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Early Puberty Is Associated With Higher Academic Achievement in Boys and Girls and Partially Explains Academic Sex Differences

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A B S T R A C T

Purpose: On average, boys have lower academic achievement than girls. We investigated whether the timing of puberty is associated with academic achievement, and whether later puberty among boys contributes to the sex difference in academic achievement.
Method: Examination scores at age 16 were studied among 13,477 British twins participating in the population-based Twins Early Development Study. A pubertal development scale, a height-based proxy of growth spurt, and age at menarche were used as indicators of puberty. Associations between puberty, sex, and academic achievement were estimated in phenotypic mediation models and biometric twin models.
Results: Earlier puberty was associated with higher academic achievement both in boys and girls. The exception was early age at menarche in girls, which associated with lower academic achievement. More than half of the sex differences in academic achievement could be linked to sex differences in pubertal development, but part of this association appeared to be rooted in prepubertal differences. The biometric twin modelling indicated that the association between puberty and academic achievement was due to shared genetic risk factors. Genetic influences on pubertal development accounted for 7%–8% of the phenotypic variation in academic achievement.
Conclusions: Pubertal maturation relates to the examination scores of boys and of girls. This can give genes related to pubertal maturation an influence on outcomes in education and beyond. Sex differences in pubertal maturation can explain parts of the sex difference in academic achievement. Grading students when they are immature may not accurately measure their academic potential.

IMPLICATIONS AND CONTRIBUTION

This study indicates that early puberty is related to higher academic achievement in boys and girls and that girls' earlier puberty explains up to half of the sex differences in academic achievement. Genetic influences on puberty are related to academic achievement. This helps understanding educational attainment and its consequences.

Educational attainment has increased significantly among both men and women in recent decades. The gains have been particularly large for women, and a sex difference in education has developed in favor of women [1]. In 29 of 34 OECD countries,

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more than 50% of all students graduating with a bachelor's degree were women, peaking at 70% in Sweden. Educational attainment is strongly associated with health [2], suggesting that this could have consequences for the health of the population. The causes of these sex differences in education are not understood [3,4]. An improved understanding of the mechanisms that link male sex, on average, to poorer educational performance is needed to develop policies to improve educational attainment and prevent drop-out.

On average, the oldest students in a class perform better than those born later, indicating positive effects of maturity [5]. Little attention has been paid to sex as a source of maturational differences. On average, girls enter puberty earlier than boys do. At the same time, the sex differences in school performance are at their largest in secondary school [6,7]. In many countries, adolescents' future educational opportunities depend heavily on the grades they receive at this time. An important question is therefore to what extent girls' "biological head start" may explain their educational outperformance of boys. The fact that the female advantage in educational attainment is observed across almost all OECD countries could indicate that biological sex differences are a part of the explanation. Such biological sex differences may always have existed. Girls have performed better in school for a long time [8,9], but this could materialize as higher educational attainment only after women's access to education improved.

Evolutionary work suggests that humans invest first in brain maturation and then in physical growth [10,11]. Physical maturity could therefore reflect the crossing of a cognitive threshold, making physically mature individuals well suited to excel in school. In contrast to this, empirical studies of pubertal maturation and social outcomes have found that an early menarche is associated with low educational attainment [12]. This indicates that early maturity is detrimental, rather than positive. However, there are limitations with using age at menarche as a maturity indicator. First, it could indicate a fast life history, where sexual reproduction becomes possible at an earlier stage, rather than maturity [10]. Second, menarche may be elicited by stressful environments [13], which are detrimental for academic achievement. Third, the focus on age at menarche as an indicator of physical maturity has precluded the possibility of making comparisons across sexes.

Sexual maturity and social outcomes are less studied in boys. A Finnish study found that an early age at first ejaculation was associated with higher educational attainment [14]. A British study found that late puberty among boys was associated with slower cognitive maturation, after adjustment for prepubertal cognitive abilities [15]. However, this study was based on the British 1958 cohort, which predates the female educational advantage.

