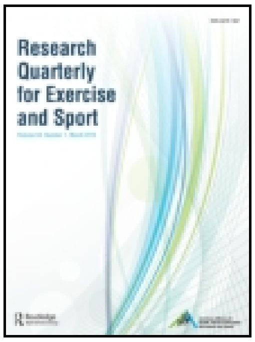

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SPECIAL TOPICS: Top 10 Research Questions

Top 10 Research Questions Related to Growth and Maturation of Relevance to Physical Activity, Performance, and Fitness

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Growth, maturation, and development dominate the daily lives of children and adolescents for approximately the first 2 decades of life. Growth and maturation are biological processes, while development is largely a behavioral process. The 3 processes occur simultaneously and interact. They can be influenced by physical activity and also can influence activity, performance, and fitness. Allowing for these potential interactions, 10 questions on growth and maturation that have relevance to physical activity, performance, and fitness are presented. The questions are not mutually exclusive and address several broadly defined topical areas: exercise and growth, body weight status (body mass index, adiposity rebound, "unhealthy weight gain"), movement proficiency (hypothesized barrier, role in obesity), individual differences, tracking, maturity-associated variation in performance, and corresponding variation in physical activity. Central to the discussion of each is the need for a biocultural approach recognizing the interactions of biology and behavior as potential influences on the variables of interest.

Keywords: body mass index, motor competence, peak height velocity, tracking

The terms growth and maturation are often treated together and at times synonymously; each, however, refers to specific biological processes. The term development is commonly used with growth and maturation and refers to changes in behavioral domains. Growth, maturation, and development occur simultaneously and interact during approximately the first two decades of postnatal life (Malina, Bouchard, & Bar-Or, 2004). The three processes can be influenced by physical activity and at the same time can also influence physical activity, performance, and fitness. Prior to identifying and discussing the 10 research questions of relevance, basic concepts related to growth, maturation, development, and physical activity and trends in changes across childhood and adolescence are briefly reviewed.

GROWTH, MATURATION, AND DEVELOPMENT

Growth refers to the increase in the size of the body as a whole and of its parts. As children grow, height and body mass increase. The latter is heterogeneous and includes changes in skeletal, muscle, and fat mass, bodily organs, and so on. Different segments of the body grow at different rates and at different times, therefore resulting in altered body proportions.

Maturation refers to progress toward the biologically mature state or biological maturity. Maturation is a process, while maturity is a state. Maturation occurs in all bodily

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organs and systems, but maturity varies with the biological system considered. Sexual maturity is fully functional reproductive capability. Skeletal maturity is a fully ossified adult skeleton. Maturation of the nervous and endocrine systems is a major factor underlying sexual, skeletal, and somatic growth and maturation.

The timing and tempo of growth and maturation vary considerably among individuals. Timing refers to when specific events or milestones in growth and maturation occur, while tempo refers to the rate at which the processes of growth and maturation progress.

Development refers to the acquisition and refinement of behaviors expected and in many instances set by society. The terms social competence, intellectual or cognitive competence, emotional competence or well-being, and moral competence are often used as the individual's behaviors develop within the context of the particular culture in which he or she was born and reared. As children experience life at home, in the neighborhood, and at school, church, sports, recreation, and other community activities, they develop cognitive, social, affective, moral, and other behaviors expected by society (i.e., they develop behavioral competence in a variety of domains).

Motor competence refers the acquisition and refinement of skillful performance in a variety of movement activities that straddle the biological and behavioral domains. The development of motor competence involves interactions between the neuromuscular system and environments of infants, children, and adolescents. Motor development involves the attainment of movement milestones such as independent walking and specific gross and fine motor patterns. The process reflects, to a large extent, underlying processes of neuromuscular maturation interacting with growth in size and proportions and the experiences of infants and children with specific environments at home, day care, and preschool, among others.

"The business of growing up" involves three interacting though distinct processes. Growth and maturation are biological processes, while development is largely a behavioral process often subsumed in the term socialization specific to a culture. The three processes dominate the daily lives of children and adolescents for approximately the first two decades of life. Interactions among the three processes vary during childhood and adolescence, among individuals, and within and between cultural groups, which emphasizes the need to approach childhood and adolescence in a biocultural framework (Malina, 2008).

Although beyond the scope of this discussion, the term development is also used to describe the biological processes of differentiation of pluripotent embryonic stem cells into specific cell types, tissues, organs, and functional units. Accordingly, development depends upon the activation and repression of genes or sets of genes interacting with hormones, nutrients, and the prenatal and postnatal environments of the individual as systems of the body are functionally refined.

The cellular processes that underlie biological growth and maturation as well as aspects of behavioral development cannot be observed or measured directly, although advances in technology are providing significant insights. The study of growth and maturation is based on standardized measurements and observations of outcomes of underlying cellular activities. Growth in height reflects the proliferation of cartilage cells at growth plates of individual bones, while stage of sexual maturity reflects neuroendocrine influences on gonadal tissues. Competence in movement skills depends on activities in the motor cortex, which regulate voluntary movements.

PHYSICAL ACTIVITY AND INACTIVITY

Physical activity and physical inactivity are multidimensional behaviors that occur in multiple contexts. Both are important avenues for learning, enjoyment, social interactions, and self-understanding. Evidence and opinion currently suggest an imbalance in the direction of increased inactivity and reduced physical activity, which has implications for the obesity epidemic and emergence of risk factors for cardiovascular and metabolic diseases in youth.

Physical activity is viewed most often in terms of energy expenditure and the stresses and strains associated with weight-bearing and ground-reaction forces. Motor skill (proficiency in a variety of movements) and fitness (performance- and health-related) are dimensions of activity. Context is an additional, important dimension that is often overlooked. It refers to types and settings of activity and includes play, physical education, exercise, sport, dance, and labor, among other activities. Contexts per se and meanings attached to them vary with age among children and adolescents, and among and within different cultural groups (Malina, 2008).

Physical inactivity or sedentary behavior also has several dimensions. Although the biomedical view of physical activity is critical of sedentary behaviors, many forms of physical inactivity are highly valued by societies—school, studying, reading, music, art, television viewing, and the like. Motorized transport is a form of inactivity that is also valued by major segments of society.

Physical activity and inactivity are independent behaviors performed in a societal context, and both have high valence in society. These behaviors are of interest to public health, medicine, and education. The public health and biomedical views focus on physical activity in the context of health promotion and disease prevention and focus on physical inactivity as a major risk factor, among others, for cardiometabolic diseases. The educational view highlights activity in the context of physical education as a component of the overall school experiences of youth. Sport—specifically, organized sport—is a major context of both physical activity and sedentary behavior (i.e., activities performed by participants and inactivity of spectators). The meanings attached to and motivations for physical activities and sedentary behaviors by children and adolescents, and also by parents, merit major attention.

