliably measured.

Weight

Weight, like height, increases through pubertal growth, with a weight spurt around the time of peak height velocity (Tanner and Whitehouse, 1976; Parizkova, 1976; Malina, 1978) often occurring after the growth spurt. However, much less is known about the weight spurt, and peak velocities typically are not charted (for an exception, see Tanner and Whitehouse, 1976). Thus, weight is represented as an absolute, as a ratio related to height, or as a percentile. Percentile ratings take into account age and height, since weight increases with both during childhood and adolescence. Few norms

are available by sexual maturation stages, even though weight varies as a function of secondary sexual status, even when age is controlled. Absolute weight or ideal weight using percentiles are used in most studies.

Absolute weight is not a good measure of physical growth (without taking into account height), but may have psychological meaning. Children may perceive the relationship between weight and height or weight and maturational status differently, or may focus more on weight gain than on the corresponding height spurt. No information exists as to how children perceive weight gain, nor if they take into account simultaneously height or maturational rate changes. Therefore, young adolescents who have experienced a rapid weight gain may perceive themselves to be overweight if they do not take into account the corresponding or antecedent growth spurt.

Another way to conceptualize weight is to categorize subjects as underweight and overweight. Both are typically defined in terms of percentile norms or number of standard deviations from the mean for age and gender groups; being 10% to 20% above or below the appropriate weight range by age and/or height is often used as criteria (Hamill *et al.*, 1976). Secondary sexual development is typically not taken into account in classifying adolescents.

Like height, measuring weight is relatively straightforward. Error of measurement is approximately ±2% with portable balance scales and ±4% with bathroom scales. If a bathroom scale is used, it should be calibrated after every two or three weighings. Individual variability also may result from observer error in reading the scale.

Besides direct measurements, school and pediatric record review may be undertaken. Self-reports are surprisingly accurate, at least within five pounds (Brooks-Gunn *et al.*, 1986). Almost all discrepancies for girls are in the direction of underreporting, which is not surprising given the cultural ideal of thinness.

A problem with assessing weight has to do with the reluctance of some girls to be weighed. In our sample of fifth- to twelfth-grade girls, approximately 2% requested to be dropped from the study upon being reminded that they would be weighed (even though the girls were weighed privately). The number of girls who refuse to participate in studies from the outset because of a weighing requirement is not known. One might expect that obese girls would be most reluctant, given the cultural demands for being slim (Garner and Garfinkel, 1980).

The relationship of weight to other pubertal indicators is much less strong than it is for height. The weight spurt typically occurs after the growth spurt.

The psychological significance of weight for children and adolescents had been repeatedly demonstrated, especially for overweight individuals (Attie and Brooks-Gunn, 1986). Perceptions of weight, even when inaccurate, also are related to psychological functioning (Duncan *et al.*, this issue; Brooks-Gunn and Warren, next issue; Tobin-Richards *et al.*, 1983). However, weight is not a useful measure for classifying individuals with respect to timing of maturation.

In summary, weight is useful for psychological research, is easy to obtain, and is fairly reliable, even though short-term fluctuations occur. It is not a particularly compelling measure of pubertal growth and is not used in maturational timing research.

Body Fat and Muscle

Rapid weight gain is associated with an accumulation of body fat in girls and with increased muscle mass in boys (Tanner, 1962, 1969, 1972). The increases occur throughout sexual maturation, with the most rapid rise in body fat typically occurring in Tanner Stages 4 and 5 and in muscle circumference in Tanner States 3 and 4 (Gross, 1984). Gains in muscle circumference are seen closely following PHV (Tanner, 1968; Malina, 1978). In addition, maximal strength of muscle occurs about one year after PHV in boys (Stolz and Stolz, 1951), with more variability seen for girls (Faust, 1977).

Even though body fat increases are not necessarily associated with obesity, the percentage of individuals classified as obese does increase after puberty. Stunkard *et al.* (1972) found that the percentage of lower socioeconomic status (SES) girls classified as obese (using skinfold thickness) increased from 10% at age 12 to 35% at age 16; in the higher SES group, it increased from 5% at age 12 to 8% at age 16. In contrast, the percentage of girls classified as thin dropped from a high during the adolescent years of 20%–25% at age 12 to 1%–2% from age 15 onwards.