It is challenging to obtain precise measures of the timing of physical maturity for both sexes in large studies. Standardized questionnaire instruments, such as the Pubertal Development Scale (PDS) [16], interrogate several phenotypes, in which the stages of pubertal maturation are self-estimated by appearance of secondary sex characteristics. Such self-assessments have been subject to criticism due to inaccuracy [17]. Height-based measures may be advantageous, compared to self-reported pubertal development, because they are comparable across sexes and are presumably less subjective. Repeated measures of height in adolescence and adulthood can be used to construct a proxy to growth spurt in longitudinal data sets [18].

If there is an association between maturity and academic achievement, it may or may not reflect causal influences of puberty on academic achievement. An alternative is that shared factors, such as genes, influence both puberty and academic achievement. With data from twins, it is possible to adjust for the genetic and shared environmental components of confounders that we do not have data on or may not even be aware of [19,20]. If an association between an individual's pubertal development and academic achievement remains after such adjustment, the observed associations are more plausibly due to causal influences.

Aims

We employed a population-based twin sample to investigate the associations between puberty and academic achievement and addressed the following preregistered (https://osf.io/z2wsc) hypotheses:

1. Pubertal development is associated with academic achievement among adolescent boys.
2. Pubertal development is associated with academic achievement among adolescent girls.
3. Differences between boys and girls in the timing of pubertal development explain a nonzero proportion of the sex differences in academic achievement.
4. The associations between puberty and academic achievement are better explained by influences from puberty on academic achievement than by a set of shared risk factors.

Methods

Sample

The Twins Early Development Study (TEDS) is a longitudinal study that recruited twins born between 1994 and 1996 in England and Wales through national birth records [21]. In total, 27,876 children were included at age 1, of which 13,477 had valid academic achievement data at age 16. After imputation (see below), we used data on 15,502 individuals. Among these were 1,216 monozygotic (MZ) male twin pairs, 1,165 dizygotic (DZ) male twin pairs, 1,475 MZ female pairs, 1,299 DZ female pairs, 2,417 opposite sex twin pairs, 84 pairs with unknown zygosity, and 190 individuals in incomplete pairs.

Ethical considerations

This paper reports a secondary analysis of existing data. Ethical approval for TEDS was received from King's College London Ethics Committee (PNM/09/10-104).

Measures

Sex. The parents reported each twin's sex on recruitment. The response options were "boy" and "girl". We had no data on gender identity.

Menarche. When girls were 12, 14, and 16 years old, they reported whether they had started menstruating and if so, they reported their age at first menstruation in years and months. We used the average of valid reports to reduce measurement error.

Puberty Development Scale (PDS). Adolescents completed the PDS [22] at age 12, 14, and 16. The scale consists of three items common to both sexes and two items specific to each sex. Each item was scored from 1 ("not yet begun") to 4 ("completed"), except menarche which was score 1 (no) and 4 (yes). The PDS score [1–4] is the average of these items.

Height development. Parents reported the children's height at age 7, and adolescents reported their own height at age 12, 14, 16, 18, and 21 years. The assessment of height in puberty and adulthood can be used as a proxy indicator of growth spurt, as it correlates highly (.84 for boys and .78 for girls) with age at peak height velocity [18]. We calculated the difference between Z-scores for current height and adult height as a sex-invariant indicator of puberty. We used the growth spurt proxies at age 12 and 14 years as puberty indicators. At age 16, adolescents were close to their adult height (on average 2.8 cm remaining for boys and .3 cm for girls). Reports of heights or height development more than four standard deviations from the mean were set to missing, assuming that they reflect measurement error (n = 182).

Academic achievement. Academic achievement at age 16 (11th grade) was defined as the average grade across all subjects at General Certificate of Secondary Education (GCSE) level and used as the outcome. In addition, teachers reported children's performance in English and mathematics at age 7, and these topics as well as science at ages 9, 10, 12, and 14 years.