GROWTH IN BODY SIZE AND COMPOSITION: AN OVERVIEW

The interval between birth and adulthood is commonly divided into age periods. The 1st year after birth (birth to the 1st birthday) is labeled infancy, which is followed by childhood. Childhood is usually subdivided into early and middle phases. The former approximates the "preschool" years, about 1 to 5 years of age. The latter approximates the "elementary school" years, about 5 to 6 years of age through 10 to 11 years of age. The upper limit of middle childhood is arbitrary because it is followed by adolescence, which is variable in age at onset. Some 9- to 10-year-old girls, for example, are already in the early stage of adolescence. The termination of adolescence is also variable, so it is also difficult to specify when adulthood begins. Biologically, some girls are sexually mature by 12 years of age and some boys are sexually mature by 14 years of age (i.e., they are biologically adult). Yet, they are adolescents in the eyes of society. Adulthood is a largely socially defined concept, usually in the context of completing high school in Western cultures, but in some instances, it is defined in the context of completing college and/or entrance into the workforce.

Height and weight are the body dimensions most commonly used to monitor growth. With age, children are expected to become taller and heavier. Size attained at a given age (status) and rate of growth (progress) are usually monitored relative to growth charts, which serve as a reference for evaluating size attained by individuals or samples of children and adolescents. Growth charts are available for many countries; the revised charts for height and weight of American children from birth to 20 years of age (Kuczmarski et al., 2000) are widely used. The sex-specific charts, based on nationally representative samples of American youth, include several percentile curves for heights and weights by age.

Height and weight increase gradually during childhood. At about 9–10 years of age in girls and 10–11 years of age in boys, the rate of growth in height accelerates, and this marks the beginning (takeoff) of the adolescent spurt, a period of rapid growth that is highly variable among individuals. With the onset of the growth spurt, the rate of growth increases until it reaches a peak (peak height velocity, PHV), the maximum rate of growth in height during the spurt. The rate of growth in height gradually decreases and eventually reaches zero. Some individuals continue to grow in height into their early 20s. Girls, on average, start their growth spurts, reach PHV, and stop growing about 2 years earlier than boys. Nevertheless, when the growth spurt starts, when PHV is reached, and when growth stops are very variable among individuals.

The growth spurt in body weight begins slightly later than that of height. In contrast to height, weight continues to increase into the 20s. Body weight is a composite of bodily tissues, but it is often viewed in terms of its lean (fat-free) and fat components. Thus, body weight = fat-free mass (FFM) + fat mass (FM). Major components of FFM are skeletal muscle and bone mineral. FFM has a growth pattern like that for height and weight and experiences a clear adolescent spurt. FM increases more gradually during childhood and adolescence. Most other body dimensions and many major organs follow growth patterns similar to the pattern for height and weight.

BIOLOGICAL MATURATION: AN OVERVIEW

The maturity status and progress of children and adolescents are traditionally monitored in the skeleton and secondary sex characteristics. Maturation of the skeleton focuses on the bones of the hand and wrist, which generally reflect the remainder of the skeleton. An X-ray of the hand and wrist is needed to assess skeletal maturation. Protocols for assessing skeletal maturation vary but are similar in principle and provide an estimate of skeletal age. Skeletal maturation can be used from infancy through adolescence and is also used with height at a given age to predict adult or mature height.

Sexual maturation is based on the development of secondary sex characteristics: breasts and pubic hair in girls and the testes and pubic hair in boys. Initial development of the breasts is, on average, the first physically apparent sign of sexual maturation in girls, followed by the appearance of pubic hair. The first overt sign of sexual maturation in boys, on average, is the initial enlargement of the testes, followed by the appearance of pubic hair. Each characteristic goes through a series of changes as the individual passes from prepuberty into and through puberty to the mature state. The changes have been summarized in five stages (described by Tanner, 1962) marking progress from the immature state (Stage 1) to the mature state (Stage 5). Secondary sex characteristics are usually assessed by a physician at a clinical examination, though self-assessments are increasingly used. Assessment requires invasion of the youngster's privacy at a time of life when he or she is learning to cope with the physiological changes occurring with puberty and the growth spurt. Monitoring of secondary sex characteristics requires utmost care and sensitivity to the youngster involved.

Stages of puberty have limitations. Stage 1 (prepubertal) indicates a lack of overt manifestation of the development of breasts, testes, or pubic hair. Prepubertal children of the same chronological age, however, can vary in skeletal age by 4 years or more (Malina et al., 2004). Subsequent stages indicate status at the time of survey but provide no information on when the individual entered a stage or how long she or he has been in a stage.

Age at menarche, the first menstrual period, is the most commonly used indicator of the timing of sexual maturity in girls; male puberty does not have a corresponding overt, physiological event. Ages at menarche of individuals can be obtained prospectively (longitudinal studies) and retrospectively (recall). The latter has major limitations with girls aged 10 to 16 years of age, as some girls have not yet attained menarche and thus are excluded. Age at menarche for a sample of girls can be estimated with the status-quo method, which requires age and menarcheal status (whether menarche has occurred or not occurred) in a large sample aged 9 to 17 years of age. Age at menarche for the sample is estimated statistically (commonly with probit analysis). Of course, sample estimates do not apply to individual girls.

Age at PHV is an excellent indicator of maturity timing. Derivation of age at PHV in individuals requires 6 or 7 years of longitudinal height measurements spanning about 9 to 16 years in girls and 10 to 17 years in boys. Heights of an individual boy or girl are mathematically modeled to derive an estimate of age at PHV and rate of growth at PHV. It is thus a post-facto indicator of maturity timing. Other features of adolescent growth can also be estimated, depending on the model used—for example, age and size at takeoff, size at PHV, and young-adult height (Malina et al., 2004).

Longitudinal studies (Bielicki, 1975; Bielicki, Koniarek, & Malina, 1984; Nicolson & Hanley, 1953) indicate clustering of chronological ages when attaining specific skeletal ages, stages of secondary sex characteristics, PHV, peak velocity of other linear dimensions, and specific percentages of mature height, and these studies suggest a general maturity factor during adolescence in both sexes. The data also suggest an additional maturity factor marking the transition into the early phases of puberty and the growth spurt (i.e., onset of puberty and takeoff of the spurt).

TRENDS IN PERFORMANCE: AN OVERVIEW

Performances on standardized tests of performance, including several fitness items, improve with age during childhood. Boys perform, on average, better than girls, but there is considerable overlap between the sexes during early and middle childhood. With the onset of adolescence, performances of boys show acceleration in improvement, while those of girls improve until about 13 to 14 years of age and then improve only slightly or level off. The trends are based on group averages. Many girls do in fact improve their performances through adolescence.