Body fat may be measured by examining skinfold thickness, percentage of body fat to total weight, or hydrostatic weighing. Measurement of skinfolds are made on one side of the body at four sites—biceps, triceps, iliac crest, and the subscapula area. The sum of these four skinfolds can be read off a table adjusted for sex and age (Durnin and Wormersley, 1974; Young *et al.*, 1968; Merrow, 1967; Wilmore and Behnke, 1970). Measurements are taken at each site three times and the average taken. Sometimes only the upper arm skinfold is measured (Merrow, 1967). Norms are available for children (Seltzer *et al.*, 1965; Tanner and Whitehouse, 1975) and

for adolescents over 16 (Durnin and Wormersley, 1974; Young *et al.*, 1968; Merrow, 1967; Wilmore and Behnke, 1970). The two criteria used for defining fatness and thinness are: (1) skinfold thickness exceeding one standard deviation from the mean for their age and gender group (Seltzer *et al.*, 1965) and (2) 10% of all children of each sex who have the thickest and thinnest skinfolds, using a minimum skinfold thickness of obesity and a maximum for thinness (Stunkard *et al.*, 1972). Although skinfold thickness measurement is noninvasive, it takes extensive training and is only mederately reliable. Three measurements per site are taken because of the unreliability.

Body fat also may be estimated from weights and heights using the equation of Mellits and Cheek (1970). Body water is used as an indicator of body fat by assuming that fat-free body weight (lean body weight) is equal to the quotient of body water divided by 0.72. The fat content represents the difference between the lean body weight and the measured body weight. Normal growth measurements may be obtained from data compiled by the National Center for Health Statistics, Health Resources Administration (DHEW, 1976). The Mellits-Cheek formula has been criticized because of the sample from which the formula was derived and the failure of many to consider the error term in the prediction equation (Billewicz *et al.*, 1976; Johnston *et al.*, 1975).

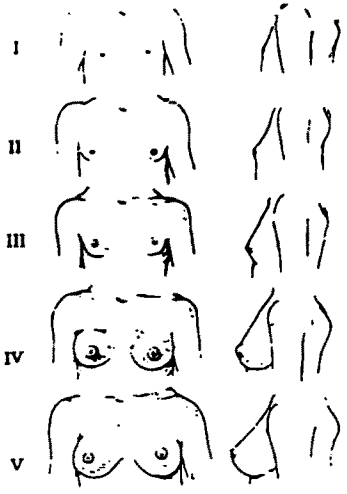
The psychological significance of body fat is similar to that of its sister measurement, weight. Like weight, it is not appropriate for timing classification research. Body fat is a more accurate indicator of pubertal growth than weight, however. Even then, it is not as highly correlated with other pubertal indices as is height. It is most highly correlated with menarche (Garn, 1980; Frisch and Revelle, 1973).

In summary, body fat is useful in some psychological research. Difficulties in reliability exist for skinfold thickness, and the body fat formula may be inaccurate. However, the former is preferred to the latter. Other techniques, such as hydrostatic weighing, are not feasible in most pubertal research. Skinfold thickness measurements may be difficult to obtain in school settings, as staff, parents, and children are unfamiliar with them. In our research, only 1 of 10 schools consented to skinfold assessments. Biceps and triceps readings, which do not require undressing, may be most likely to be favored by school- or community-based studies. However, skinfold thickness is not appropriate for classifying adolescents as to timing of maturation.

SECONDARY SEXUAL CHARACTERISTICS

The progression of secondary sexual characteristics has been carefully documented by Tanner (1962, 1969, 1978) and colleagues. For girls, changes

in breast and body hair development and for boys, body hair, changes in facial hair, voice lowering, penis development, and testicular volume have been examined. Data are most complete for pubic hair development in both sexes, breast development in girls, and penile development and testicular volume in boys. The sexual maturation stages will be discussed first, followed by a brief presentation for each pubertal event separately.



BREASTS

Please circle the stage your daughter currently is in.

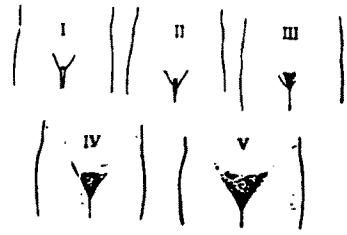
I. No breast development.

