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Adolescent Biological Maturity and Physical Activity: Biology Meets Behavior

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The decline in physical activity (PA) across adolescence is well established but influence of biological maturity on the process has been largely overlooked. This paper reviews the limited number of studies which examine the relationship between timing of biological maturity and PA. Results are generally inconsistent among studies. Other health-related behaviors are also considered in an effort to highlight the complexity of relationships between biological maturation and behavior and to provide future research directions.

Regular participation in physical activity (PA) has health, fitness and behavioral benefits for children and adolescents (87). Patterns of PA established in childhood and adolescence may track into the adult years, though relationships tend to be moderate (53,54). On the other hand, PA tends to decline, on average, over adolescence (1,3,16,39,61,76,91,92,96). The majority of studies are cross-sectional and the adolescent-associated decline approaches 50% in some studies. Adolescent-related changes in specific contexts of PA are less studied. Participation in organized sport does not decline during adolescence in the Amsterdam

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Longitudinal Growth and Health Study (96), while a sport score increases across adolescence in a cross-sectional sample of Portuguese youth (79). Correlates of the adolescent decline in PA are complex (77), but most discussions do not include biological variables except for the body mass index (BMI). Better understanding these factors and their interactions would help inform interventions and strategies aimed at increasing adolescent PA.

Physiological, psychological, social and behavioral changes characterize adolescence. The growth spurt in height, changes in body shape, proportions and composition, and sexual maturation (puberty) and attainment of reproductive capacity are most prominent (90). Sexual maturation also has important societal or cultural dimensions. Puberty usually starts with the breast development in girls and genital enlargement in boys, though there are considerable interindividual differences in the timing of these events (56). Earlier or later development of secondary sexual characteristics relative to age and sex peers may influence self-perceptions and intragroup dynamics. Earlier and later maturing youth are not in biological synchrony (off time compared with on time or average maturers) with peers. Differential timing of sexual maturation and the growth spurt relative to age and sex peers may be relevant to the decline in PA. Indeed, preliminary research suggests that the adolescent decline in PA may be more closely associated with biological age than chronological age (23,83,92).

The relationship between timing of biological maturity (early, average or late) and adolescent participation in PA has not been systematically evaluated. However, in the last two years (2007–2009), nine studies, limited largely to females and to North American and British youth, have addressed the topic (see below). This paper reviews the recent studies and also studies of other health-related behaviors (smoking, alcohol and drug use) and psychosocial development in an attempt to highlight the complexity of relationships between biological maturity and PA, an important health-related behavior.

Biological Maturity and Health Behaviors: Two Hypotheses

Two hypotheses regarding the relationship between the timing of biological maturity and health behaviors and/or psychosocial functioning are prominent in the literature. The hypotheses, however, have not been directly applied to PA which is a behavior.

The *stage termination hypothesis* or *early maturation hypothesis* posits that only early maturing adolescents are at particular risk for psychosocial problems and adoption of unhealthful behaviors (68). This hypothesis is based on the assumption that early maturation interrupts the regular course of behavioral development. Accordingly, early maturers have less time and are less prepared to resolve normal developmental tasks of adolescence. Further, based on their apparent physical maturity, early maturers might be pressured by adult and peer expectations that are not consistent with their cognitive and social-emotional development.

The *maturational deviance hypothesis* proposes that any deviation from the norm relative to chronological age peers (i.e., early or late maturation) heightens the risk for psychosocial problems (2). The hypothesis is based on the assumption that normative events that occur earlier or later than expected are stressful for the individuals. Accordingly, off time individuals are at risk because their physical development is incongruent with the peer group.

Presently available research generally supports the stage termination hypothesis, suggesting that early biological maturation is associated with poorer body image (35,63), negative initial reactions to puberty—inconvenience, ambivalence and confusion (75), and increased distress, anxiety, depression and psychosomatic symptoms (35,43,44,50). Among 178 U.S. girls, for example, sexual maturity at 11 years predicted lower psychological well-being at 13 years, including depression (I hate myself, I have difficulty sleeping), global self-worth (I am often disappointed with myself), and weight-related maturity fears (I don't like changes in my body because they make me feel fat; 24). Early maturity is also linked with early substance abuse (25), alcohol abuse (20) and initiation of sexual behavior (14).

Corresponding literature for boys is limited and inconclusive. Although some research suggests greater vulnerability to psychological problems (66) and unhealthy behaviors (smoking; 86) in early maturing boys, other data indicate greater risk for psychological symptoms and psychosocial problems in late maturing boys (26,37). Consistent with the "deviance hypothesis," both early and late maturation may be risk factors for negative consequences, such as higher rates of delinquency, in boys (100). In contrast, early maturing boys also show greater self-esteem, confidence, popularity and physical attractiveness compared with later-maturing boys (28,40–42).

Biological Maturity and Physical Activity

Since PA is a behavior, it is reasonable to assume that the timing of biological maturity is related to adolescent PA. Results of presently available research, however, are equivocal. Table 1 summarizes the findings from previous research and includes a calculated Cohen's d statistic where possible. Cohen's d (i.e., the difference between the groups means divided by the pooled standard deviation of the groups) is used to indicate the magnitude of the differences (i.e., effect size) in physical activity across extreme maturity groups. With regards to Cohen's d, an effect size of 0.2–0.3 is considered a small effect, 0.5–0.8 a medium effect, and 0.8 and above a large effect (18).

No difference in self-reported PA was noted among 208 early, average and late maturing 11-year old girls (64), and change in maturity status over the 12 month period between 11 and 12 years ($n = 150$) was not associated with change in PA (49). No significant difference was observed in pedometer steps among 86 early, average and late maturing 13-to-14 year old girls (27) and breast development was not associated with accelerometer assessed daytime PA among a small group ($n = 40$) of Senegalese adolescent girls (although average maturing girls did participate in more PA during the night; 8). Likewise, participation in moderate-to-vigorous PA (MVPA; accelerometry) did not differ between early and late maturing girls 8-to-16 years (84) and 9-to-14 years (99). In a short-term longitudinal study ($n = 2247$), early maturing girls in grade 7 reported more time sedentary than late maturing girls (~11 years), but the maturity difference was not observed in grades 8, 9 and 10 (~12-to-16 years; 95). No association was found between maturity status and self-reported vigorous PA (VPA; 95). In contrast, early maturing 10-to-12 year old girls had significantly less pedometer steps per day than average and late maturing girls (27). The maturity difference persisted after controlling for leg length (individuals with longer legs cover the same distance with fewer steps), but