Covariates. An early puberty has been found to be associated with high body mass index (BMI) [23], low educational background [24], low general cognitive abilities (*g*) [25], and non-White ethnicity [26]. These factors may also be associated with academic achievement. Weight was reported at the same times as height and used to calculate body mass index. Maternal and paternal educational attainment was reported when the children were 7 years old, with six ordered response categories ranging from GCSE or less to higher degrees, plus an "other" category that we set to missing. We used *g* measured at age 7 as a composite of verbal (WISC Vocabulary test and WISC Similarities test) and nonverbal (McCarthy Conceptual Groups test and WISC Picture Completion test) cognitive abilities [27,28]. Reports of at least one non-European among up to three home languages were used as an imperfect indicator of non-European ethnicity.

Statistical analyses

Associations between puberty and academic achievement (hypothesis 1 and 2). All measures were adjusted for the exact age at measurement by linear regression and set to missing if they were measured more than one year apart from the designated age. To avoid excluding individuals with partially complete data, we multiply imputed 50 data sets [29] using the 'MICE' package for R [30]. We imputed all variables for individuals who had valid data on at least one of the puberty indicators or on academic achievement defined as GCSE (analyzed sample n = 15,502).

We split the sample by sex to estimate the associations between pubertal development and academic achievement, in line with hypothesis 1 and 2. We used multiple linear regression models that accounted for the statistical dependency between twins by applying generalized estimating equations. For boys, we used PDS and height development as the indicators of puberty. For girls, we additionally used age at menarche. We regressed academic achievement on sex, the puberty indicators, and the covariates mentioned previously.

Sex differences in puberty and academic achievement (hypothesis 3). We tested to what extent the associations between sex and academic achievement were reduced when adjusted for the puberty indicators. We tested whether puberty mediated the effect of sex on academic achievement (hypothesis 3) by bootstrapping the indirect effect (c' in Figure 1), with 10,000 repetitions. The bootstrapping of indirect effects was done by 200 resamples in each of the 50 data sets, which were then pooled ("MI Boot PS") [31].

Direct influences versus shared risk factors (hypothesis 4). Because sex is randomly assigned at conception, we assume that its relations with puberty and academic achievement (paths *a* and *c'* in Figure 1) are not confounded. However, many factors could confound the association between puberty and academic achievement (path *b* in Figure 1). We used a twin design to adjust for genetic and environmental factors shared by co-twins and tested if any association between puberty and academic achievement remained. By assuming that MZ twins share 100% of genetic factors, that DZ twins share 50% of genetic factors, and that the shared environment contributes equally to similarity among MZ and same-sex DZ twins, variance and covariance can be decomposed into additive genetic (A), shared environmental (C), and individual-specific (E) components. We estimated three models of the relation between puberty and academic achievement, shown in Figure 2. The relation was explained by a combination of direct influences and shared risk factors in model 1, by only direct influences in model 2, and by only shared risk factors in model 3. The models were fitted to raw data in OpenMx 2.14.11 [32] for R. We tested whether the goodness of fit deteriorated when fixing a set of parameters to 0. We used the Akaike Information Criterion [33] for model selection. A fifth preregistered research question on genetic sex differences is addressed in Supplemental Table S9.

Results

Descriptive results

Figure 3 shows the proportion of boys versus girls along the distribution of height development, PDS, and academic achievement. Continuous distributions are shown in Supplemental Figure S1. Supplemental Table S1 presents the number of observed cases and the means and standard deviations (SDs) of the variables for girls and boys. On average, girls had higher academic achievement at age 16, whereas there were no differences in teacher reported performance at age 12 or 14. Supplemental Table S2-S4 show the Pearson correlations between the variables. The puberty indicators correlated moderately. Differences between continued participants and

Figure 1. Model with total effect only (no mediation; left) and with indirect effect (mediation; right). The total effect *c* is divided into a direct effect *c'* and an indirect effect *a***b*.