II. The first sign of breast development has appeared. This stage is sometimes referred to as the breast budding stage. Some palpable breast tissue under the nipple, the flat area of the nipple (areola) may be somewhat enlarged.

III. The breast is more distinct although there is no separation between contours of the two breasts.

IV. The breast is further enlarged and there is greater contour distinction. The nipple including the areola forms a secondary mound on the breast.

V. Mature Stage. Size may vary in the mature stage. The breast is fully developed. The contours are distinct and the areola has receeded into the general contour of the breast.



PUBIC HAIR

Please circle the stage your daughter currently is in.

I. No pubic hair.

II. There is a small amount of long pubic hair chiefly along vaginal lips.

III. Hair is darker, coarser and curlier and spreads sparsely over skin around vaginal lips.

IV. Hair is now adult in type, but area covered is smaller than in most adults. There is no pubic hair on the inside of the thighs.

V. Hair is adult in type, distributed as an inverse triangle. There may be hair on the inside of the thighs.

Fig. 1. Tanner stages for females' breast and pubic hair development.

Sexual Maturation Stage

Following Reynold and Wines (1948, 1951), Tanner devised a system for rating the amount of growth in breasts and pubic hair for girls and in the penis and pubic hair for boys. This system superimposes stages upon a continuous process, as Tanner has noted. Such a system allows for classification of an individual's amount of growth as well as for comparison across cohorts and with other pubertal processes. Thus, the "Tanner stages," as they are often termed, do not represent qualitative changes, but a characterization of quantitative change. Schematic drawings and written explanations of the five stages of development are presented in Figure 1 for girls (breast and pubic hair growth) and Figure 2 (a and b) for boys (penile and pubic hair growth). Stage 1 is prepubertal and Stage 5 postpubertal for each sex.

Typically, the adolescents' development is rated by a pediatrician or nurse-practitioner during a physical examination. Often, each breast is rated separately and the average score computed, given that development across breasts is sometimes asynchronous. With training, inter-observer reliability is adequate. The rating of breast development has been critized for not discriminating among areolar contours, papillary elevation, and breast fat. Breast fat is problematic in that large variations exist for females in Stage 5. However, as a general measure, the breast ratings do discriminate among prepubertal, pubertal, and postpubertal girls.

Other measurement techniques have been developed, given the reluctance of some adolescents to have a physical examination, feelings of parents, and school concerns. To our knowledge, no pubertal study has been conducted within a public school system in America using pediatricians' examinations. Even within clinic settings, many adolescents are hesitant to have a physical examination conducted. Girls may be more hesitant than boys; at the National Institutes of Health, investigators are having less difficulty recruiting boys than girls for a study involving Tanner ratings especially those in Stages 4 and 5 (Susman, personal communication). Other concerns involve expense, time, and the necessity of a pediatrician and nurse-practitioner for the physical examination.

To overcome these difficulties, several investigators have developed alternative techniques for Tanner staging. In one, nude photographs of the child are taken (front and profile positions). Sexual maturation ratings made from photographs are fairly reliable, although some difficulties arise when using black-and-white rather than color pictures (Petersen, 1976). Photographs may be as objectionable to school personnel, parents, and adolescents as are physical examination (and perhaps even more so). Another approach is to ask adolescents or parents to rate current physical development using photographs or schematic drawings of the five sexual matura-

tion stages. these attempts have been successful in medical and school settings and correlate well with nurse-practitioner ratings (Morris and Udry, 1980; Duke *et al.,* 1980; Brooks-Gunn *et al.,* 1986).

