Published in final edited form as:

J Pediatr. 2007 November ; 151(5): 488–493. doi:10.1016/j.jpeds.2007.04.017.

Advanced Pubertal Status at Age 11 and Lower Physical Activity in Adolescent Girls

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Abstract

Objective—To examine the relationship between pubertal timing and physical activity.

Study design—A longitudinal sample of 143 adolescent girls was assessed at ages 11 and 13 years. Girls' pubertal development was assessed at age 11 with blood estradiol levels, Tanner breast staging criteria, and parental report of pubertal development. Girls were classified as early maturers ($n = 41$) or later maturers ($n = 102$) on the basis of their scores on the 3 pubertal development measures. Dependent variables measured at age 13 were average minutes/day of moderate to vigorous and vigorous physical activity as measured by the ActiGraph accelerometer.

Results—Early-maturing girls had significantly lower self-reported physical activity and accumulated fewer minutes of moderate to vigorous and vigorous physical activity and accelerometer counts per day at age 13 than later maturing girls. These effects were independent of differences in percentage body fat and self-reported physical activity at age 11.

Conclusion—Girls experiencing early pubertal maturation at age 11 reported lower subsequent physical activity at age 13 than their later maturing peers. Pubertal maturation, in particular early maturation relative to peers, may lead to declines in physical activity among adolescent girls.

Although the health benefits of physical activity are widely promoted, many youth do not meet physical activity recommendations. In 2005, only 59.9% of adolescent girls in the United States participated in at least 30 minutes of moderate physical activity or 20 minutes of vigorous activity on 3 or more days per week.¹ Furthermore, both males and females evidence a decline in physical activity across adolescence. Adolescent girls report lower levels of physical activity than boys from middle childhood onward^{2,3} and exhibit greater rates of decline in physical activity across adolescence.¹

Few studies have examined factors that predict or explain the noted decline in physical activity among adolescent girls. One particular factor leading to low physical activity among girls may be the psychological experience of puberty and in particular the timing of pubertal maturation.^{4–7} Although links between pubertal maturation and physical activity have been examined in a number of studies, the vast majority of studies to date have examined physical activity as a predictor, rather than a consequence, of pubertal maturation. In general, these studies found that competitive female athletes reported later menarche than nonathletes.^{8,9} Later menarche among athletes was hypothesized to be the result of differences in percentage body fat and

energy balance.^{10,11} More recent studies indicate that much of the difference in pubertal timing between athletes and nonathletes is the result of self, coach, or parent selection of girls into sports^{9,12} in response to their physical stature, suggesting that pubertal maturation may be the initiating factor in the link between pubertal timing and physical activity. To the authors' knowledge, pubertal timing has not been examined as a precursor to low physical activity among adolescent girls. Therefore, with a longitudinal sample of girls examined at ages 11 and 13 years, this study tests the hypothesis that girls who experience early pubertal maturation at age 11 will exhibit lower subsequent levels of physical activity at age 13 compared with later-maturing girls.

METHODS

Participants

Participants were 143 adolescent non-Hispanic white girls who were part of a longitudinal study examining girls' nutrition, dieting, physical activity, and health. Approval for research involving human participants was obtained from the Institutional Review Board at the Pennsylvania State University. Participants were assessed at ages 11 (mean = 11.33, SD = .29) and 13 (mean = 13.32, SD = .28) years. Parents and the participants provided written informed consent for all procedures. Only girls (n = 143) who had measures of both pubertal development and physical activity were included in this study. No differences in girls' body mass index (BMI), girls' self-reported physical activity, girls' breast development, fathers' education, or family income were noted for girls who were and were not included in the final sample.

Measures

Girls' BMI, percent body fat, and self-reported physical activity were measured at ages 11 and 13 years. Data regarding pubertal status, parental education, and family income were collected at age 11. An objective assessment of girls' physical activity (with accelerometers) was obtained at age 13.