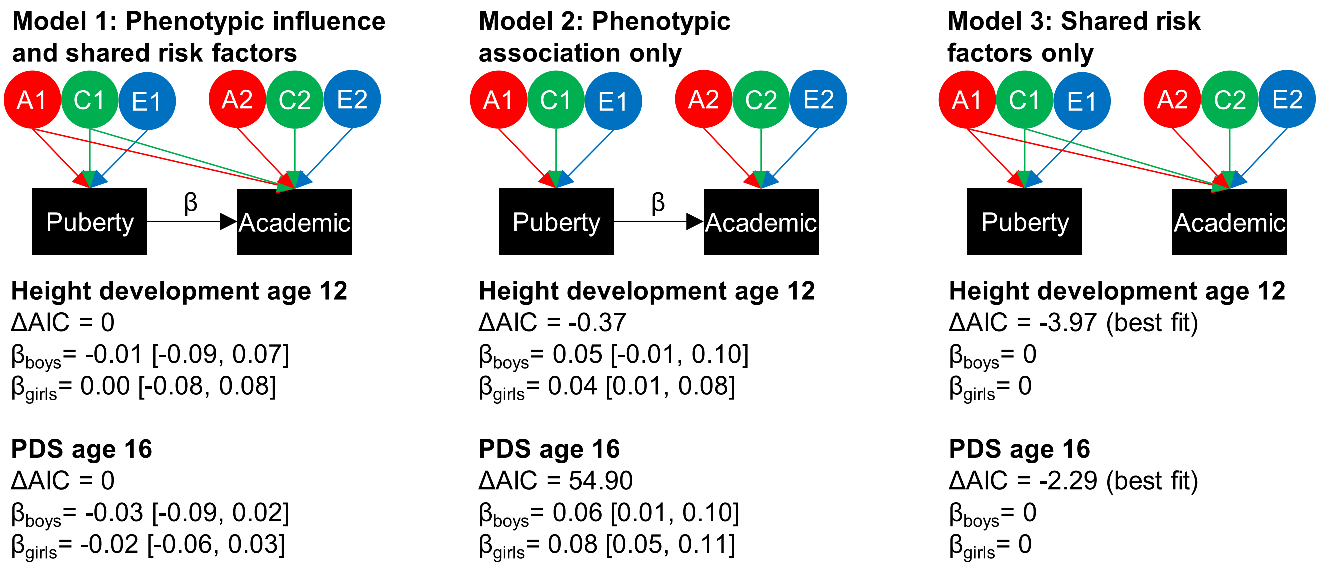

Figure 2. Biometric models of the association between puberty and academic achievement, including estimates of direct effects from puberty on academic achievement in the models. Models two and three are nested under model 1. A1, C1, and E1 represent additive genetic, shared environmental, and individual-specific environmental factors influencing puberty. A2, C2, and E2 represent similar factors influencing academic achievement that are not shared with puberty. Model one is algebraically equivalent to the Cholesky decomposition often used in twin studies. PDS = Pubertal Development Scale; ep = estimated parameters; AIC = Akaike information criterion.

individuals who dropped out for the study are described in Supplemental Table S5.

Puberty and academic achievement in boys (hypothesis 1)

Table 1 shows the associations between puberty and academic achievement. Among boys, height development measured at age 12 and 14 and PDS at age 14 and 16 were associated with better grades. Adjusted for sociodemographic and child factors at age 7, effect sizes were reduced, but height development at age 12 and 14 and PDS at age 16 predicted higher academic achievement, whereas PDS at age 12 predicted lower academic achievement. When each puberty indicator was adjusted for the others, PDS at age 12 was associated with lower academic achievement, whereas PDS at age 16 was associated with higher academic achievement. Hypothesis 1 was thus supported.