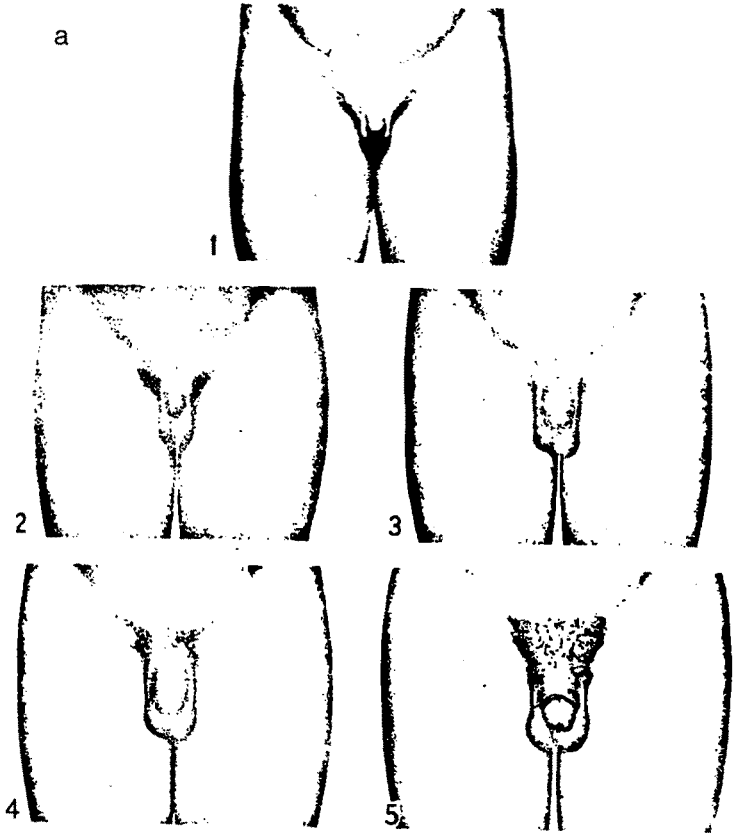
In our convergent validity study, we found that mothers were able to rate their daughters' development as accurately as their daughters did. In schools where administrators do not want their students to rate the drawings, parents may be a viable alternative. Whether parents would be able to rate their sons' growth as accurately as their daughters' development is not known. It is expected that mothers may not be able to do so, given opposite-sex modesty norms. Fathers may not see their pubescent sons unclothed as frequently as mothers see their daughters unclothed, so that using parents as information sources for boys may be problematic.

Secondary sexual characteristics are correlated with gonadotropins, specifically estradial, testosterone, follicle stimulating hormone (FSH) and luteinizing hormone (LH). However, variations do occur, as is illustrated in Figure 3 (T4 levels by pubic hair growth for 11- to 14-year-old females). Relationships also exist for PHV, menarche (for girls), body fat, and muscle mass. Figures 4 and 5 illustrates the relationship between body fat and Tanner staging and muscle circumference from the National Health Survey data (Gross, 1984). However, none of these pubertal measures correlate perfectly with one another, as mentioned previously.

In addition, the duration of any stage is not easily predicted and large individual variations exist (Marshall and Tanner, 1969, 1970). Age of entry into a stage is not related to duration or rate of progression through the stage. Thus, information taken at one time is not predictive of later development to any significant degree. Finally, asynchronies between secondary sexual characteristics are common. The timing and sequence of pubic and axillary hair differ, as do pubic hair and breast growth and pubic hair and penile growth.

The Tanner stages may be profitably used in psychological studies of pubertal status or timing. In some, the two Tanner measurers are averaged (Duncan *et al.,* this issue); in others, they are analyzed separately (Brooks-Gunn and Warren, 1985). We suggest that analyses be conducted separately if investigators have any interest in possible hormonal influences (pubic hair growth being more androgen dependent and breast growth being more estrogen dependent) or in socially mediated effects (breast but not pubic hair growth being directly observable by others).

Tanner ratings also have been used to classify on-time and off-time maturers. Using the National Health Survey data, the Tanner cut-offs for defining early, on-time, and late maturers by gender and by age have been calculated (Gross, 1984); 20% of the sample was classified as early, 60% as on time, and 20% as late.



Penis and Scrotum

Stage 1. The infantile state which persists from birth until puberty begins. During this time the genitalia increase slightly in over-all size, but there is little change in general appearance.