Measures of Body Composition

BMI AND OVERWEIGHT STATUS—Girls' height and weight were measured in triplicate and were used to calculate their BMI (weight (kg)/height (m)²). Age and sex-specific BMI percentiles and z-scores were calculated by use of the 2000 growth charts from the Centers for Disease Control and Prevention. Girls with a BMI percentile ≥ 85 and < 95 were defined as "at risk of overweight" and girls with a BMI percentile of ≥ 95 were defined as overweight.¹³

Percent body fat—Dual-energy X-ray absorptiometry was used to measure girls' percent body fat. Whole body scans were done with the Hologic QDR 4500W (S/N 47261; Hologic Inc, Bedford, MA) in the array scan mode and analyzed with whole body software, QDR4500 Whole Body Analysis (Hologic Inc). Dual-energy X-ray absorptiometry has received widespread use and is the preferred method of assessing body composition among children, because it provides an accurate, reliable, and noninvasive means of quantifying bone mineral content and body mass content, including fat and lean mass, while minimizing radiation exposure during measurement.¹⁴⁻¹⁷

Measures of Pubertal Development

Estradiol—Blood samples collected on filter paper were used to measure levels of estradiol (pg/mL). Girls arrived at the laboratory at 7:45 A.M. after an overnight fast. All blood samples were collected between 8 A.M. and 9 A.M. The samples were air dried and then frozen until assayed as outlined in Shirliff et al.¹⁸ The estradiol assay has been validated against serum samples in both adults and children, and its sensitivity is sufficient for the detection of prepubertal levels

of estradiol in girls. Specifically, the minimum concentration at which estradiol could be distinguished from 0 was 2 pg/mL. The intraassay coefficient of variation was 16%, and the interassay coefficient was 8.9%.

Breast development—Girls' breast development was assessed by use of Tanner's criteria for pubertal breast stages.¹⁹ Stages range from 1 (no development) to 5 (mature development). Visual inspection of each breast was made unobtrusively by a trained nurse and a nurse's assistant while using a stethoscope to check heart rate. In cases where ratings of the 2 breasts were not equal, the lower stage was used because the girl had not fully attained the higher stage.

Pubertal development scale—Mothers provided information on their daughter's pubertal development by completing the pubertal development scale (PDS).²⁰ The PDS is a nonintrusive measure of pubertal development and consists of 6 items assessing growth or change in height, the presence of body hair (including underarm and pubic hair), skin changes, especially the presence of pimples, breast development, and menstruation. Previous research supports the reliability and validity of this scale.^{20,21}

Classification of Timing of Puberty

Each measure of pubertal development outlined above has strengths and weaknesses. The estradiol assay provides an objective measure of a hormone associated with pubertal development. There is, however, substantial between-individual variation in the level of estrogen at any stage of pubertal development and within-individual variation throughout the menstrual cycle, making it difficult to determine a specific cutoff to define early maturation. The assessment of breast development can also be problematic. Although we were able to obtain a visual assessment of breast development, rather than relying on self-reports from girls, fat tissue can be mistaken for breast tissue in cases where the breast is not palpated. A key advantage of this method, however, is that it is widely used by researchers and clinicians, thereby increasing its applicability. Finally, the advantage of the PDS is that it is simple and inexpensive to administer. It is, however, based on the assumption that mothers are knowledgeable about daughters' pubertal status.

Because of the strengths and weaknesses described above, information from these 3 measures were combined into an overall index of pubertal status, which categorized girls as having either earlier or later timing of puberty at age 11 relative to the sample. Earlier developers were girls who fulfilled 2 of the following 3 criteria: (a) highest tertile for estradiol; (b) Tanner stage 3 or higher for breast development; and (c) highest tertile for the PDS. With these criteria, 41 girls were classified as earlier developers, and 102 were classified as later developers (Table I). The aforementioned criteria were chosen to identify a select group of girls who were clearly more physically mature than girls of the same age. Consequently, these groups indicate timing of puberty relative to same age peers in the sample and are not intended as clinical indexes of either precocious or delayed puberty.

Measures of Physical Activity

Self-reported physical activity—The Children's Physical Activity scale (CPA) was used to measure girls' self-reported physical activity at age 11. In a self-administered survey, girls responded to 15 questions such as "I participate in sports almost every day" with a 4-point scale ranging from 1 = completely false to 4 = completely true. Scores on the 15 items were averaged to create a score ranging from 1 (low activity) to 4 (high activity). In previous studies, scores on the CPA have been correlated in the expected direction with 1-mile run/walk time ($r = -.43$, $P < .0001$), body fat percentage ($r = -.41$, $P < .0001$), and BMI ($r = -.32$, $P < .0001$).²² The internal consistency coefficient for the CPA in this study was $\alpha = .73$, indicating acceptable internal reliability.