Puberty and academic achievement in girls (hypothesis 2)

In girls, height development, particularly at age 12, was associated with better academic achievement. PDS was also associated with better academic achievement, most strikingly at age 16 (Table 1). These results support hypothesis 2. As a contrast to this, a later menarche was also associated with better academic achievement in adjusted analyses.

Puberty and sex differences in academic achievement (hypothesis 3)

Table 2 presents mediation analyses of sex, puberty, and academic achievement (cf. Figure 1). The results in the upper part are not adjusted for social background or child characteristics at age 7. On average, boys performed .23 SDs less well in school than girls. Height development at age 12 mediated 28% of the effect of sex on academic achievement, whereas PDS at age 16 mediated 36%. Together, the puberty indicators mediated 56% of the sex differences in academic achievement and reduced the direct effect of male sex on academic achievement to -.10.

The lower part of Table 2 presents results adjusted for social background and child characteristics at age 7. Height development at age 12 and PDS at age 16 were the strongest mediators of sex on academic achievement. The puberty indicators could together explain 40% of the sex differences in academic achievement. This is somewhat less than in the unadjusted analyses and means that parts of the maturational differences could be explained by factors that were present before the onset of puberty. These results support hypothesis 3.

Supplemental Tables S6-S7 replicate hypothesis 1-3 with percentile variables. Puberty was not related to teacher rated school performance at age 12 or 14 (Supplemental Table S8).

Shared risk factors versus direct effects (hypothesis 4)

Height development at age 12 and PDS at age 16 were most consistently linked with academic achievement, and therefore analzsed in biometric models. Supplemental Table S9 shows that the same genetic factors underlay these phenotypes in boys and girls, and Supplemental Figure S2 detail their genetic and environmental interrelations. The three models of the association between academic achievement and the puberty indicators are shown in Figure 2 along with the estimates of the direct effects under each model. The best fitting models included no direct paths connecting puberty to academic achievement and explained the relation by shared risk factors. The full models were relatively close in fit (cf. [34]) and also indicated small or non-significant phenotypic influences of puberty on academic achievement. The results thus contradict hypothesis 4. The full models are shown in Supplemental Figure S3. Academic achievement was 58% heritable for boys and 51% heritable for girls. In the best fitting model, genetic influences on PDS