Table 1 Summary of the Methods Used in Research Examining the Relationship Between Biological Maturity and Physical Activity

Study	N	Sex	Age	Study Design	Maturity Indicator	PA assessment	Finding
Baker et al. 2007 (4)*	143	♀	11, 13 yrs	Longitudinal (2 time points)	Blood estradiol, parental report using PDS	Accelerometer	EM at 11 years associated with ↓ MVPA (d=-.47) & VPA (d=-.55) at 13 years, but not self-report PA at 11 years (d=.23)
Benefice et al. 2001 (8)	40	♀	13,14,15 yrs	Longitudinal (3 time points)	Breast	Accelerometer	At 14 and 15 yrs only, AM associated with more acceleromter counts during the night (d=.56)
Drenowatz et al. 2009 (27)	268	♀	10–12 yrs	Cross-sectional	Predicted APHV	Pedometer	EM associated with ↓ steps per day (d=.32) but the association was attenuated after controlling for BMI (d=.20)
Knowles et al. 2009 (49)	150	♀	11,12 yrs	Longitudinal (2 time points)	PDS	Questionnaire	No association (d=-.26)
Niven et al. 2007 (64)	208	♀	11 yrs	Cross-sectional	PDS	Questionnaire	No association (d=.23)
Riddoch et al. 2004 (71)	5595	♂♀	11 yrs	Cross-sectional	Pubic hair and Breast Development (in girls only)	Accelerometer	Stage of pubertal development was inversely related to PA in girls and to a lesser extent in boys[a]
Romon et al. 2004 (72)	510	♂♀	8–18 y	Cross-sectional	Secondary sex characteritics**	Pedometer	EM associated with ↑ steps per day among boys; but the association disappeared when CA was controlled. No association among girls[a].

(continued)

Table 1 ***(continued)***

Study	N	Sex	Age	Study Design	Maturity Indicator	PA assessment	Finding
Sherar et al. 2009 (84)	182	♀	8–16 yrs	Cross-sectional	Predicted APHV, recalled age at menarche	Accelerometer	No association in elementary (EM *vs* LM d=.32) and high school (EM *vs* LM d=-.36) students
van Jaarsveld et al. 2007 (95)	5863	♂♀	11–12 yrs	Cross-sectional	PDS	Questionnaire	EM associated with ↑ sedentary behavior among boys (d=.11 *vs.* AM) and younger girls (grade 7 only).EM associated with ↑ VPA among boys (d=.14 *vs* AM; d=.15 *vs* LM). No association in girls VPA (EM *vs* AM d=.07; EM *vs* LM d=.05; AM *vs* LM d=.02)
Wickel & Eisenmann, 2007 (98)	167	♂♀	13–14 yrs	Cross-sectional	Predicted APHV	Pedometer	No association in boys (d=.30) or girls (d =.43)
Wickel et al. *In Press (99)*	161	♂♀	9–14 yrs	Cross-sectional	Predicted APHV	Accelerometer	No association in boys (d=.60) or girls (d=.44)

Note. CA = chronological age; EM, AM, LM= early, average and late maturers; VPA = vigorous physical activity (PA); MVPA = moderate-to-vigorous PA; PDS= pubertal development. APHV = age at peak height velocity; d= Cohen d (effect size; d= 0.2–0.3 indicates a small effect, 0.5–0.8 indicates a medium effect, and >0.8 indicates a large effect (18). N.B. Where specific groups are not specified, Cohen d was calculated across more than one maturity group.* biological maturity assessed at 11 years and PA assessed at 13 years; ** = specific secondary sex characteristic measured is unknown [a]Effect size (cohen d) unavailable disappeared after controlling for BMI (31). Early maturing girls also participated in less self-reported PA and accumulated fewer minutes of MVPA (31 ± 12 v. 38 ± 16 min/day) and VPA (3 ± 2 v. 5 ± 5 min /day) per day at 13 years than late maturing girls (4). Pubic hair and breast development (parental report) were inversely related (linear trend, $p < .001$) to PA (accelerometry) in 11 year old girls (71).

Corresponding data for boys are less extensive. Among 10-to-12 year old boys, pedometer steps/day were greater among prepubertal (mean = 10,509 steps/day) compared with postpubertal (mean = 8103 steps/day) boys (72). The authors did not specify pubertal criteria and did not control for CA. Age increased, on average, across pubertal groups so that differences in steps per day PA are likely age- and/or size- rather than maturity-related. In contrast, pedometer steps per day did not differ among early, average and late maturing boys 13-to-14 years of age (99). Self-reported PA was not related to pubertal development in boys 11-to-14 years of age (13) and was inversely related (linear trend, $p < .119$) to minutes spent in MVPA (accelerometry) in 11-year old boys (71). The latter relationship was not as strong as observed in girls of the same age (see above). In a longitudinal study spanning 5 years, early maturity was consistently associated with higher levels of self-reported VPA in a cohort of 2982 boys 11-to-12 years at baseline but also with more sedentary behavior compared with on time and late maturation (95).

Why the Inconsistent Findings?

Several factors may be related to the inconsistent results. These include the indicator used to assess biological maturity status and whether it is self-reported or clinically assessed; methods used to create the maturity groups; expected maturity homogeneity; small sample sizes; the impact of psychological and/or sociodemographic interacting/mediating factors; the independent impact of chronological age and/or grade at school on PA; and lastly, the measurement tool used to assess PA.

Choice of Maturity Indicator. All measures of biological maturity status have limitations (7,11). Skeletal age (SA) is the gold standard for assessing biological maturity since it can be assessed across childhood and adolescence in contrast to appearance of secondary sex characteristics and age at peak height velocity (APHV) which are limited to the interval of puberty and the growth spurt. A variety of maturity indicators have been used in the studies (see Table 1), including the pubertal development scale (PDS), recalled age at menarche, hormonal assays, APHV (predicted and directly estimated), and secondary sex characteristics. Though related, the indicators are not equivalent. Sexual, somatic and skeletal maturation occur at different times during adolescence although variation is reduced around the time of the maximal growth in height (56) The appearance of pubic hair is an early event whereas age at menarche is a late event in sexual maturation; they may not reflect the same underlying hormonal or physiological mechanisms (58,82).