Performances during adolescence are influenced, in part, by individual differences in the timing of the adolescent spurt. A number of performance tasks show well-defined adolescent spurts in boys. Measures of static strength (grip, arm pull), power (vertical jump), and functional strength (flexed arm hang) show peak gains, on average, after PHV, while measures of speed and agility (shuttle run), speed of arm movement (plate tapping), and lower back flexibility (sit and reach) show peak gains before PHV (Beunen & Malina, 1988; Malina et al., 2004). The trends for measures of strength and power are similar in timing to those for body mass and muscle mass, both of which experience maximum growth after PHV. The earlier adolescent spurts for running speed and lower back flexibility may be related to growth of the lower extremities. Height is composed of the legs, trunk, neck, and head, and the legs experience maximum growth first. Thus, boys have relatively longer legs for their heights early in the adolescent spurt, and this may influence running speed and lower trunk flexibility.

Data relating performances of girls to the adolescent spurt are not extensive. Like boys, girls show an adolescent spurt in static strength of the arm and power (vertical jump) after maximum growth in height. The magnitude of the growth spurt in strength, however, is only about half of the maximum gain in boys. Longitudinal data for other performance tasks in girls are limited (Beunen & Malina, 1988; Malina et al., 2004), which highlights the need for longitudinal study of changes in performances of girls through the interval of the adolescent growth spurt. When performances of girls are related to the time before and after menarche, there are no consistent trends. Menarche, however, is a late maturational event that occurs after PHV; major gains in growth and performance have already occurred (Malina et al., 2004).

TRENDS IN PHYSICAL ACTIVITY: AN OVERVIEW

Studies of physical activity have historically been based on questionnaires among school-age children and adolescents. On average, the level of physical activity tends to gradually increase during childhood, reaches a peak circa 12 to 14 years of age, and subsequently declines. Boys are, on average, more active than girls, though the sex difference is attenuated when maturity status is controlled in adolescence (Thompson, Baxter-Jones, Mirwald, & Bailey, 2003). Nevertheless, age trends in activity vary among studies and with measurement instrument and context.

More recent surveys are based on accelerometry and often focus on epochs of moderate-to-vigorous physical activity (MVPA), the intensity of activity that is most often associated with health benefits (Strong et al., 2005). Observations derived from 4 to 7 days of accelerometry in a nationally representative sample of U.S. youth indicated a decline in MVPA from 9 through 15 years of age in both sexes, higher levels of MVPA in boys than in girls, and higher levels of MVPA on weekdays compared with weekend days in both sexes (Nader, Bradley, Houts, McRitchie, & O'Brien, 2008). Boys exceeded the recommended 60 min of MVPA at all ages except 15 years, while girls exceeded the recommendation from 9 to 13 years of age, when levels of MVPA fell below 60 min.

Systematic reviews (Sallis, Prochaska, & Taylor, 2000; Van der Horst, Paw, Twisk, & van Mechelen, 2007) indicate a variety of factors that influence physical activity among children and adolescents. The reviews, however, define childhood too broadly, from 3 to 12 years of age, At the younger ages, children are still developing basic movement skills, while at the upper ages, most girls and many boys are already pubertal. Except for body mass index (BMI), potential biological correlates of activity were not considered. Motor proficiency and level of physical fitness were also not evaluated among correlates of activity. Twin and family studies show familial aggregation of physical activity-related traits and suggest the potential influence of genotypic, common environmental, and/or both factors (Bouchard, Malina, & Perusse, 1997; Teran-Garcia, Rankinen, & Bouchard, 2008). More recently, interindividual variation in biological maturity status has been noted as an important correlate of activity among adolescents (Sherar, Cumming, Eisenmann, Baxter-Jones, & Malina, 2010).

TOP 10 QUESTIONS

With the preceding as background, 10 questions addressing interrelationships among growth, maturation, physical activity, performance, and fitness are considered. The questions are set in the context of youth in developed countries, and inferences to other regions need caution. Given the complexities of these processes, behaviors, and outcomes, the questions are not mutually exclusive, but fall into several categories.

Exercise and Growth

1. Is Regular Physical Activity Essential to Support Normal Growth and Maturation?

Studies spanning nearly a century (see reviews by Malina, 1969, 1979; Rarick, 1960; Steinhaus, 1933) have suggested that regular physical activity, including training for sport, has a stimulatory and presumably beneficial influence on growth. In the comprehensive review "Exercise and Growth," Rarick (1960) highlighted the need for activity:

> There seems to be little question that certain minima of muscular activity are essential for supporting normal growth and for maintaining the protoplasmic integrity of the tissues. What these minima mean in terms of intensity and duration of activity has not been ascertained. (p. 460)

This question persists at present but is framed not necessarily in the context of growth, but in terms of health- and fitness-related benefits of regular physical activity for children and adolescents. Specifically, what type and amount (frequency, intensity, duration) of physical activity is needed to bring about beneficial effects in bone, muscle, and adipose tissues and in indicators of health status and physical fitness in youth? Recent critical evaluations of the available evidence dealing with the effects of physical activity on adiposity, bone mineralization and strength, musculoskeletal function, and physical fitness have been recently summarized (Physical Activity Guidelines Advisory Committee, 2008; Strong et al., 2005) and have been extended to include risk factors for cardiovascular and metabolic diseases in youth. The evaluations were largely based on school-age youth approximately 6 to 18 years of age. There is a need to address the question noted in the previous paragraph to more narrowly defined age groups from childhood through adolescence and among adolescents of contrasting biological maturity status. The issue of maturity-related variation is discussed in more detail later in the article.

The focus of the question addressed is the amount and type of physical activity needed to bring about beneficial effects. This is important, but several related questions merit attention. For example, what type and amount of activity are needed to maintain the beneficial effects of physical activity on bodily tissues and indicators of health and fitness? And can changes associated with or attributed to physical activity be partitioned from those associated with normal growth and maturation? The normal course of growth and maturation is to increase in size and mass and components of mass (skeletal muscle, bone mineral, FM).

For example, youth who regularly engage in physical activity tend to have less adiposity (skinfolds, percent fat) than do those who engage in less activity; however, enhanced activity programs as in interventions appear to have a minimal effect on adiposity in normal-weight youth. The issue of activity volume has not been systematically addressed. It is possible that normal-weight youth require a greater activity volume. In contrast to normal-weight youth, physical activity interventions with overweight and obese youth result in reductions in overall adiposity and in visceral (abdominal) adiposity (Strong et al., 2005). As another example, gains in strength associated with resistance training among children and adolescents appear to be independent of changes in body composition and estimated muscularity (Malina, 2006). Studies also commonly combine youth across a broad range of ages and analyses do not control for the potential effects of age per se. Measures of strength are positively related to maturity status, and studies of resistance training do not ordinarily control for individual differences in maturation.