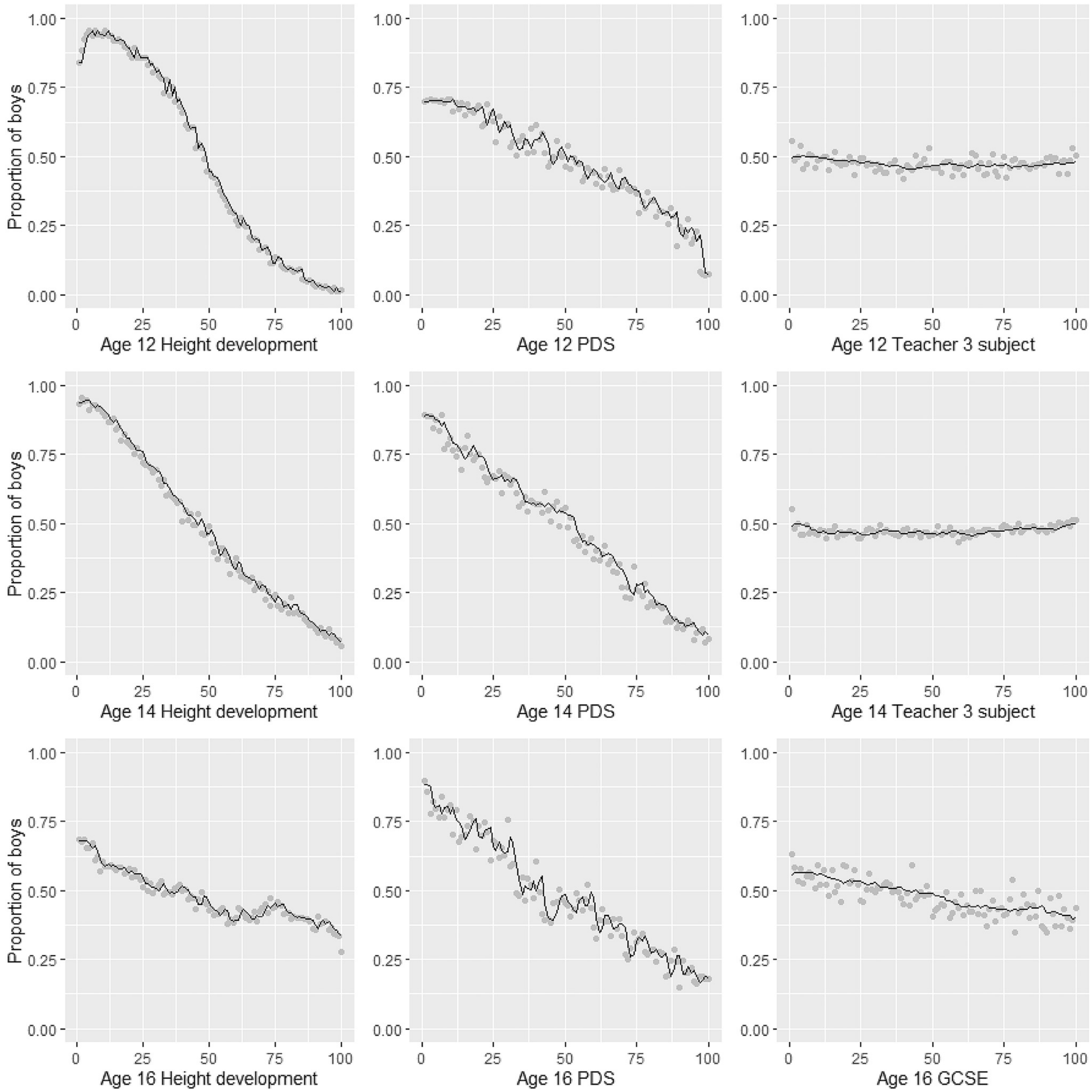

Figure 3. Proportion of boys in each percentile of the distributions of height development, pubertal development scale (PDS), and teacher reported school performance or academic achievement at age 12, 14, and 16. The grey dots show the proportion of boys in each of the 100 percentiles, whereas the solid line is smoothed. Including imputed data.

accounted for 8% of the phenotypic variation in academic achievement for boys and 7% for girls. For height development, the association was smaller, and the shared genetic influences with academic achievement were not significant.

Discussion

Advanced puberty was associated with higher academic achievement in boys and in girls, and the different timing of puberty in boys versus girls accounted for half of the sex difference in academic achievement. Late puberty appeared to be a marker of risk for low academic achievement, rather than a cause of it.

The finding that early puberty is associated with higher academic achievement in boys is consistent with studies using self-reported puberty indicators [14,15]. We found this using a height-based indicator related to growth spurt, which is likely to have low subjectivity. The negative association between PDS at age 12 and boys' later academic performance could parallel results for menarche in girls [12], although we cannot exclude that this result is due to high subjectivity in PDS.

Table 1
Associations between indicators of puberty and academic achievement (General Certificate of Secondary Education score) at age 16 among boys and girls

Boys	Bivariate	Adjusted for background	Adjusted for background and other puberty indicators
Height development, 12	.07 [.03, .11]	.04 [.00, .08]	.04 [−.01, .09]
Height development, 14	.07 [.02, .11]	.04 [.01, .08]	.02 [−.03, .08]
PDS, 12	−.03 [-.09, .03]	−.05 [−.10, .00]	−.09 [−.15, −.03]
PDS, 14	.07 [.01, .13]	.03 [−.02, .08]	−.02 [−.08, .04]
PDS, 16	.28 [.20, .36]	.12 [.04, .20]	.12 [.03, .21]
Girls	**Bivariate**	**Adjusted for background**	**Adjusted for background and other puberty indicators**
Height development, 12	.04 [.01, .07]	.02 [−.01, .05]	.05 [.01, .09]
Height development, 14	.03 [.00, .07]	.02 [−.02, .06]	.00 [−.05, .05]
PDS, 12	−.03 [−.07, .02]	−.03 [−.07, .01]	−.06 [−.11, −.01]
PDS, 14	.05 [.00, .11]	.02 [−.03, .07]	.01 [−.05, .07]
PDS, 16	.28 [.21, .36]	.15 [.07, .22]	.16 [.08, .24]
Age at menarche	.01 [−.01, .04]	.02 [.00, .04]	.03 [.00, .05]