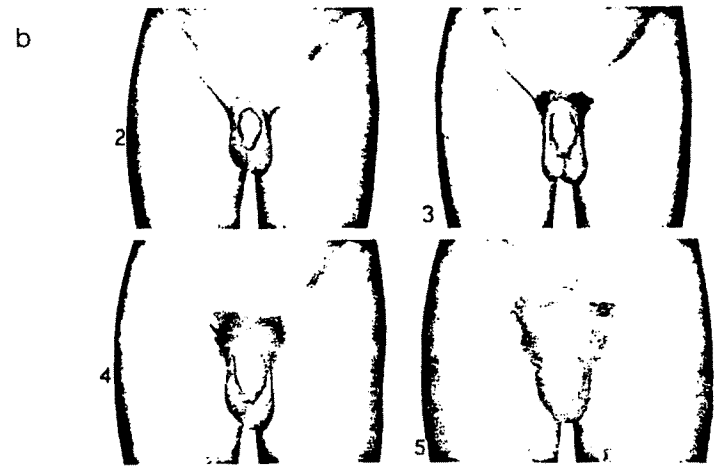
Stage 2. The scrotum has begun to enlarge, and there is some reddening and change in texture of the scrotal skin.

Stage 3. The penis has increased in length and there is a smaller increase in breadth. There has been further growth of the scrotum.

Stage 4. The length and breadth of the penis have increased further and the glans has developed. The scrotum is further enlarged, and the scrotal skin has become darker.

Stage 5. The genitalia are adult in size and shape.

Fig. 2(a). Tanner stages for males' penis and scrotum growth.



Pubic Hair

Stage 1. There is no true pubic hair, although there may be a fine velvus over the pubes similar to that over other parts of the abdomen.

Stage 2. Sparse growth of lightly pigmented hair which is usually straight or only slightly curled. This usually begins at either side of the base of the penis.

Stage 3. The hair spreads over the pubic symphysis and is considerably darker and coarser and usually more curled.

Stage 4. The hair is now adult in character but covers an area considerably smaller than in most adults. There is no spread to the medial surface of the thighs.

Stage 5. The hair is distributed in an inverse triangle as in the female. It has spread to the medial surface of the thighs but not up the linea alba or elsewhere above the base of the triangle.

Fig. 2(b). Tanner stages for males' pubic hair growth.

In summary, the Tanner ratings have great applicability to psychological research. The changes are salient to adolescents and may be used to identify maturational timing groups. A variety of techniques may be used to rate adolescents, even if physical examinations are not feasible.

Hair Growth

The development of hair involves pubic, axillary, and facial hair, all of which show different developmental progressions. Hair growth may be related to androgen secretion, in part from the adrenal gland. An as yet uniden-

Fig. 3. Tanner pubic hair rating for females by testosterone levels.

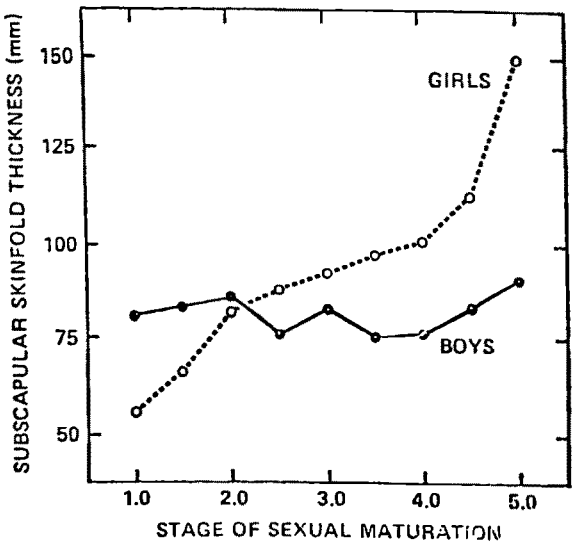


Fig. 4. Skinfold thickness for males and females by stage of sexual maturation (from Gross, 1984).

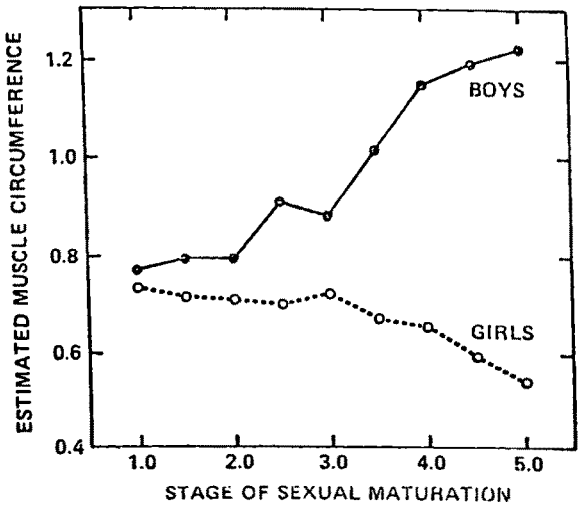


Fig. 5. Estimated muscle circumference for males and females by stage of sexual maturation (from Gross, 1984).