Error in estimating biological age (timing) is a related issue. Recalled age at menarche has error associated with memory. Clinical and self-assessment of pubertal status show variation within and between observers and also between self and physician ratings (59). Self- or parental- reported secondary sex characteristics may have limited to poor validity. Moreover, when a youngster is observed in a study, he/she is in a particular stage of puberty; it is neither known when he/she attained this stage nor how long he/she has been in the stage.

It is possible that PA varies with maturity indicator. For example, initial appearance of secondary sex characteristics may be more closely related to disengagement from PA among girls than APHV and/or menarche, both of which are late events in puberty. The appearance of secondary sex characteristics, in particular breast development, may contribute to feelings of self consciousness and perceptions of discomfort associated with participation in PA (88). It is also possible that hormonal changes and subsequent alterations in body composition which accompany the onset of puberty may be related to the decline in PA (99).

The timing of peak height velocity (PHV) may be more closely related to PA than other maturity indicators. Earlier APHV may positively influence PA behaviors due in part to the adolescent spurt in muscle mass and strength which occur after PHV (69). Early maturing boys, on average, have a larger muscle mass and greater muscular strength during the transition into the growth spurt and during the interval of maximum growth (56). The size and strength advantages provide a performance advantage in sport (the most visible form of PA) and may impact involvement in overall PA through athlete socialization and selection (22). Successful adolescent male athletes are generally early maturing (52,56,57,81). It is not certain whether the association between early maturation and sport success in adolescent males contributes to daily PA, but youth who participate in sports on a regular basis during adolescence have higher estimated daily PA and are more likely to participate in PA as young adults (6,45,89).

Self-Reported Versus Independently Measured Biological Maturity. Studies of the relationship between timing of biological maturity and PA have generally used more direct methods of assessing maturity status. In contrast, research investigating the relationship between maturity timing and other health related behaviors, such as substance abuse and delinquent behaviors, has generally used self-report measures such as the Pubertal Development Scale (67) or self-assessment of secondary sex characteristics. Individuals are asked to rate their level of pubertal development in relation to their peers, often on a five-point scale from "matured much earlier" to "matured the same time" to "matured much later", or in relation to a set of established criteria presented in text and/or pictorial form. Thus, the individual's perception of his/her pubertal timing/status rather than actual pubertal timing/status is being assessed (29,60). Actual and perceived timing probably overlap, but the two are distinct measures reflecting different biological and psychosocial processes (29). Two adolescents with the same assessed biological age might have perceptions of their pubertal timing relative to peers which differ markedly. Assessments are also influenced by the perceived pubertal status of peers.

Perceptions of pubertal timing relative to peers rather than actual pubertal timing may be associated with decreased PA during adolescence. Using such an approach, pubertal status was related to self-reported problem behaviors (substance abuse, disobeying parents, antisocial behavior) in 226 girls and boys 9-to-17 years of age, but the association disappeared when CA was controlled (33). When both CA and maturity status were controlled, the association between subjective maturity status and self-report behaviors persisted. The observations suggest that self-perceptions of maturity status may be more proximal to adolescent behavior than actual biological maturity or chronological age. Self-report measures of biological maturity status can be influenced by several extraneous factors including social desirability, awareness of maturity status of peers and ability to compare their status relative to established criteria. Such factors probably influence how accurately an individual rates his/her maturity status. They may also contribute to the poor agreement between the PDS and clinical assessment (85). Caution is thus warranted in using the PDS as an objective measure of maturity (see (49) p. 9). Self-assessment secondary sex characteristics (comparing development to standardized photographs or schematic drawings), however, has an acceptable level of agreement with assessments of clinicians or trained-examiners in some (30,62), but not all (12,78) studies in normal weight children. This suggests that the PDS may be more influenced by self-perceptions of maturity than actual maturity, per se.

Biological Maturity Categories. Methods of classifying individuals as early, average (on time) or late vary. In general, most maturity indicators show a standard deviation of approximately one year (56). Historically, a skeletal age (SA) within plus or minus one year of CA was used to define average or on time status; SA in advance of CA by more than one year was indicative of early maturation and SA behind CA by more than one year was indicative of late maturation. A similar method has been applied to APHV. If APHV falls between 14.0 ± 1.0 yrs, a boy is classified as average in the timing. Boys with APHV <13.0 yrs and >15.0 yrs are classified, respectively, as early and late maturing. Corresponding cut-points for girls would be based on an average APHV of 12.0 ± 1.0 yrs; early and maturing girls attain PHV <11.0 yrs and >13.0 yrs, respectively. A SA band of three months has also been used to define early and late maturity (47). Three months, however, is within the range of error associated with assessments of SA and may mask real maturity differences (56).

In a large representative sample of children one would expect the majority to be average or on-time in maturity timing. In such samples, specific cut-points can be used to define maturity groups, e.g., early maturity in NHANES III was defined as the lowest quartile of menarcheal age (70). If a sample is not sufficiently large, numbers of early or late maturing youth may be too small for inferential statistics. Maturity categories based on an even split of the sample, such as tertiles or quartiles have thus been used (4,24,63,71,84,99). The method is attractive because it creates groups of the same size, but it is questionable whether the extreme groups are actually early and late maturing.

Maturity Heterogeneity and Homogeneity. Interindividual differences in biological maturity status among youth of the same CA and sex are considerable. Ages at PHV for individuals ranged from 9.3 to 15.0 yrs and 10.3–13.2 yrs in Swiss and British girls, and from 12.0 to 15.8 yrs and 11.9–16.2 yrs among Swiss and British boys, respectively (56). On the other hand, variation in breast, genital or pubic hair and in SA at the time PHV is reduced considerably (56). Although this wide variation in the age of attaining pubertal milestones varies considerably between adolescents, it is not an even distribution. In fact within a sample of adolescents, the majority will be average maturing. For example, 97% of a cross-sectional sample (n = 101) of elementary school girls predicted APHV fell within the range of 11.0 to 12.0 yrs (84).

Sampling. Maturity-related observations for other adolescent behaviors tend to be more consistent, but sample sizes tend to be larger. For example, in a sample of 36,549 boys and girls 14-to-16 years, pubertal timing was associated with emotional and behavioral problems (43). Such sample sizes are rarely seen in pediatric PA research, especially in studies examining relationships between biological maturity and PA. Sample sizes are reduced given the time and expense required to use objective measures of PA (accelerometers, pedometers). The small (d = 0.2–03) and medium (d = 0.5–0.8) effect sizes seen among some of the pedometer and accelerometer studies that found no significant difference in PA between maturity groups (e.g., (84,98,99) suggests that inadequate power could have contributed to the nonsignificant findings (see Table 1). It is likely that larger samples are needed to accurately evaluate associations between maturity status and PA. Conversely, purposeful samples of the extremes of maturity status may be required.