Objectively-measured physical activity—Objective assessments of physical activity were obtained with the ActiGraph 7164 accelerometer (Shalimar, FL). The ActiGraph is a uniaxial accelerometer designed to detect vertical accelerations ranging in magnitude from 0.05g to 2.00g with a frequency response of 0.25 to 2.50 Hz. These measures allow for the detection of normal human motion and will reject high-frequency vibrations encountered during activities such as operation of a lawn mower. The Actigraph 7164 has been shown to be a valid and reliable tool for assessing physical activity in children and adolescents.²³

After receiving detailed instructions regarding the care and use of the accelerometers, girls were instructed to wear the ActiGraph at all times, except when bathing and swimming, for 7 consecutive days. The ActiGraph was worn on the right hip (mid-axilla line at the level of the iliac crest). Non-wearing time for each monitoring day was calculated by counting the number of zero counts accumulated in strings of 20 minutes or longer. Girls were included in the analyses if they had 4 or more days with 10 or more hours of wearing time.²⁴ Previous work has shown that 4 days of monitoring provides reliable estimates of usual physical activity in adolescent youth.²⁵ In this study, 75.2% of girls had 7 valid monitoring days, with 14.3%, 6.8%, and 3.8% providing 6, 5, and 4 valid days, respectively. Among the participants with 4 or more valid monitoring days, daily wear time ranged from 763.4 minutes to 1282 minutes, with an average of 1086 ± 116 minutes.

Raw accelerometer counts were uploaded to a customized software program for determination of total daily counts, and daily time spent in moderate (MPA), vigorous (VPA), and moderate-to-vigorous (MVPA) physical activity. The age-specific count thresholds corresponding to the aforementioned intensity levels were derived from the metabolic equivalent prediction equation developed by Freedson et al.^{3,26} To accommodate the 30-second epoch length, count thresholds were divided by 2.²⁷

Statistical Analyses

Differences in body composition and physical activity between earlier-maturing and later-maturing girls at ages 11 and 13 were assessed with *t* tests. The relationship between pubertal timing and subsequent physical activity was assessed with multiple regression analysis. Specifically, pubertal timing at age 11 was used to predict subsequent physical activity at age 13, controlling for physical activity and percentage body fat at age 11. A composite measure of family socioeconomic status (SES) created with principal components analysis of mother's education, father's education, and family income was also entered as a covariate in analyses. Outcome variables at age 13 included minutes of MVPA, VPA, and raw accelerometer counts; a separate regression model was run for each outcome variable. Self-reported physical activity at age 11 was entered as a covariate to account for the likely scenario that girls who are more physically active at age 11 are also more physically active at age 13.¹² Percent body fat at age 11 was entered as a covariate to account for the possibility that girls with higher body fat percentages had both earlier pubertal timing and lower levels of physical activity and that body fatness, rather than pubertal timing, was responsible for differences in physical activity at age 13. Pubertal status was entered as a dichotomous variable.

RESULTS

The percentage of girls who lived in households with reported incomes of less than \$35,000, \$35,001 to \$49,999, or \$50,000 or more per year was 16%, 24%, and 60%, respectively. The average years of education for mothers was 14.42 years and for fathers was 14.89 years. On the basis of the composite pubertal development variable, 30% (*n* = 41) of the girls were classified as earlier maturers, and 70% (*n* = 102) of the girls were classified as later maturers (Table I). With respect to weight status, at age 11, 31% of girls were at risk of overweight, and

13% were overweight. At age 13, 28% of the girls were at risk of overweight, and 12% were overweight.

At age 11, earlier-maturing girls had significantly higher height, weight, percent body fat, and BMI scores than later-maturing girls (Table II). No significant group differences in self-reported physical activity were noted at age 11. At age 13, earlier-maturing girls continued to have significantly higher weight and BMI scores and had significantly higher percent body fat than later-maturing girls. There was no height difference between early- and late-maturing girls. Significant differences were noted in both accelerometer and self-report measures of physical activity at age 13, with early-maturing girls being less physically active.

As shown in Table III, pubertal timing at age 11 was a significant predictor of objectively measured physical activity at age 13. After controlling for age 11 physical activity (CPA), percent body fat, and SES, earlier-maturing girls engaged in significantly fewer minutes per day of MVPA and VPA at age 13 than later developers. In comparison to later-maturing girls, earlier-maturing girls engaged on average in 6.07 fewer minutes per day, or 42.5 fewer minutes per week, of MVPA and 2.17 per day, or 15 minutes per week, of VPA. Similarly, early pubertal maturation at age 11 was associated with significantly lower total accelerometer counts per day at age 13 after controlling for covariates. Adding age and height as covariates did not affect the results of the analysis.