tified pituitary-adrenal androgen-stimulating hormone has been hypothesized to account for hair growth (Grumbach *et al.*, 1977). Pubic rather than axillary body or facial hair development is most frequently studied, as is evident from the Tanner staging data (see Figures 1 and 2).

Breast Development

Breast development is believed to be influenced by the secretion of estrogen, specifically estradiol from the ovary. Other contributing factors may be hormones secreted by the anterior pituitary gland such as prolactin. Also indicative of increased estrogen secretion is the increase in body fat and menarche (Warren, 1983). Like hair growth, breast development is ultimately controlled by a pituitary-adrenal hormone, in this case one stimulating estrogen (Grumbach *et al.*, 1977). Breast development is typically assessed using the Tanner staging method (see Figure 1).

Testicular and Penile Development

Growth of the testes is usually the first sign of puberty in the male; it occurs about six months later than secondary sexual development in girls, which usually begins with breast development. In general, a longitudinal measurement of greater than 2.5 cm in a testis is compatible with pubertal testicular enlargement. The testicular volume index (length $\times$ width of right testis and length $\times$ width of left testis/2) and testicular volume measured by comparison of testes with ellipsoids of known volume correlate with stages of puberty (Styne and Grumbach, 1978). These elliptical models were introduced by Zachman *et al.* (1974). The testis is palpated and compared with these models. The size of the stretched penis also may be measured with a centimeter ruler (Schonfeld, 1943). Typically, penile development is measured using Tanner stages (see Figure 2).

The maturation of the male phallus usually correlates closely with pubic hair development, since both are under androgen control. However, pubic hair, phallus, and testes development are classified separately. Genital development proceeds faster than growth of pubic hair.

Other changes include deepening of the voice, a relatively late event. Most pubertal males exhibit some enlargement of their areolae and underlying breast tissues, and some complain of breast tingling and tenderness during this period. In most instances, this modest adolescent gynecomastia regresses after a few years (Roche *et al.*, 1971a).

The timing of pubertal events relative to the growth spurt in boys is substantially different from that in girls. Girls usually show acceleration of

linear growth at the onset of puberty and reach peak height velocities relatively early in the pubertal process; boys typically reach their peak height velocities when genital and pubic hair ratings are at Tanner Stage 4 or 5.

Little is known about the psychological meaning of these changes to boys, with exception of ejaculation (Shipman, 1971; Gaddis and Brooks-Gunn, 1985). Timing classification relies on penile growth, as assessed by the Tanner staging method. While these changes have psychological significance, they have not been studied extensively. Penile growth is the only event used to date in maturational timing research.

Menarche

Menarche, or the onset of menstruation, occurs relatively late in the maturational sequence, typically after the peak growth spurt, between Tanner Stages 4 and 5, and in the middle of the fat-weight spurt (Marshall and Tanner, 1969). The events which initiate normal puberty development and culminate in menarche and normal cyclicity in girls are not well understood. Research suggests that the events are probably initiated in the central nervous system (CNS) which releases the toxic inhibitory control of gonadotropin luteinizing and follicle stimulating hormone secretion from the pituitary.

Puberty is marked by a rise in FSH secretion, nocturnal spurting of gonadotropins, and finally enhanced release of FSH and later LH in response to intravenous LRH (luteinizing-releasing hormone). The pattern of LRH stimulation also appears to be important, as intermittent LRH injections can initiate puberty in humans (Styne and Grumbach, 1978; Swerdoloff, 1978; Valk *et al.*, 1980). Full maturity of the CNS hypothalamic-pituitary-gonadal unit in the female is marked by the development of an adult pattern of episodic release of gonadotropins and eventually in normal menstrual cyclicity (Grumbach *et al.*, 1974; Styne and Grumbach, 1978).