In contrast to beneficial effects of habitual physical activity on youth, concern has been expressed about potentially negative influences, specifically intensive training for sport, on growth and maturation during childhood and adolescence. Regular physical activity, of course, is not equivalent to training for sport, which is generally specific. Issues related to training and the growth and maturation of young athletes have been previously addressed (Malina, 1998; Malina, Baxter-Jones, et al., 2013; Malina & Rogol, 2011). There is need for comprehensive studies of youth regularly training for sport that not only include monitoring growth and maturation longitudinally, but also include simultaneous monitoring of the overall training environment of the respective sports (i.e., training protocols [preseason, in-season], work–rest patterns during training, differential selection and dropout, behaviors of adults involved [coaches, parents, administrators], dietary control, and related factors). Such a comprehensive approach would provide a broader framework within which to evaluate growth- and maturation-related questions among youth athletes.

Issues Related to Body Weight

2. Is BMI the Most Appropriate Metric for Overweight and Obesity in Youth?

BMI (kg/m^2) is the most commonly used indicator of weight status, specifically overweight and obesity. Although valuable for population surveys of weight status, the BMI has limitations (Flegal et al., 2009; Keys, Fidanza, Karvonen, Kimura, & Taylor, 1972; Malina, 2012). It is also often used as an indicator of adiposity or fatness, but the BMI is not a measure of body composition. It is significantly correlated with both FFM and FM in normal-weight youth (Malina & Katzmarzyk, 1999) and is perhaps more closely associated with lean mass rather than FM among relatively thin youth (Freedman et al., 2005). The BMI may not accurately predict body fat while estimated percentage fat associated with cutoffs for overweight and obesity vary with age, more so in girls than in boys (R. W. Taylor, Jones, Williams, & Goulding, 2002). Ethnic variation in body composition, fat distribution, and BMI are additional considerations (Malina, 2005).

Several cutoff values of the BMI to classify weight status, specifically overweight and obesity, are available. The charts for American youth (Kuczmarski et al., 2000) and those recommended by the World Health Organization (WHO; de Onis et al., 2007) present specific percentiles. The percentiles used to define overweight and obesity, however, may not necessarily be representative of the true meaning of percentiles (see Zhu, 2012). The International Obesity Task Force (IOTF) used adult criteria to define cut points for overweigh and obesity (Cole, Bellizzi, Flegal, & Dietz, 2000) and also for several levels of thinness at the low end of the BMI range (Cole, Flegal, Nicholls, & Jackson, 2007). More recently, BMI standards scaled to predicted percentage body fat in American youth have been developed for the FITNESSGRAM® battery (Laurson, Eisenmann, & Welk, 2011; Welk, de Saint-Maurice Maduro, Laurson, & Brown, 2011).

The U.S. charts are based on surveys of nationally representative samples of the noninstitutionalized civilian population from the 1960s to 1994 (Kuczmarski et al., 2000). Body weights of American children and youth increased significantly between surveys in 1976–1980 and 1988–1994, whereas as height did not significantly change (Kuczmarski et al., 2000; Roche, 1999). The gain in body weight from the late 1970s through the mid-1990s was viewed as undesirable from a public health perspective so that in developing the updated growth charts for body weight and BMI, the values from 1988–1994 were not used. Thus, the charts are to some extent criterion-referenced in that public health authorities decided on levels of weight and weight-for-stature (BMI) that are presumably conducive to better health.

Data for nationally representative samples of children and adolescents aged 2 to 18 years of age from Brazil, Great Britain, Hong Kong, The Netherlands, Singapore, and the United States were used to develop the IOTF criteria (Cole et al., 2000, 2007). In establishing the cutoff points, curves were mathematically fitted to the pooled BMI data from the six countries so that they passed through adult criteria to define overweight (BMI of 25.0 kg/m^2) and obesity (30 kg/m^2) and three grades of thinness (16.0 kg/m^2, 17.0 kg/m^2, and 18.5 kg/m^2) at 18 years of age (WHO, 1998). The WHO charts were developed from WHO growth standards for children from birth to 5 years of age and 1977 U.S. reference data for older ages using updated statistical methods (de Onis et al., 2007).

In developing the Fitnessgram reference, BMI was scaled to low- and high-risk levels of percentage body fat based on the triceps and subscapular skinfolds (Slaughter et al., 1988) in nationally representative U.S. surveys of children and adolescents aged 5 to 18 years of age from 1999 to 2004 (Laurson et al., 2011). The prediction equations for boys were specific to pubertal status; criteria for pubertal status were simply described as the "Tanner stages" without specifying whether stage of genital or pubic hair maturation or both were assessed (see Tanner, 1962, for the specific criteria for each characteristic). Pubertal status, however, was not assessed in the national surveys utilized to develop the BMI reference; it was assumed boys younger than 12.0 years of age were prepubertal and boys 14.0 years of age or older were postpubertal, while boys aged 12.0 years through 13.9 years were pubertal. This assumption overlooks interindividual and ethnic variation in genital and pubic hair maturation (Sun et al., 2002).

Given the variety of criteria for evaluating weight status with the BMI, there is a need for a critical evaluation of the suggested cutoffs. For example, U.S. and IOTF cut points for the BMI differ for obesity but are reasonably similar for overweight (Malina, 2012). One can also inquire into the growth and maturity characteristics of youth whose weight status was variably classified by different criteria (Malina, Peña Reyes, Bali Chavez, & Little, 2013; Malina, Skrabanek, & Little, 1989), as well as potential behavioral implications of weight status misclassifications.

The BMI is considered a component of physical fitness (Pate, Oria, & Pillsbury, 2012), but it is also a factor that influences fitness. Studies of relationships between the BMI and fitness generally focus on the overweight and obese extremes. Data addressing relationships between fitness and the broad spectrum of BMIs within an age group are limited. Results from a national sample of Taiwanese school youth suggested differential effects on individual tests (sit and reach, sit-ups, standing long jump, 800/1,600-m runs), which varied with age and sex (Huang & Malina, 2010). Relationships became more parabolic with age in three of the four items (sit-ups, jump, run). The results highlight the need to evaluate the influence of the BMI on fitness through the spectrum of the BMI in different age groups and to not focus exclusively on overweight and obese youth. It is possible that a low BMI is also associated with poor or marginal fitness.

3. What Is the Implication of the "Adiposity Rebound" for Subsequent Weight Status and Physical Activity?

BMI declines, on average, from about 1 year of age into the early years of middle childhood, and then it increases. The rise in BMI after it reaches a low point at about 5 to 6 years of age has been labeled the "adiposity rebound" (Rolland-Cachera et al., 1984). Evidence suggests than an earlier rebound is associated with increased rates of relative weight gain (S. M. Williams, 2005), with fatness in middle childhood (S. M. Williams & Goulding, 2009), and with an elevated BMI in childhood, adolescence, and young adulthood (Rolland-Cachera et al., 1987). Other data suggest a greater probability of overweight/obesity in the late 20s among those with an earlier rebound and a heavier BMI at rebound (Whitaker, Pepe, Wright, Seidel, & Dietz, 1998) and of overweight at 35 to 45 years in women, but not in men, from the Fels Longitudinal Study (Guo et al., 2000). Skeletal age did not differ among early-, average-, and late-adiposity rebound groups at 4, 6, and 8 years of age, but between 10 to 16 years of age, somewhat later skeletal maturation was associated with a late compared with an early rebound (Rolland-Cachera et al., 1984). An earlier age at menarche was also associated with an early adiposity rebound (S. Williams & Dickson, 2002).