DISCUSSION

Results from this study indicate that earlier timing of pubertal development at age 11 is associated with lower levels of physical activity at age 13. This relationship remained after controlling for body fatness, self-reported physical activity, and family SES at age 11. Consequently, the identified associations are not driven by preestablished levels of physical activity (ie, low-active girls maturing more quickly than high-active girls) or body fat (ie, girls who are more overweight and more sedentary going through puberty earlier than their leaner peers). These findings indicate that early-maturing girls are at an increased risk of physical inactivity during adolescence and that additional research on possible factors explaining this association is warranted.

Early pubertal timing combined with low levels of physical activity may place girls at particular risk of negative health outcomes. Previous research indicates that early pubertal maturation is linked with negative mental and physical health outcomes such as poor body image,²⁸ eating disorders,²⁹ and increased breast cancer risk.³⁰⁻³² Physical inactivity is also a risk factor for negative health outcomes such as obesity,³³ cardiovascular disease,^{34,35} diabetes,³⁶ depression,³⁷ ovarian cancer,³⁸ and lower levels of social functioning.³⁹ Drawing together these 2 bodies of research suggests that early-maturing girls who are inactive may experience compounded risk for negative health outcomes. The possibility of increased risk among early-maturing girls provides further justification for research on mechanisms linking early maturation and physical inactivity and ways to promote physical activity in this high-risk group.

Early pubertal maturation may lead to low physical activity for a variety of reasons including both intrapersonal factors (eg, body esteem, depression, and perceived skill) and interpersonal factors (eg, parent and peer support). With regard to intrapersonal factors, early-maturing girls have been found to have poorer body image than their later-maturing peers,⁴⁰ which has been identified as a constraint to both participation in and enjoyment of leisure activities.^{41,42} Earlier-maturing girls may be reluctant to participate in physical activity in settings they believe draw attention to their bodies. Higher levels of depression exhibited by early-maturing girls³⁷ may also decrease girls' motivation for engaging in physical activity. In addition to decreasing girls' motivation for physical activity, the physical changes of puberty may impact

girls' ability to participate in physical activity. For example, breast development may directly reduce spontaneous physical activity because of the need for appropriate clothing. Furthermore, puberty-related changes put girls at a performance disadvantage in some sports.⁴³ As a result, earlier-maturing girls may self-select out of sports because they are less skilled than their later-maturing peers.⁴³

Early-maturing girls may also decrease their physical activity during adolescence as a result of changes in interpersonal factors such as interactions with parents and peers. Parent-daughter relationships change significantly during puberty. Parents, particularly fathers, may be uncomfortable with the changes in their daughter's body.⁴⁴ Along similar lines, early-maturing girls report that adults expect them to behave more maturely.⁴⁴ This combination of parental discomfort regarding their daughter's more mature body and their tendency to encourage more adult behaviors may result in parents providing less support for "childlike" activities such as playing outdoors and more encouragement for less physically strenuous activities that are perceived as more feminine. Although parental support is important throughout childhood and into adolescence,⁴⁵ peers become increasingly influential during this developmental period.⁴⁶ Research shows that earlier-maturing girls tend to associate with an older peer group.⁴⁷ Given the general decline in physical activity with age in adolescence,⁴⁸ earlier-maturing girls are likely to belong to a peer group that is less active than their age cohort. In sum, there is a broad range of factors that may explain the link between pubertal timing and physical activity, including intrapersonal and interpersonal factors that warrant future investigation.

This study has a number of strengths. The longitudinal design of the study allowed the examination of the effect of pubertal timing among young adolescent girls (at age 11) on their physical activity levels 2 years later (at age 13) controlling for physical activity levels at age 11. Additional strengths include the use of multiple measures of pubertal development to classify pubertal timing and the use of an objective measure of physical activity. There were also several limitations. Participants in the study were primarily white girls residing in central Pennsylvania. Therefore results may not generalize across geographic areas or ethnicities. It is possible that very different associations would be identified between pubertal timing and physical activity among other ethnic groups given ethnic differences in pubertal timing,⁴⁹ ideal body shape,⁵⁰ and baseline physical activity.¹ An additional limitation is the use of a self-report measure of physical activity at age 11 (objective monitoring was not available at age 11) for which relatively little measurement work has been done. Differences in physical activity between earlier- and later-maturing girls may have existed at age 11, but the self-report physical activity measure may not have been sensitive enough to detect them. Finally, the measurement of pubertal development resulted in limitations. Because of the limited age span that was assessed, it was not possible to separate the effects of early pubertal timing from pubertal development per se. In addition, because 2 of the 3 variables used to measure pubertal status were not assessed at age 13, potential relationships between tempo of pubertal timing and physical activity could not be explored.