Ethnicity. A factor not ordinarily considered in the PA literature is ethnic variation in timing. American Black girls, for example, attain menarche, on average, earlier than American White girls. There is similar variation in SA and APHV (56).

Individuals are embedded in cultural and social contexts which influence perceptions and values and interact dynamically with the timing and tempo of biological changes during puberty. Ethnic variation in perception of puberty and PA merits concern. The developmental pattern of self-esteem differs between American Black and American White girls (15). Global self-worth declines in White girls but is stable in Black girls from 9-to-14 years. Adjusting for stage of sexual maturity, BMI (higher in Black girls) and household income (lower in Black girls) did not alter the trends. Further, as BMI increased, scores for perceived physical appearance and perceived social acceptance decreased, more so in White than in Black girls (15). Implications of these observations for patterns of PA during adolescence require further investigation.

Mediating/Interacting Factors. The inconsistent findings on the relationship between maturity timing and PA may reflect interactions with other factors that increase risk for inactivity. Given variability in PA within samples not all early maturing youth become inactive. Similarly, rather than early maturity creating depression, it may accentuate preexisting behavioral problems (17). This possibility is consistent with the diathesis-stress perspective that preexisting individual differences interact with the pubertal transition such that some adolescents develop depression while others do not (36). Low self-esteem in girls who mature early and in boys who mature late predicts depression in late adolescence (34,38,67). In the context of PA, there may be individual characteristics that differentiate early maturing adolescents who become inactive from those who do not. Hence, girls who participate in high levels of PA in preadolescence may be buffered from the possible influence of early maturation on activity habits. Likewise, early maturing girls and late maturing boys with low self-esteem may be more likely to disengage from PA during adolescence. Among 11 year old girls, social physique anxiety was greater in the more mature compared with less mature peers (63). Moreover, social physique anxiety contributed to low levels of PA only among girls who were motivated to be active primarily for body-related reasons. Although relationships of biological maturity status to PA, social physique anxiety and motives to be active were not considered, the results highlight the complexities of possible relationships. It is likely that disengagement from PA during adolescence is associated with a variety of behavioral, social and biological factors interacting with timing of maturation. Individual differences in tempo of maturation are additional factors. Tempo refers to the rate at which the individual progresses through puberty and the growth spurt (56). These conjectures require further research.

Physical characteristics associated with variation in maturity status may have significant social stimulus value for peers, parents, educators and coaches, and may influence involvement in PA through socialization and/or selection (23). Body size of adolescent female gymnasts, for example, is associated with perceptions of supportive, instructive and punitive behaviors from coaches (22). Other factors contributing to variation in PA include the demands of specific activities and activity contexts, and cultural ideals regarding PA and progress toward adulthood/maturity. Research to date has not simultaneously considered cultural contextual variables and timing of biological maturity in studies of adolescent PA. This requires a biocultural approach (55); PA should not be studied exclusively from cultural or biological perspectives.

Cigarette and alcohol involvement is related to the timing of biological maturity among 11-to-14 year old girls and boys and social context mediated most associations (32). The association for cigarette use was mediated by family context, specifically, early maturing youth with less authoritative parents smoked more cigarettes. Parental support of PA may thus buffer the potentially negative effect of early maturation. Biological maturity may also differentially affect PA depending on social context, for example, family socioeconomic/sociodemographic status. For a more complete understanding of PA, it is essential to consider interactions between psychological and social factors and biological maturity.

Chronological Age Matters!

Chronological age (CA) independently influences the relationship between biological maturation and PA. Grade in school is often used as a proxy for CA even though CA can vary considerably within a grade. It is possible that age and grade may exert a stronger influence than biological maturity on PA behaviors. Among 8-to-15 year old girls, level of PA was related to grade in school—as grade increased, PA decreased, while biological maturity status was not related to PA (84). Barriers to PA were also more closely related to grade. Among a sample of adolescents, grade groups may exert a greater influence on PA behaviors than variation in biological maturity status. A related factor is the social structure of a grade or school which may influence adolescent behaviors (21).

Self-Reported Versus Objectively Assessed Physical Activity. Subjective and objective methods have been used to assess PA—questionnaires, direct observation and electronic movement sensors. Recent studies exploring the relationship between timing of biological maturity and PA are based on self-report (13,64,95), pedometers (27,98) and accelerometers (4,71,84,99). The advantages, disadvantages and implications of different PA assessment tools are beyond the scope of this discussion (19,74,80,97). Choice of PA assessment tool will likely impact results and may contribute to inconsistencies in findings. It is generally believed, for example, that self-report PA is influenced by the social desirability of reporting particular behaviors. Individuals tend to overestimate PA and underestimate sedentary pursuits such as watching television (80). Social desirability is associated with the BMI among 8-to-10 year old American Black girls (48). Early maturing girls are generally heavier and have greater percentage body fat than late maturing girls of the same CA during adolescence (56). Thus it may be that early maturing girls are more prone to social desirability and over-reporting of PA than late maturing peers. Unfortunately, the relationship between biological maturity status and social desirability is not established.

Although objective monitoring of PA is more accurate, it does not provide information on context, the activities per se which influence enjoyment, psychosocial outcomes and persistence. Cost and administrative time for objective assessments limit sample sizes.

The lack of consistent results in the previous studies may be explained by the varied techniques used to assess physical activity. Virtually all published studies to date have used aggregate physical activity variables, such as total energy expenditure via self-report questionnaire, or accelerometer measurements of minutes of MVPA. Advanced data-reduction software now enables more detailed information on physical activity and inactivity behaviors to be derived from accelerometer counts and, thus, allows movement frequency, intensity, and duration to be investigated more comprehensively. For example, information can be provided on the minutes spent in sedentary, light, moderate and vigorous physical activity. Furthermore, information on when the activity is accumulated can also be provided, for example weekend and weekday activity and physical activity during the daily commute to and from school. Benefice et al. (8) found that within a sample of Senegalese adolescent girls, midpubertal girls (average maturing) were more active during the night, but not during the day; thus, highlight the importance of studying physical activity at higher resolution.

Does Physical Activity Have a Biological Basis?