The decline in BMI from about 1 year of age to its low point implies that linear growth is proceeding more rapidly than growth in body mass. The legs are growing faster than the trunk so that children have proportionally longer legs with increasing age. In addition, subcutaneous fatness and estimated percentage fat decline, on average, through 6 to 7 years of age (Malina et al., 2004). One can inquire, therefore, what specifically changes during the adiposity rebound? Some data suggest an accelerated rate of growth in lean tissue mass and a reduction in FM during the BMI rebound (Campbell, Williams, Carlin, & Wake, 2011; Plachta-Danielzik et al., 2013). By inference, the increase in adiposity characteristic of middle childhood occurs after the BMI rebound. Nevertheless, girls with early rebound have an increased rate of gain in FM compared with girls with a late rebound (R. W. Taylor, Goulding, Lewis-Barned, & Williams, 2004). Changes in relative fat distribution at this time also merit study—for example, skinfold thicknesses on the trunk versus those on the extremities or visceral versus subcutaneous abdominal fat.

Further research is needed into the nature of the BMI rebound and other changes occurring about this time. Many children, but not all, experience a small growth spurt in height, labeled the mid-growth spurt, from 6 to 8 years of age (Malina et al., 2004). There does not appear to be a sex difference in the timing of the mid-growth spurt, but the spurt occurs more frequently in boys than in girls (Gasser et al., 1985; Sheehy, Gasser, Molinari, & Largo, 1999; Tanner & Cameron, 1980).

Fundamental movement patterns develop during the interval of decline in the BMI in early childhood and many reach mature form between 5 and 7 years of age (Seefeldt & Haubenstricker, 1982; i.e., the interval of the adiposity rebound and mid-growth spurt). There is a need to more critically evaluate motor development in the context of changes in body size, proportions, and composition that occur at these ages. Available longitudinal data sets that include motor development, height, weight, and other variables should be revisited in the context of new hypotheses and advances in analytical methods.

Physical activity during the interval of the adiposity rebound and mid-growth spurt also merits study. Limited data suggest an association between fatness and low levels of physical activity and increased television viewing among children in the age range that includes the adiposity rebound (Janz et al., 2002). Potential relationships between physical activity and inactivity and the adiposity rebound need critical evaluation in longitudinal designs.

4. What Is the Role of Physical Activity in the Prevention of "Unhealthy Weight Gain" During Childhood and Adolescence?

It is imperative to address the issue of "unhealthy weight gain" and the role of physical activity in efforts to prevent overweight and obesity during childhood and adolescence. Several longitudinal studies suggest a potentially important role of physical activity in the prevention of overweight/obesity during different phases of growth. Early childhood and the transition into middle childhood may be important windows of opportunity for intervention to limit excess weight gain. More active children aged 4 to 11 years of age have less fatness in early adolescence and may also have a later adiposity rebound (Moore et al., 2003). Children involved in organized sports and indoor physical activity programs during kindergarten and first grade increase in their BMI at a slower rate from about 6 to 10 years of age compared with children not involved in such programs (Dunton et al., 2012). In addition, an increase in physical activity during adolescence may limit the accrual of FM in boys but not girls (Mundt et al., 2006). Maintenance of smaller gains in BMI and FM through regular physical activity over time thus has the potential to prevent unhealthy weight gain and in turn reduce risk for overweight/obesity. How much physical activity and at what intensity is needed to limit excess gains in weight, and in turn, FM and BMI?

Given the individuality in growth rate and the timing and tempo of the adolescent growth spurt, it is difficult to specify "unhealthy weight gain." What is the expected weight gain in nonobese children? Incremental growth charts from the Fels Longitudinal Study of individuals born and reared from 1929 to 1978 (i.e., before the obesity epidemic) may be useful in this regard (Baumgartner, Roche, & Himes, 1986; Roche & Himes, 1980).

Movement Proficiency

5. Is There a Critical Level of Movement Proficiency That Facilitates Physical Activity and Sport Participation in Children and Adolescents?

A proficiency barrier between the development of fundamental motor skills and the transition to more complex movement skills (as in games and eventually specific sports) has been postulated (Seefeldt, 1980). Accordingly, children deficient in fundamental motor skills and/or in learning experiences to develop basic skills may experience difficulty when they attempt more complex activities. By inference, there may be a level of movement competence above which a child would be more likely to engage in various physical activities, including sport, and below which a child would be less likely to engage in such activities.

If the hypothesized barrier in movement proficiency exists, it is essential to identify potential correlates associated with motor development per se and with the growth characteristics of the child, the child's family environment, aspects of their social environments, and day care, among others. For example, what is the influence of parental involvement in activities with their children or time spent outdoors on motor development? What are the potential influences of siblings, playmates, and/or peers; day-care or preschool attendance; and caregivers and/or teachers on motor development in young children?

The hypothesized barrier may emerge during the transition from early into middle childhood when fundamental motor skills are ordinarily sufficiently developed. These are also the ages when participation in a variety of youth sports begins. Do youth sports programs afford appropriate interventions to remedy a proficiency barrier? Or do youth sports programs exacerbate the barrier and contribute to discontinuation of participation in sport and physical activity? With increasing age and as youngsters pass through childhood into early adolescence, is the barrier affected by biobehavioral interactions associated with individual differences in the timing of sexual maturation and the growth spurt?

6. What Is the Role of Movement Proficiency or Lack of Proficiency in the Development of Obesity?

Youth more proficient in movement skills are more likely to be physically active. This is apparent among children aged 3 to 5 years (Fisher et al., 2005; H. G. Williams et al., 2008) and 8 to 10 years (Wrotniak, Epstein, Dorn, Jones, & Kindilis, 2006), as well as in adolescents 13 and 15 years of age (Okely, Booth, & Patterson, 2001). The relationships are more apparent at the extremes of motor proficiency, but the variance in physical activity explained by motor proficiency is relatively small. Some evidence also suggests that a high level of motor coordination at 6 years of age buffers the decline in physical activity with increasing age from 6 to 10 years (Lopes, Rodrigues, Maia, & Malina, 2011).

On the other hand, motor coordination is less developed in overweight and obese children compared with normal-weight children aged 5 to 9 years of age (Graf et al., 2004). Overweight and obese children in Grades 4 through 10 (aged ~9–15 years) are more likely to demonstrate lower levels of development of fundamental motor skills (Okely, Booth, & Chey, 2004), while obese children and adolescents of both sexes show, on average, lower scores on performance-related fitness tests requiring projection of the body (Beunen et al., 1983; Malina et al., 1995). Overall, the data indicate reduced levels of coordination and poorer performances in tasks requiring movement or projection of the body through space among obese youth.