Self-reports of menarche are quite accurate, across all birth cohorts and ages (Garn, 1980). However, around the time of menarche, a few girls may misreport menarche. In one study of 50 girls called every 10–12 weeks to see if they had begun to menstruate, 2 said they had begun, but in a subsequent interview stated that they had not (Brooks-Gunn and Ruble, 1982). In another study of 87 junior high school students, 89% of the mothers and daughters agreed as to the girls' menarcheal status. Six girls denied menarche had occurred when it had (according to mother), and 3 did not know or declined to say, while their mothers said it had not occurred (Petersen, 1983).

Because menarche is so easy to measure and many mothers and daughters are comfortable answering questions about it, menarche is used as a proxy

for maturational status and as a partial validation of other measures. For example, in the Milwaukee study, correlations between nurses' rating of maturation (taken during a height and weight measurement with clothed subjects) and self-reports of menarche were 0.29 for sixth-graders and 0.44 for seventh graders (Simmons *et al.*, 1983). In the Chicago study, reports of menarche were highly correlated with breast and body hair development (0.62–0.74; Petersen, 1983).

The psychological significance of menarche has been extensively studied (Brooks-Gunn, 1984). In addition, more timing studies have used menarche than all other maturation events combined (Grief and Ulman, 1982). However, almost all studies use different criteria to define groups, as is discussed in the preceding paper (Brooks-Gunn *et al.*, this issue).

Thus, menarche is a useful measure, as it is easily collected, raises few concerns with parents, school administrators, or girls themselves, and is reliably ascertained via self-report. However, as it occurs relatively late in the pubertal process, it is not adequate for the classification of status or timing in girls under age 12 or under seventh grade. For example, a premenarcheal sixth-grader may be on time or late and it is impossible to predict, on an individual basis, which she will be. *Post hoc* classifications, based on menarcheal status at age 14 or in eighth grade, may be misleading since the sixth-grader's status may not be accurately inferred from her eighth-grade status.

Pubertal Classifications

Instead of measuring changes specific to breast, body hair, menarche, and penile development, Petersen *et al.* (in press) has developed an interview to assess six aspects of sexual maturation in girls and boys. For boys, the six are height growth, foot growth, skin changes, voice changes, facial hair, and body hair. For girls, the six are height growth, foot growth, skin changes, body hair, breast development, and menarche. Young adolescents are asked if they have begun to develop in each area using a 4-point scale (from 1 = no, not at all to 4 = yes, a lot), with the exception of menarche (coded dichotomously with 1 = premenarcheal and 4 = postmenarcheal). Based on the scale scores, subjects are classified as prepubertal, early pubertal, mid-pubertal, or postpubertal if they report no development on voice, pubic hair, and facial hair, early pubertal if they report initial development on one or two of the three events (or advanced development on one but no development on the other two), and mid-pubertal if some development has begun on all three (or advanced development on one or two and no development on the others). Girls are classified as prepubertal if they have not

begun to develop breasts or pubic hair and are premenarcheal, early pubertal if they are premenarcheal but have begun breast or pubic hair development, mid-pubertal if they are premenarcheal but have developed some breasts *and* pubic hair. Alpha coefficients for the scales are high; correlations between PHV and self-reported pubertal status range from 0.40 to 0.65 across sixth, seventh, and eigth grades (Petersen *et al.*, in press).

CONCLUSIONS

One of the major lessons to be learned from the English and American growth studies is that puberty is a series of correlated events, not a unitary process. Conceptualizing maturation as a process leads to several conclusions related to its measurement. First, any one measure will not accurately represent an individual's current status. No measure necessarily characterizes pubertal status better than another. Indeed, the choice of a measure depends on the purpose of the study, the feasibility of obtaining accurate measures, and the importance of distinguishing between biological processes and the social significance of the event. Thus, secondary sexual development carries meaning for the individual, while skeletal growth may not. Within the secondary sexual characteristics, breast growth may be more salient to adults and peers than less noticeable pubic hair growth; thus, others may treat the adolescent girl differently as a function of the former, but not the latter (Brooks-Gunn and Warren, 1985). Whether similar differences would be obtained for boys is not known.

Second, classification systems are superimposed on continuous events. Thus, PHV is estimated from continuous data based on slope differentials. Sexual maturation stages are not qualitative in nature, even though they are sometimes treated as such. Caution is urged in the interpretation of such data as qualitative rather than quantitative.