Habitual PA is a complex behavioral phenotype determined by the interaction of biological and psychosocial factors and the physical environment (55). Puberty and the growth spurt are dynamic biological processes that interact with each other and also with adolescent behavioral development. Physical activity is a behavior and as such is involved in the dynamic interactions. The biological basis of PA (51,73,93) and potential biological correlates of PA associated with sexual maturation and the growth spurt require more attention.

Rowland (73) was perhaps the first to argue for an inherent control/regulatory center for PA within the central nervous system; the hypothesized center was labeled the *'activity-stat'*. The logic and evidence for an activity-stat were as follows. Early starvation impacts basal metabolic rate; the temporal change in PA with age parallels changes in resting metabolic rate; experimental central nervous system lesions and pharmacological interventions in animals; pharmacological treatment of children with attention deficit hyperactivity disorder (ADHD); and evidence for genotypic contributions to habitual PA suggest a centrally controlled mechanism. The age-related decline in PA during adolescence seemingly occurs in all mammals. The decline in PA during adolescence and potential maturity-associated variation may be related to the cascade of neuroendocrine changes that trigger the onset of puberty and growth spurt and attainment of sexual maturity (56,90).

Rationale for careful study of maturity-associated variation in PA either cross-sectionally or longitudinally is implicit in the underlying neuroendocrine processes that trigger and modulate adolescent growth and sexual maturation. Maturation of the hypothalamic-pituitary-gonadal axis mediates the release of gonadotropins. Subsequent neural reorganization and rapid changes in maturity status and in body size and composition may directly or indirectly influence PA.

As noted among early adolescent girls (10.3 yrs), early maturing girls show lower PA than average (on time) or late maturing peers (27). The results were significant when variation in leg length was statistically controlled. This is relevant because the growth spurt in leg length precedes that in height. However, when BMI was controlled, PA differences by maturity group were no longer significant suggesting that body mass per se and/or fatness influences PA in early maturing girls. Although a potential role for psychosocial influences cannot be dismissed, it is important to consider the possible role of biological factors. Many biomarkers that may influence energy expenditure have been identified (65,93,94). Some of the biomarkers may be a product of adipose tissue metabolism (leptin) or may be indirectly involved in the accumulation of adiposity and energy regulation including PA. Longitudinal research is needed to gain insights into the role of neuroendocrine maturation and associated changes in biomarkers during puberty and their potential influence on the hypothesized 'activity-stat'.

Conclusions

Findings are inconsistent among studies which examine the relationship between biological maturity and PA, and associations, when noted, are generally low. There are major analytical and methodological limitations in the existing research evaluating the relationship between the timing of biological maturation and adolescent participation in PA. Data are limited by small sample sizes, lack of consideration of interacting and/or mediating influences, and quality of assessments of maturity and PA. Furthermore, associations do not permit causal interpretation. Future research needs to adopt a more sophisticated study design and analytical approach (such as structured equation modeling) to unravel underlying mechanisms that have an impact on PA-behavior. Hopefully, this overview of available data and associated problems will encourage others to pursue this dimension of adolescence and provide a better understanding of the potential role biological maturation, more specifically its timing, in adolescent PA.

Future Directions

1. Future research should adopt a 'biocultural perspective' (55), considering the interaction of timing of biological maturity and psychological and social contexts as they relate to adolescent PA. If associations are identified, the research may help to generate conceptual models for the interaction between biological maturation and PA. A logical sequel would be the design of interventions to alter contexts and thereby decrease possible negative impacts of variation in the timing of biological maturity.
2. There is a need to clarify whether the actual or perceived timing of biological maturation reflect different biological and psychosocial processes which may or may not differentially impact PA. It would be useful to systematically study the discordance between subjective, self-reported indicators and objective assessments of maturity status, and their association with PA.
3. Selectively sampling boys and girls at the extremes of the maturity continuum within single CA groups may provide insights into potential associations. The meaning of early or late maturation to 11 and 14 year olds is likely quite different. Examination of PA in extreme groups may shed more light on the impact of maturity timing on PA. Tracking of these individuals from early

adolescence through adolescence and into young adulthood would add to understanding PA trajectories among youth and how they relate to adolescent and young adult health.

4. Associations among social desirability, monitored and self-reported PA, and biological maturation need careful evaluation to clarify social desirability as a potential confounder to observed relationships between self-reported PA and maturity status.
5. The adolescent growth spurt and sexual maturation are highly individualized biologically and behaviorally. Cross-sectional and longitudinal studies are needed to better understand the underlying neuroendocrine processes and biomarkers and their influence on the hypothesized 'activity-stat'.
6. Within a group of children of the same chronological age there are likely to be children who have advantages in physical fitness tests due largely to variation in maturity status (9,10,46). Studies have shown that physical fitness is related to PA in adolescents but correlations are generally low to moderate (5). There is a need for creative research designs, both cross-sectional and longitudinal, to inform our understanding of relationships among biological maturity, physical fitness and PA during the transition into adolescence and during adolescence per se.

Reference

1. Aaron, D.J., A.M. Kriska, S.R. Dearwater, et al. The epidemiology of leisure physical activity in an adolescent population. *Med. Sci. Sports Exerc.* 25:847–853, 1993.
2. Alasker, F.D., and M. Rutter. Timing of puberty and reactions to pubertal changes. In: *Psychosocial disurbances in young people*. Cambridge, UK: Cambridge University Press, 1995, pp. 37–82.
3. Allison, K.R., E.M. Adlaf, J.J. Dwyer, D.C. Lysy, and H.M. Irving. The decline in physical activity among adolescent students: a cross-national comparison. *Can. J. Public Health.* 98:97–100, 2007.
4. Baker, B.L., L.L. Birch, S.G. Trost, and K.K. Davison. Advanced pubertal status at age 11 and lower physical activity in adolescent girls. *J. Pediatr.* 151:488–493, 2007.
5. Baquet, G., J.W. Twisk, H.C. Kemper, E. Van Praagh, and S. Berthoin. Longitudinal follow-up of fitness during childhood: interaction with physical activity. *Am. J. Hum. Biol.* 18:51–58, 2006.
6. Barnekow-Bergkvist, M., G. Hedberg, U. Janlert, and E. Jansson. Adolescent determinants of cardiovascular risk factors in adult men and women. *Scand. J. Public Health.* 29:208–217, 2001.
7. Baxter-Jones, A.D.G., J.C. Eisenmann, and L.B. Sherar. Controlling for maturation in pediatric exercise science. *Pediatr. Exerc. Sci.* 17:18–30, 2005.
8. Benefice, E., D. Garnier, and G. Ndiaye. Assessment of physical activity among rural Senegalese adolescent girls: influence of age, sexual maturation, and body composition. *J. Adolesc. Health.* 28:319–327, 2001.
9. Beunen, G., M. Ostyn, J. Simons, R. Renson, and D. Van Gerven. Chronological and biological age as related to physical fitness in boys 12 to 19 years. *Ann. Hum. Biol.* 8:321–331, 1981.
10. Beunen, G.P., R.M. Malina, J. Lefevre, et al. Skeletal maturation, somatic growth and physical fitness in girls 6-16 years of age. *Int. J. Sports Med.* 18:413–419, 1997.
11. Beunen, G.P., A.D. Rogol, and R.M. Malina. Indicators of biological maturation and secular changes in biological maturation. *Food Nutr. Bull.* 27:S244–S256, 2006.