Low levels of physical activity are often indicated as a potential cause and consequence of obesity (i.e., reduced physical activity leads to weight gain, which in turn leads to overweight and obesity, and in turn further reduction in physical activity). Limited movement proficiency may be an important covariate in this process (i.e., low motor skill may lead to reduced physical activity, which leads to weight gain and excess weight-for-height; overweight and obesity, in turn, may contribute to impaired progress in movement skill and in turn to a further reduction in physical activity).

The preceding scenario suggests several questions. First, does early obesity impede the development of motor coordination and proficiency? Second, does lack of motor coordination or proficiency in movement skills place a child at risk for obesity? Third, does the level of motor proficiency influence physical activity in obese youth? If so, what specific factors mediate the process? Fourth, is obesity a function of reduced physical activity, or is reduced activity a function of obesity? There is also a need to address these issues in nonobese children who subsequently become obese. What are the consequences for their movement proficiency and physical activity? Conversely, there is a need to consider the movement proficiency and physical activity of overweight/obese youth who return to normal-weight status.

Individual Differences

7. What Is Unique About Individuals Who Do Not Respond as Expected to Physical Activity Programs or Interventions?

Activity programs and interventions typically focus on group outcomes, mean changes, and size effects, among others, often to the neglect of variability within samples. Why would we expect all individuals to respond to such programs in the same manner? This is also true of sport-training programs, albeit with more specialized samples of athletes.

It is essential to move beyond group outcomes and to consider interindividual variation in responses to activity intervention and training protocols. For example, peak oxygen consumption (VO_2max) increased, on average, from 44.7 mL/kg/min to 47.6 ml/kg/min after a 12-week aerobic training protocol in a sample of 35 boys and girls aged 10.9 to 12.8 years (Rowland & Boyajian, 1995). The mean relative gain was 6.5%, but changes in individuals ranged from −2.4% to +19.7%. Six youngsters showed relative changes in peak VO_2 between 0% and −2.4%. Similarly, 12 weeks of aerobic training in 15 obese girls (aged 13.1 ± 1.8 years) resulted in improved insulin sensitivity without significant changes in body mass and percentage fat (Nassis et al., 2005). Yet, relative change in the insulin area under the curve decreased (improved sensitivity) in 11 girls, showed a negligible change in 1 girl, and increased (poor sensitivity) in 3 girls. Similar variation among individual girls was also evident for the glucose area under the curve.

Such variation in response to training or activity interventions is real and begs several questions. What is the influence of negligible or negative responses to activity programs on the youth participants? They are working as hard as the others but show little if any beneficial effects. What are the characteristics—physical, physiological, maturational, and/or behavioral—of youngsters who do not respond as expected? How can we modify programs to accommodate the outliers? What are the determinants of interindividual differences in response to activity programs? Individuality in response to training is in part genetic and involves genotype–environment interactions (Bouchard et al., 1997, 1999; Bouchard & Rankinen, 2001). It is reasonable to assume similar factors in response to physical activity interventions and youth sports programs, among other activities.

Tracking of Activity and Fitness

8. Is the Adult-Based Concept of Health-Related Physical Fitness Relevant for Children and Adolescents?

The physical fitness of youth was historically viewed in a primarily performance-oriented context, but it has shifted to an almost exclusively health-related focus in the context of health concerns that surface in adulthood (Malina, 1991, 1995, 2007). Children and adolescents, of course, are not miniature adults. Components of fitness change as a function of growth, maturation, development, and interactions among the three processes.

The concept of health-related fitness as applied to youth is based on one or both of the following assumptions: First, regular physical activity during childhood and adolescence will favorably influence health-related fitness and in turn prevent or impede the development of several adult diseases that include physical inactivity in a complex multifactorial etiology; and second, habits of physical activity during childhood and adolescence will favorably influence habits of physical activity in adulthood and in turn will continue to favorably influence health-related fitness and health status during adulthood.

The assumptions imply that habits of physical activity and indicators of health-related physical fitness, among other variables such as motor proficiency and weight status, track from childhood through adolescence, from adolescence into adulthood, and through adulthood. Tracking refers to the relative stability of a characteristic, or the maintenance of relative position or rank in a group, over time (Malina, 1996). Longitudinal observations for at least two points in time are needed to study tracking. Correlations between observations at two or more age points are used most often to estimate tracking or stability over time. Other approaches include risk analysis, which permits estimates of the odds of maintaining a specific behavior or characteristic over time, and linear models, which can use data over unequally spaced intervals and can account for missing values.

Presently available data suggest at best moderate relationships between physical activity during youth and activity in adulthood (Malina, 1996, 2001a, 2001b, 2001c). Data tracking physical activity within adulthood (20+ years of age) are available largely over the short term, about 3 to 7 years, with limited data spanning longer intervals. Correlations range from low to high, decrease with longer intervals, and decrease with increasing age (Malina, 2001c). Associations should be considered in the context of the instruments (largely questionnaires, recall) and contexts of activity. Indicators of activity in youth do not reflect the same contexts or attributes of activity as in adulthood. Many youth, for example, view activity as equivalent to sport, which is not a primary context of activity as adulthood progresses.

Relationships between activity and fitness during youth, and relationships between youth activity and fitness and adult activity and health are, however, more complex than correlations and odds ratios. The life cycle includes several temporally arranged transitions within a specific cultural context. Childhood and adolescence are dominated by required schooling, which includes many socially sanctioned and valued forms of physical inactivity. Biological and social demands associated with the transition into and through adolescence entail a variety of biosocial interactions and adaptations. College attendance often prolongs adolescence in many cultures, while additional stresses are associated with the transition into the workforce. Job demands, marriage, family life, and responsibility for child rearing dominate a major portion of adulthood. The transition into retirement follows, often simultaneously with changes in functional capacities associated with biological aging. Superimposed upon these culturally and biologically related transitions are factors that may influence the transitions per se or create new ones (e.g., disease, accident, job changes, social and political events, natural events, etc.). How are habits of physical activity affected by specific transitions and events in the life span? How is health-related fitness and health status affected? Although earlier events may predict the present, they do not predict the future!

Allowing for the complexity of "growing up" and successfully transitioning into adulthood, several questions need study. What factors—biological, behavioral, or cultural—influence the tracking of activity and fitness during childhood and adolescence, from youth into adulthood, and within adulthood? What is unique about those individuals in whom activity and fitness (and related variables) track compared to those in whom they do not track? What are the determinants of tracking and nontracking? Evidence is limited. During a 26-year span, from 14 to 40 years, for example, adolescent anthropometric characteristics, fitness and sport participation, and parental socioeconomic status and sport participation accounted for a small portion of the variance in physical activity among male adults ($R^2 = .04–.16$). However, these variables accounted for a greater proportion of the variance when men with low and high activity levels were contrasted ($R^2 = .04–.37$), though estimates varied with the indicator of physical activity considered (Beunen et al., 2004).