Third, some measures are highly related to one another, while others are not. Weight and body fat are not good proxies for maturational status generally, while PHV is. Thus, the choice of a measure may be based in part on intercorrelations with other measures, but any single measure will not correlate highly with all other prepubertal processes. One approach, used by Petersen is to rate pubertal development on a series of events.

Fourth, rater reliability is an issue for many measures, even those that seem relatively straightforward. Of most concern are the self-reports of sexual maturation stages and observer ratings of "figure" development. While adequate reliability has been obtained, making self-reports attractive options in studies where nurse-practitioner ratings are not possible, some error is inevitable (Petersen, Crockett, and Boxer, 1985; Brooks-Gunn *et al.*, 1986).

The collapsing of Stages 4 and 5, which many adolescents have difficulty distinguishing, may make the use of self-report data on Tanner staging even more attractive. In any case, they are a viable alternative for school-based studies. Observer ratings of clothed subjects, on the other hand, do not show high convergent validity with other measures and are not an alternative for assessing pubertal status.

In general, the costs and benefits of using any measurment technique must be carefully assessed. In school- and community-based studies, self-report data on secondary school characteristics and actual height and weight data may be the norm. In more specialized studies, schematic drawings of secondary sexual characteristics may be used. Typically, pediatric ratings of secondary sexual characteristics or measurements of skinfold thickness do not take place outside medical settings or at least without substantial pediatric input into a community study. The most difficult to collect and expensive data involve hormone assessments. With regard to subject compliance, pediatric examinations and the drawing of blood are most likely to be problematic.

As this brief review of pubertal status measures concludes, we would like to consider what at first glance seems to be a major omission. As is evident from the title of the paper, we take a developmental perspective. But, the discussion of pubertal status and timing has not yet considered change. From what has been said, it is clear that individuals vary with respect to age of onset, rate of progression, and duration of puberty. Thus, knowing an individual is in Stage 2 for breast development at any point in time does not allow for an accurate prediction of the time to be spent in that stage or the time at which Stage 4 will be reached.

The psychological effects of different rates of progression or duration of puberty could be studied as easily as timing effects. Until recently, few studies have collected both pubertal and psychological data across the early adolescent life phase. Yearly, or even more ideally biyearly, physical data need to be collected to assess rate and duration. In addition, some measures are more amenable to the study of rate and duration than others, with secondary sexual characteristics perhaps being the best. Eichorn (1975) has discussed the importance of such an approach, but to date, it has not been employed in psychological studies.

Asynchronies within pubertal processes also may lend themselves to a developmental perspective. To complicate matters, the variation in age of onset, rate, and duration is not the same across pubertal processes. Knowing an individual is in Stage 2 for breast development does not allow us to assume that she is in Stage 2 for pubic hair development. It is likely that she is in an adjacent stage, but that means she may be in Stage 1, 2, or 3. For example, in the Harpenden growth study, of 88 girls reaching pubic hair

Stage 2, 16% were in breast Stage 1, 49% in Stage 2, 27% in Stage 3, and 8% in Stage 4. Over time, these asynchronies may be altered. In addition, the duration of puberty may differ for different pubertal processes. In the Marshall and Tanner (1969) analysis, the duration for Stages 2–5 for breasts was 4.2 years and for pubic hair 2.7 years. Thus, duration was shorter for pubic hair growth than breast development. How these maturational differences affect the individual is not known. Longitudinal studies are beginning to address issues related to differential rates and duration of pubertal processes.

In summary, the choice of a physical parameter and measurement technique is contingent upon the purpose of the study, the density of measurement points, the concerns of the school and community, staff availability, and collaborative arrangements with pediatricians. If a developmental perspective is taken, then repeated physical measurements are necessary. In some cases (e.g. height and menarche), such data might be obtained retrospectively. In others (e.g., secondary sexual characteristics), prospective data must be collected. To date, the research has conceptualized pubertal status as a process at one point in time rather than as a process that changes over time. In addition, reliance on univariate rather than multivariate measures of maturation characterizes the current literature. The investigative groups represented in these two special issues of the *Journal of Youth and Adolescence* are attempting to incorporate a developmental perspective into their research.

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