12. Bonat, S., A. Pathomvanich, M.F. Keil, A.E. Field, and J.A. Yanovski. Self-assessment of pubertal stage in overweight children. *Pediatrics.* 110:743–747, 2002.
13. Bradley, C.B., R.G. McMurray, J.S. Harrell, and S. Deng. Changes in common activities of 3rd through 10th graders: the CHIC study. *Med. Sci. Sports Exerc.* 32:2071–2078, 2000.
14. Brown, J.D., C.T. Halpern, and K.L. L'Engle. Mass media as a sexual super peer for early maturing girls. *J. Adolesc. Health.* 36:420–427, 2005.
15. Brown, K.M., R.P. McMahon, F.M. Biro, et al. Changes in self-esteem in black and white girls between the ages of 9 and 14 years. The NHLBI Growth and Health Study. *J. Adolesc. Health.* 23:7–19, 1998.
16. Caspersen, C.J., M.A. Pereira, and K.M. Curran. Changes in physical activity patterns in the United States, by sex and cross-sectional age. *Med. Sci. Sports Exerc.* 32:1601–1609, 2000.
17. Caspi, A., and T.E. Moffitt. Individual differences are accentuated during periods of social change: the sample case of girls at puberty. *J. Pers. Soc. Psychol.* 61:157–168, 1991.
18. Cohen, J. *Statistcial Power Analysis for the Behavioural Sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates, 1988.
19. Corder, K., U. Ekelund, R.M. Steele, N.J. Wareham, and S. Brage. Assessment of physical activity in youth. *J. Appl. Physiol.* 105:977–987, 2008.
20. Costello, E.J., M. Sung, C. Worthman, and A. Angold. Pubertal maturation and the development of alcohol use and abuse. *Drug Alcohol Depend.* 88(Suppl. 1):S50–S59, 2007.
21. Couzin, J. Friendship as a Health Factor. *Science.* 323:454–457, 2009.
22. Cumming, S.P., J.C. Eisenmann, F.L. Smoll, R.E. Smith, and R.M. Malina. Body size and perceptions of coaching behaviors by adolescent female athletes. *Psychol. Sport Exerc.* 6:693–705, 2005.
23. Cumming, S.P., M. Standage, F. Gillison, and R.M. Malina. Sex differences in exercise behavior during adolescence: is biological maturation a confounding factor? *J. Adolesc. Health.* 42:480–485, 2008.
24. Davison, K.K., J.L. Werder, S.G. Trost, B.L. Baker, and L.L. Birch. Why are early maturing girls less active? Links between pubertal development, psychological well-being, and physical activity among girls at ages 11 and 13. *Soc. Sci. Med.* 64:2391–2404, 2007.
25. Dick, D.M., R.J. Rose, R.J. Viken, and J. Kaprio. Pubertal timing and substance use: associations between and within families across late adolescence. *Dev. Psychol.* 36:180–189, 2000.
26. Dorn, L.D., E.J. Susman, and A. Ponirakis. Pubertal timing and adolescent adjustment and behavior: Conclusions vary by rater. *J. Youth Adolesc.* 32:157–167, 2003.
27. Drenowatz, C., J.C. Eisenmann, K.A. Pfeiffer, E.E. Wickel, D. Gentile, and D. Walsh. Maturity-related differences in physical activity among 10- to 12-year-old girls. *Am. J. Hum. Biol*. 2009.
28. Dubas, J.S., J.A. Graber, and A.C. Petersen. The effects of pubertal development on achievement during adolescence. *Am. J. Educ.* 99:444–460, 1991.
29. Dubas, J.S., J.A. Graber, and A.C. Petersen. A longitudinal investigation of adolescents changing perceptions of pubertal timing. *Dev. Psychol.* 27:580–586, 1991.
30. Duke, P.M., I.F. Litt, and R.T. Gross. Adolescents' self-assessment of sexual maturation. *Pediatrics.* 66:918–920, 1980.
31. Eisenmann, J.C., and E.E. Wickel. Moving on land: an explanation of pedometer counts in children. *Eur. J. Appl. Physiol.* 93:440–446, 2005.
32. Foshee, V.A., S.T. Ennett, K.E. Bauman, et al. A test of biosocial models of adolescent cigarette and alcohol involvement. *J. Early Adolesc.* 27:4–39, 2007.
33. Galambos, N.L., G.C. Kolaric, H.A. Sears, and J.L. Maggs. Adolescents' subjective age: An indicator of perceived maturity. *J. Res. Adolesc.* 9:309–337, 1999.