The questions can be expanded to include cardiovascular and metabolic risk factors. Given the current obesity epidemic and the association between obesity and increased prevalence of cardiometabolic risk factors and associated comorbidities (e.g., type 2 diabetes) in youth, adult health concerns are increasingly emerging among youth. Physical activity and cardiorespiratory fitness are independently related to cardiometabolic risk factors in children and adolescents, but they explain only a fraction of the variance (Andersen et al., 2006; Brage et al., 2004; Ekelund et al., 2007; Rizzo, Ruiz, Hurtig-Wennlöf, Ortega, & Sjöström, 2007). Activity and fitness during youth also do not account for a large portion of the variance in adult physical activity, fitness, and health (Eisenmann, Wickel, Welk, & Blair, 2005; Hancox, Milne, & Poulton, 2004; Hernelahti et al., 2004; Sacker & Cable, 2006). Adiposity is an additional and independent risk factor. Overall, physical activity, cardiorespiratory fitness, and adiposity explain a limited amount of the variance in cardiometabolic risk after controlling for several potential confounders. Data also suggest moderate stability of indicators of cardiometabolic health from childhood and adolescence into adulthood (Eisenmann, Welk, Wickel, & Blair, 2004; Katzmarzyk et al., 2001). Relationships between youth physical activity and/or fitness and the tracking of cardiometabolic risk factors from childhood through adolescence and into adulthood need more detailed study. For example, if activity and fitness are independent risk factors, what are the pathways, biological and/or cultural, through which they operate to influence cardiometabolic health?

Biological Maturation

9. What Is the Impact of Individual Differences in Biological Maturation on Physical Fitness and Performance During Childhood and Adolescence? Does Maturity-Associated Variation Persist Into Adulthood?

Interindividual variation in biological maturation influences growth, performance, and physical fitness, but data are more available for boys than for girls (Malina et al., 2004). Most data are limited to strength- and performance-related fitness and, to a lesser extent, aerobic fitness. Studies generally contrast youth by maturity status within age groups. Early-maturing boys within an age group have an advantage in strength, power, and speed tasks compared with average and late-maturing boys. Efforts to quantify variance in specific performance items attributable to maturity per se or interactions with body size generally highlight the latter. Corresponding data for girls, on the other hand, suggest inconsistent performance differences among contrasting maturity groups.

Variation in performance and fitness associated with maturity status and timing merits further study in both sexes. There is a need to include a broader variety of performance and fitness tasks (than those traditionally studied) and to consider behavioral factors (e.g., peer relations, motivation, perceived competence, social physique anxiety, and others) in an effort to better understand the influence of interindividual differences in biological maturation per se and potential interactions with behaviors on the performance and fitness of adolescent boys and girls.

Maturity-associated variation is also a factor in sport success among youth (Malina, 1994, 2002, 2009), and assessment of maturity status and timing is an integral component of athlete selection and development models (Reilly, Williams, & Richardson, 2003). Prior to adolescence, male and female youth athletes span the spectrum from late through average to early maturation (Malina, 2011; Malina, Baxter-Jones, et al., 2013). Differential persistence or dropout and/or sport-specific selection (exclusion) practices, among other factors, alter the composition of participants in specific sports as youth progress through adolescence. Advanced and average maturity status within an age group is characteristic of adolescent male athletes, while average and late maturity status within an age group are characteristic of female athletes (Malina, 1983, 1998, 2011; Malina, Baxter-Jones, et al., 2013). The changing makeup of youth athlete participants as they pass from childhood into adolescence and during adolescence merits further study. Using mean ages at PHV (data from Malina & Kozieł, 2014, in press) as an example, late- (13.4 ± 0.4 years) and average- (11.9 ± 0.5 years) maturing girls are, respectively, in more biological (and perhaps behavioral) synchrony with average- (14.0 ± 0.5 years) and early- (12.6 ± 0.4 years) maturing boys. On the other hand, early-maturing girls (10.2 ± 0.5 years) and late-maturing boys (15.7 ± 0.6 years) are not in biological and behavioral synchrony with the other groups and are also less often represented in samples of adolescent youth athletes. Why? What is unique about early-maturing girls and late-maturing boys—biologically, behaviorally, or both—that may not be conducive to success in sport? Or do the differential distributions of adolescent athletes by maturity status reflect the demands of specific sports and/or preferential selection by adults who coach the sports?

Research within the context of sport has predominantly focused on performance and fitness characteristics associated with individual differences in maturation, with limited consideration of indirect effects of maturation on selection and socialization experiences. Accordingly, future research needs to investigate how individual variance in maturation influences self-perceptions of youth athletes and the perception and treatment of youth athletes by peers, coaches, and administrators, among others.

What is the implication of maturity-associated variation so apparent during adolescence for activity and fitness in adulthood? Data are limited. Differences in strength and motor performance among maturity groups of Belgian boys, so apparent during adolescence, were eliminated or reversed at 30 years of age (Lefevre, Beunen, Steens, Claessens, & Renson, 1990), while later maturation was associated with better muscular function at 45 to 49 years of age in this sample (Beunen et al., 2009). Corresponding comparisons of female adults by adolescent maturity status are lacking and merit study.

A corollary of the preceding is the persistence or nonpersistence of maturity-associated variation in body composition beyond adolescence into adulthood. An early age at PHV was associated with an elevated BMI, FM, and central adiposity in men aged 18 to 20 years of age (Kindblom et al., 2006). The BMI differed significantly among early-, average-, and late-maturing adolescent boys (based on modeled ages at PHV) during adolescence but did not differ among the maturity groups at 30 years of age, although early-maturing boys had relatively more subcutaneous fat on the trunk through adolescence and at 30 years of age (Beunen et al., 1994). On the other hand, comparison of subcutaneous fat distribution in early- and late-maturing boys and girls at 13 to 16 years and at 21 to 27 years of age indicated no clear maturing-related pattern (Van Lenthe et al., 1996). Note, however, that a difference of 3 months between skeletal and chronological ages was used to establish the maturity groups. This range is too narrow; a difference of 3 months is well within the range of error associated with estimates of skeletal age. Allowing for potential limitations of recalled ages at menarche, early in contrast to average and late menarche, was associated with a higher BMI, elevated fatness, and poorer metabolic profile among women aged 18 to 44 years (Chen et al., 2011).

10. What Is the Influence of Individual Differences in Biological Maturation on Physical Activity? An Important Corollary of This Question Is Methodological: What Is the Validity of Noninvasive Estimates of Biological Maturity Status and Timing?