Although results from this study do not directly speak to the mechanisms that may lead early-maturing girls to disengage from physical activity, they highlight that early-maturing girls are at risk of low physical activity. Individuals interacting with adolescent girls such as doctors, teachers, parents, and coaches should be aware of this fact and seek ways to maintain girls' interest in physical activity as they transition through puberty.

Acknowledgements

We would like to thank Dorothy Schmalz for her valuable assistance in collecting the data and the families who have participated in this study since the girls were 5 years old.

Supported by NIH grants (HD 32973, M01 RR10732) and (HD 46567-01).

Glossary

BMI, Body mass index; CPA, Children's Physical Activity scale; MPA, Moderate physical activity; MVPA, Moderate to vigorous physical activity; PDS, Pubertal development scale; SES, Socioeconomic status; VPA, Vigorous physical activity.

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Table I

Measures of pubertal status at age 11 for girls classified as earlier or later maturing

Measure	Maturation timing (age 11)		T value	P value
	Earlier maturation (n = 41)	Later maturation (n = 102)		
Mean estradiol (pg/mL)	12.51 (7.42)	4.21 (3.74)	3.89	<.001
Mean PDS	2.51 (0.36)	1.77 (0.37)	4.66	<.001
Mean breast development stage	2.83 (0.74)	2.00 (0.61)	2.96	<.001
Stage 1 (%)	0%	15%		
Stage 2 (%)	34%	73%		
Stage 3 (%)	51%	9%		
Stage 4 (%)	12%	3%		
Stage 5 (%)	3%	0%		

Mean (SD) scores for BMI, percentage body fat and physical activity for earlier and later maturing girls at ages 11 and 13

Table II

Age	Measure	Maturation timing (age 11)		T value	P value
		Earlier maturation (n = 41)	Later maturation (n = 102)		
11	Weight (kg)	51.26 (13.95)	42.04 (8.88)	3.89	<.001
	Height (cm)	152.6 (6.82)	146.93 (6.32)	4.66	<.001
	BMI	21.86 (4.77)	19.37 (3.22)	2.96	.005
	BMI z-score	.92 (.88)	-.37 (.91)	3.21	.002
	Percentage body fat	30.15 (6.80)	27.47 (6.89)	2.06	.042
13	Self-reported PA	2.98 (.35)	2.90 (.35)	-1.15	.254
	Weight (kg)	61.65 (16.68)	52.86 (10.99)	3.02	.004
	Height (cm)	161.57 (6.78)	159.66 (6.22)	1.47	.144
	BMI	23.53 (5.65)	20.63 (3.77)	2.96	.004
	BMI z-score	.89 (.85)	-.30 (.92)	3.47	<.001
	Percentage body fat	30.81 (6.15)	26.00 (6.77)	3.63	<.001
	Self report PA	2.64 (.40)	2.84 (.39)	2.68	.008
	MPA (avg min/d)	28.18 (10.04)	32.96 (12.19)	-2.20	.028
	MVPA (min/d)	30.83 (11.62)	37.80 (15.90)	-2.94	.004
	VPA (min/d)	2.65 (2.19)	4.87 (4.61)	-3.89	<.001
Accelerometer counts/d		326515 (81126)	375039 (99912)	-2.84	.003

MPA, MVPA and VPA were assessed with accelerometers.

Table III

Results from regression analyses with pubertal timing at age 11 to predict physical activity at age 13 controlling for physical activity, percent body fat, and SES at age 11

Outcome at age 13	Independent variable and covariates at age 11	b	β	P value
Moderate to Vigorous PA	Intercept	22.22		.134
	Self-reported PA (cov)	6.46	.150	.108
	Percentage body fat (cov)	-0.11	-.049	.607
	SES (cov)	-.15	-.014	.875
	Early pubertal timing (IV)	-6.07	-.202	.025
Vigorous PA	Intercept	-2.85		.492
	Self-reported PA (cov)	3.01	.241	.008
	Percentage body fat (cov)	-.03	-.055	.556
	SES (cov)	.26	.085	.338
	Early pubertal timing (IV)	-2.17	-.230	.009
Accelerometer counts/d	Intercept	226,636		.018
	Self-reported PA (cov)	51,249	.184	.048
	Percentage body fat (cov)	-61	-.004	.964
	SES (cov)	-2211	-.032	.727
	Early pubertal timing (IV)	-45440	-.215	.016

IV, Independent variable; Cov, covariates; b, unstandardized beta weight; β , standardized beta weight; PA, physical activity.