34. Ge, X., R.D. Conger, and G.H. Elder, Jr. Pubertal transition, stressful life events, and the emergence of gender differences in adolescent depressive symptoms. *Dev. Psychol.* 37:404–417, 2001.
35. Graber, J.A., J. Brooks-Gunn, and M.P. Warren. The vulnerable transition: puberty and the development of eating pathology and negative mood. *Womens Health Issues.* 9:107–114, 1999.
36. Graber, J.A., J. Brooks-Gunn, and M.P. Warren. Pubertal effects on adjustment in girls: Moving from demonstrating effects to identifying pathways. *J. Youth Adolesc.* 35:413–423, 2006.
37. Graber, J.A., P.M. Lewinsohn, J.R. Seeley, and J. Brooks-Gunn. Is psychopathology associated with the timing of pubertal development? *J. Am. Acad. Child Adolesc. Psychiatry.* 36:1768–1776, 1997.
38. Harter, S., and N.R. Whitesell. Multiple pathways to self-reported depression and psychological adjustment among adolescents. *Dev. Psychopathol.* 8:761–777, 1996.
39. Heath, G.W., M. Pratt, C.W. Warren, and L. Kann. Physical activity patterns in American high school students. Results from the 1990 Youth Risk Behavior Survey. *Arch. Pediatr. Adolesc. Med.* 148:1131–1136, 1994.
40. Jones, H.E. *Motor performance and growth*. Berkley: University of California Press, 1949.
41. Jones, M.C. A study of socialization patterns at the high school level. *J. Genet. Psychol.* 93:87–111, 1958.
42. Jones, M.C., and N. Bayley. Physical maturing among boys as related to behavior. *J. Educ. Psychol.* 1950:129–148, 1950.
43. Kaltiala-Heino, R., E. Kosunen, and M. Rimpela. Pubertal timing, sexual behaviour and self-reported depression in middle adolescence. *J. Adolesc.* 26:531–545, 2003.
44. Kaltiala-Heino, R., M. Marttunen, P. Rantanen, and M. Rimpela. Early puberty is associated with mental health problems in middle adolescence. *Soc. Sci. Med.* 57:1055–1064, 2003.
45. Katzmarzyk, P.T., and R.M. Malina. Contribution of organized sports participation to estimated daily energy expenditure in youth. *Pediatr. Exerc. Sci.* 10:378–386, 1998.
46. Katzmarzyk, P.T., R.M. Malina, and G.P. Beunen. The contribution of biological maturation to the strength and motor fitness of children. *Ann. Hum. Biol.* 24:493–505, 1997.
47. Kemper, H.C., R. Verschuur, J.M. Ritmeester, J. Rutenfranz, R. Mocellin, and F. Klimt. Maximal and aerobic power in early and late maturing teenagers. In: *Children and Exercise*. Champaign, Illinois: Human Kinetics, 1986, pp. 213–225.
48. Klesges, L.M., T. Baranowski, B. Beech, et al. Social desirability bias in self-reported dietary, physical activity and weight concerns measures in 8- to 10-year-old African-American girls: results from the Girls Health Enrichment Multisite Studies (GEMS). *Prev. Med.* 38(Suppl.):S78–S87, 2004.
49. Knowles, A.M., A.G. Niven, S.G. Fawkner, and J.M. Henretty. A longitudinal examination of the influence of maturation on physical self-perceptions and the relationship with physical activity in early adolescent girls. *J. Adolesc*. 2008.
50. Laitinen-Krispijn, S. E.J. Van der, A.A. Hazebroek-Kampschreur, and F.C. Verhulst. Pubertal maturation and the development of behavioural and emotional problems in early adolescence. *Acta Psychiatr. Scand.* 99:16–25, 1999.
51. Lightfoot, J.T. Sex hormones' regulation of rodent physical activity: a review. *Int. J. Biol. Sci.* 4:126–132, 2008.
52. Malina, R.M. Physical growth and biological maturation of young athletes. *Exerc. Sport Sci. Rev.* 22:389-433.:389-433, 1994.
53. Malina, R.M. Physical activity and fitness: pathways from childhood to adulthood. *Am. J. Hum. Biol.* 13:162–172, 2001.
54. Malina, R.M. Tracking of physical activity across the lifespan. *President's Council on Physical Fitness and Sports Research Council.* 3:1–8, 2001.

55. Malina, R.M. Biocultural factors in developing physical activity levels. In: *Youth Physical Activity and Inactivity,* A.L. Smith and S.J.H. Biddle (Eds.). Champaign, IL: Human Kinetics, 2008.
56. Malina, R.M., C. Bouchard, and O. Bar-Or. *Growth, maturation and physical activity*. Champaign, IL: Human Kinetics, 2004.
57. Malina, R.M., S.P. Cumming, P.J. Morano, M. Barron, and S.J. Miller. Maturity status of youth football players: a noninvasive estimate. *Med. Sci. Sports Exerc.* 37:1044–1052, 2005.
58. Marshall, W.A., and J.M. Tanner. Variations in pattern of pubertal changes in girls. *Arch. Dis. Child.* 44:291–303, 1969.
59. Matsudo, S.M.M., and V.K.R. Matsudo. Self-assessment and physician assessment of sexual maturation in Brazilian boys and girls: Concordance and reproducibility. *Am. J. Hum. Biol.* 6:451–455, 1994.
60. Michaud, P.A., J.C. Suris, and A. Deppen. Gender-related psychological and behavioural correlates of pubertal timing in a national sample of Swiss adolescents. *Mol. Cell. Endocrinol.* 254-255:172–178, 2006.
61. Nader, P.R., R.H. Bradley, R.M. Houts, S.L. McRitchie, and M. O'Brien. Moderate-to-vigorous physical activity from ages 9 to 15 years. *JAMA.* 300:295–305, 2008.
62. Neinstein, L.S. Adolescent self-assessment of sexual maturation: reassessment and evaluation in a mixed ethnic urban population. *Clin. Pediatr. (Phila.).* 21:482–484, 1982.
63. Niven, A., S. Fawkner, A.M. Knowles, J. Henretty, and C. Stephenson. Social physique anxiety and physical activity in early adolescent girls: the influence of maturation and physical activity motives. *J Sports Sci.* 27:299–305, 2009.
64. Niven, A.G., S.G. Fawkner, A. Knowles, and C. Stephenson. Maturational differences in physical self-perceptions and the relationship with physical activity in early adolescent girls. *Pediatr. Exerc. Sci.* 19:472–480, 2007.
65. Novak, C.M., and J.A. Levine. Central neural and endocrine mechanisms of non-exercise activity thermogenesis and their potential impact on obesity. *J. Neuroendocrinol.* 19:923–940, 2007.
66. Petersen, A.C., and L. Crockett. Pubertal timing and grade effects on adjustment. *J. Youth Adolesc.* 14:191–206, 1985.
67. Petersen, A.C., L. Crockett, M. Richards, and A. Boxer. A self-report measure of pubertal status: Reliability, validity, and initial norms. *J. Youth Adolesc.* 17:117–133, 1988.
68. Petersen, A.C., B. Taylor, and J. Aldelson. The biological approach to adolescence: Biological change and psychosocial adaptation. In: *Handbook of adolescent psychology*. New York: Wiley, 1980, pp. 117–155.
69. Rauch, F., D.A. Bailey, A. Baxter-Jones, R. Mirwald, and R. Faulkner. The 'muscle-bone unit' during the pubertal growth spurt. *Bone.* 34:771–775, 2004.
70. Remsberg, K.E., E.W. Demerath, C.M. Schubert, W.C. Chumlea, S.S. Sun, and R.M. Siervogel. Early menarche and the development of cardiovascular disease risk factors in adolescent girls: the Fels Longitudinal Study. *J. Clin. Endocrinol. Metab.* 90:2718–2724, 2005.
71. Riddoch, C.J., C. Mattocks, K. Deere, et al. Objective measurement of levels and patterns of physical activity. *Arch. Dis. Child.* 92:963–969, 2007.
72. Romon, M., L. Lafay, J.L. Bresson, et al. Relationships between physical activity and plasma leptin levels in healthy children: the Fleurbaix-Laventie Ville Sante II Study. *Int. J. Obes. Relat. Metab. Disord.* 28:1227–1232, 2004.
73. Rowland, T.W. The biological basis of physical activity. *Med. Sci. Sports Exerc.* 30:392–399, 1998.
74. Rowlands, A.V. Accelerometer assessment of physical activity in children: an update. *Pediatr. Exerc. Sci.* 19:252–266, 2007.
75. Ruble, D.N., and J. Brooks-Gunn. The experience of menarche. *Child Dev.* 53:1557–1566, 1982.