Interactions between biological maturation and behavior among adolescents have long been a topic of interest (see, e.g., the longitudinal studies at the University of California, Berkeley—the Guidance Study, Berkeley Growth Study, and Oakland Growth Study, which date to 1929–1931; Jones, Bayley, MacFarlane, & Honzik, 1971). Physical activity is a behavior, and interindividual differences in biological maturation have received increased attention as a factor affecting activity during childhood and especially adolescence (Eaton & Yu, 1989; Eisenmann & Wickel, 2009; Sherar, Cumming, et al., 2010). Both direct and indirect effects of biological maturation are indicated. Biological sex per se and advanced maturation of girls compared with boys contribute to sex differences in physical activity among children and adolescents (Cumming, Standage, Gillison, & Malina, 2008; Eaton & Yu, 1989; Machado Rodrigues et al., 2010; Thompson et al., 2003).

Indirect effects on activity during adolescence are mediated by beliefs, self-perceptions, social interactions, and social expectations, and also by more subtle societal and cultural factors (Cumming, Sherar, Pindus, et al., 2012; Pindus et al., 2013).

The preceding concepts apply to sport, a highly valued context of youth physical activity. Sport, however, shows sport-related selectivity during the transition into adolescence and during adolescence. Although youth can choose to participate or drop out from a sport, selection decisions in most sports are ordinarily made by adults without input from the youth athletes. As noted, selectivity tends to follow maturity-related gradients evident in data for skeletal age and secondary sex characteristics of adolescent athletes (see Malina, 1983, 1998, 2002, 2011; Malina, Baxter-Jones, et al., 2013).

The literature addressing influences of individual differences in biological maturation on physical activity and sport talent development programs is increasingly dependent upon noninvasive indicators of maturation, which need validation. Why is there focus on noninvasive indicators of biological maturation? Established indicators of maturation traditionally used in growth studies and in clinics have limitations. Skeletal age requires low-dose radiation exposure and individuals experienced in the different assessment protocols; secondary sex characteristics are invasive of personal privacy and are often limited to the clinical setting (self-assessments are used, but some find these also invasive); age at PHV is an after-the-fact indicator that requires 6 to 7 years of longitudinal height records that span adolescence; and recalled age at menarche has major limitations among youth (depending on age, many girls in a sample may not have attained menarche).

Two noninvasive estimates are increasingly used in studies of physical activity and sport: percentage of predicted adult stature at the time of study (Roche, Tyleshevski, & Rogers, 1983) and predicted maturity offset (time before or after PHV)/age at PHV (offset minus age; Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). The former provides an estimate of maturity status, while the latter provides an estimate of maturity timing.

Percentage of predicted mature height attained at a given age has been used in studies of physical activity (Cumming, Sherar, Gammon, Standage, & Malina, 2012; Cumming, Standage, Gillison, Dompier, & Malina, 2009; Eaton & Yu, 1989) and fitness (Drenowatz et al., 2013) and in studies of youth athletes (Malina, Cumming, Morano, Barron, & Miller, 2005; Malina, Morano, et al., 2006). Percentage of predicted mature height at a given age had moderate concordance with skeletal age in male youth participants in American football (Malina, Dompier, Powell, Barron, & Moore, 2007) and soccer (Malina, Coelho e Silva, Figueiredo, Carling, & Beunen, 2012), and it provided a reasonably equivalent range of distribution when classifying individuals as early-maturing, on time, or late-maturing.

Maturity offset/predicted age at PHV has been used in studies of physical activity (Beets, Vogel, Forlaw, Pitetti, & Cardinal, 2006; Morrissey, Wenthe, Letuchy, Levy, & Janz, 2012; Sherar, Esliger, Baxter-Jones, & Tremblay, 2007; Sherar et al., 2009; Weeks & Beck, 2012; Wickel & Eisenmann, 2007; Wickel, Eisenmann, & Welk, 2009) and in studies of young athletes, both boys (Malina et al., 2012; Matthys, Vaeyens, Coelho e Silva, Lenoir, & Philippaerts, 2012; Mendez-Villanueva et al., 2010; Mohamed et al., 2009; Sherar, Baxter-Jones, Faulkner, & Russell, 2007; Till, Cobley, O'Hara, Chapman, & Cooke, 2010; Vandendriessche et al., 2012) and girls (Gay, Monsma, & Torres-McGehee, 2011; Nurmi-Lawton et al., 2004; J. M. Taylor, Portas, Wright, Hurst, & Weston, 2012; Vandorpe et al., 2011). The popular long-term athlete development model (Balyi, Cardinal, Higgs, Norris, & Way, 2005) also calls for the assessment or prediction of the time of PHV.

Studies relating maturity offset/predicted age at PHV to actual age at PHV derived from an independent longitudinal data set are limited. Maturity offset and predicted age at PHV varied with age per se and with maturity status based on actual age at PHV in longitudinal samples of Polish boys (Malina & Kozieł, 2014) and girls (Malina & Kozieł, in press). Predicted age at PHV increased with age at prediction in both boys and girls, and differences between predicted and actual ages at PHV were especially marked between early- and late-maturing youth within each sex. The range of variation in predicted age at PHV within single-year chronological age groups was also consistently less than half of that observed in longitudinal studies of boys and girls, which limits its utility in classifying youth into contrasting maturity categories. Similar age dependence was also noted in maturity offset and predicted age at PHV in a small longitudinal sample of Belgian female artistic gymnasts (Malina, Claessens, et al., 2006).

Application of maturity offset as a categorical (pre-PHV, post-PHV) rather than continuous variable was suggested by Mirwald et al. (2002). This may be reasonable in girls and boys attaining PHV "on time" (i.e., average), ~11.0 to 13.0 years and ~13.0 to 15.0 years of age, respectively (Malina et al., 2004), recognizing, of course, the dependence of the prediction upon age per se.

With few exceptions, studies using maturity offset/predicted age at PHV have combined participants spanning chronological age ranges of 3 years or more and have used the prediction to classify youth into maturity groups relative to PHV (pre-PHV, at PHV, or post-PHV) or on the basis of predicted age at PHV (late, average, early). Dependence of the prediction equations on age will influence subgroup composition. Studies combining girls and boys (Mahon, Marjerrison, Lee, Woodruff, & Hanna, 2010; Meylan, Cronin, Oliver, Hughes, & McMaster, 2012) are confounded by sex differences in maturity timing. Age per se and sex differences in offset will influence participant distribution within maturity groups.

Studies applying noninvasive indicators of maturity status and especially timing are increasing as researchers seemingly are seeking a “quick fix” to the issue of interindividual differences in biological maturation as related to physical activity, performance, and sport. Unfortunately, there is no quick fix. There is a need for care in designing studies, for further validation and development of noninvasive indicators of maturity status and timing, and for the development of new noninvasive measures and reference values based upon contemporary growth data.

CONCLUSION

The processes of growth, maturation, and development occur simultaneously and interact as boys and girls progress from infancy through childhood and adolescence into adulthood. Many factors can influence these processes. The present discussion focused on indicators of growth and maturation that may be influenced by physical activity and on factors that can influence physical activity, performance, and fitness. The questions presented are complex and are not mutually exclusive. Central to each is the need to recognize the interactions of biology and behavior as potential influences on the selected variables of interest (i.e., a biocultural approach).

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