76. Sallis, J.F. Age-related decline in physical activity: a synthesis of human and animal studies. *Med. Sci. Sports Exerc.* 32:1598–1600, 2000.
77. Sallis, J.F., J.J. Prochaska, and W.C. Taylor. A review of correlates of physical activity of children and adolescents. *Med. Sci. Sports Exerc.* 32:963–975, 2000.
78. Schlossberger, N.M., R.A. Turner, and C.E. Irwin, Jr. Validity of self-report of pubertal maturation in early adolescents. *J. Adolesc. Health.* 13:109–113, 1992.
79. Seabra, A.F., D.M. Mendonca, M.A. Thomis, R.M. Malina, and J.A. Maia. Sports participation among Portuguese youth 10 to 18 years. *J Phys Act Health.* 4:370–380, 2007.
80. Shephard, R.J. Limits to the measurement of habitual physical activity by questionnaires. *Br. J. Sports Med.* 37:197–206, 2003.
81. Sherar, L.B., A.D. Baxter-Jones, R.A. Faulkner, and K.W. Russell. Do physical maturity and birth date predict talent in male youth ice hockey players? *J Sports Sci.* 25:879–886, 2007.
82. Sherar, L.B., A.D. Baxter-Jones, and R.L. Mirwald. Limitations to the use of secondary sex characteristics for gender comparisons. *Ann. Hum. Biol.* 31:586–593, 2004.
83. Sherar, L.B., D.W. Esliger, A.D. Baxter-Jones, and M.S. Tremblay. Age and gender differences in youth physical activity: does physical maturity matter? *Med. Sci. Sports Exerc.* 39:830–835, 2007.
84. Sherar, L.B., N.C. Gyurcsik, M.L. Humbert, R.F. Dyck, S. Fowler-Kerry, and A.D. Baxter-Jones. Activity and barriers in girls (8-16 yr) based on grade and maturity status. *Med. Sci. Sports Exerc.* 41:87–95, 2009.
85. Shirtcliff, E.A., R.E. Dahl, and S.D. Pollak. Pubertal development: correspondence between hormonal and physical development. *Child Dev.* 80:327–337, 2009.
86. Simon, A.E., J. Wardle, M.J. Jarvis, N. Steggles, and M. Cartwright. Examining the relationship between pubertal stage, adolescent health behaviours and stress. *Psychol. Med.* 33:1369–1379, 2003.
87. Strong, W.B., R.M. Malina, C.J. Blimkie, et al. Evidence based physical activity for school-age youth. *J. Pediatr.* 146:732–737, 2005.
88. Summers-Effler, E. Little girls in women's bodies: Social interaction and the strategizing of early breast development. *Sex Roles.* 51:29–44, 2004.
89. Tammelin, T., S. Nayha, A.P. Hills, and M.R. Jarvelin. Adolescent participation in sports and adult physical activity. *Am. J. Prev. Med.* 24:22–28, 2003.
90. Tanner, J.M. *Growth at Adolescence*. Oxford: Blackwell Scientific Publications, 1962.
91. Telama, R., and X. Yang. Decline of physical activity from youth to young adulthood in Finland. *Med. Sci. Sports Exerc.* 32:1617–1622, 2000.
92. Thompson, A.M., A.D. Baxter-Jones, R.L. Mirwald, and D.A. Bailey. Comparison of physical activity in male and female children: does maturation matter? *Med. Sci. Sports Exerc.* 35:1684–1690, 2003.
93. Thorburn, A.W., and J. Proietto. Biological determinants of spontaneous physical activity. *Obes. Rev.* 1:87–94, 2000.
94. Tou, J.C., and C.E. Wade. Determinants affecting physical activity levels in animal models. *Exp. Biol. Med. (Maywood).* 227:587–600, 2002.
95. van Jaarsveld, C.H., J.A. Fidler, A.E. Simon, and J. Wardle. Persistent impact of pubertal timing on trends in smoking, food choice, activity, and stress in adolescence. *Psychosom. Med.* 69:798–806, 2007.
96. van Mechelen, W., J.W. Twisk, G.B. Post, J. Snel, and H.C. Kemper. Physical activity of young people: the Amsterdam Longitudinal Growth and Health Study. *Med. Sci. Sports Exerc.* 32:1610–1616, 2000.
97. Welk, G.J., C.B. Corbin, and D. Dale. Measurement issues in the assessment of physical activity in children. *Res. Q. Exerc. Sport.* 71:S59–S73, 2000.
98. Wickel, E.E., and J.C. Eisenmann. Maturity-related differences in physical activity among 13-14- year old adolescents. *Pediatr. Exerc. Sci.* 19:384–392, 2007.

99. Wickel, E.E., and J.C. Eisenmann. Maturity-associated variation in moderate-to-vigorous physical activity in 9-14 year olds. *J Phys Act Health.*, in press.
100. Williams, J.M., and L.C. Dunlop. Pubertal timing and self-reported delinquency among male adolescents. *J. Adolesc.* 22:157–171, 1999.