Notes: Second and third column are adjusted for the following variables observed at age 7: teacher reported school performance, body mass index, standardized height, general cognitive abilities, maternal and paternal education, and non-European home language. Results from linear regression with generalized estimating equations.
PDS = Pubertal Development Scale.

Advanced puberty was related to high achievement also among girls. Interestingly, early menarche was linked to poor achievement, as in previous studies [12]. Thus, our results indicated that menarche and the other puberty indicators had opposite effects, despite being moderately correlated. The most successful pupils appeared to be girls who are developed in terms of height and bodily characteristics, but without early menarche. A Finnish study has found some tendencies pointing in the same direction [14]. The reason for these observations is unclear and warrants further studies. Early menarche relates to lower adult height [35] and our findings may be explained if early menarche interferes with cognitive development as it does with growth. In any case, our results add nuance to studies linking early puberty in girls, defined as menarche, to negative psychosocial outcomes [12]. Growth hormones versus gonadal hormones may also exert different psychological influences. This could mean that the psychosocial impacts are best understood if puberty is studied as a multidimensional phenomenon.

Pubertal differences between boys and girls explained around half of the sex differences in academic achievement. The indirect effect was largest for the PDS, but remarkably, it was also significant for height development, which is more directly comparable across sexes and less subjective. This is in line with research indicating slower physical and cortical maturation among males [36].

The relation between puberty and academic achievement was better explained by shared genetic factors than by direct influences of puberty on academic achievement. Such a finding would be unexpected if a late onset of puberty directly hampered academic achievement. The finding is reconcilable with biological explanations where late puberty is an indicator of late maturation also in psychological factors related to academic achievement, such as being motivated and capable of doing schoolwork. Sex differences in conscientiousness may be a candidate for explaining sex differences in academic achievement [37]. Researchers have for decades tried to understand how

Table 2
Direct and indirect associations between sex, puberty, and academic achievement at age 16, crude and adjusted

Unadjusted	Male on puberty (a)	Puberty on academic achievement (b)	Direct male on academic achievement (c')	Indirect male on academic achievement through puberty (a*b)
Total effect of male (c)			−.23 [−.24, −.21]	
Height development, 12	−1.49 [−1.52, −1.46]	.05 [.03, .07]	−.16 [-.19, −.12]	−.06 [−.07, −.06]
Height development, 14	−.93 [−.97, −.90]	.05 [.02, .08]	−.18 [−.21, −.15]	−.03 [−.04, −.03]
PDS 12	−.38 [-.40, −.37]	−.02 [−.05, .01]	−.24 [-.26, −.21]	.01 [.01, .01]
PDS 14	−.54 [-.56, −.52]	.06 [.02, .09]	−.20 [−.22, −.17]	−.02 [−.02, −.01]
PDS 16	−.33 [-.35, −.31]	.26 [.21, .32]	−.14 [−.17, −.11]	−.08 [−.09, −.08]
All at once	Multiple	Multiple	−.10 [−.14, −.06]	−.13 [−.16, −.10]
Adjusted	**Male on puberty (a)**	**Puberty on academic achievement (b)**	**Direct male on academic achievement (c')**	**Indirect male on academic achievement through puberty (a*b)**
Total effect of male (c)			−.20 [−.22, −.18]	
Height development, 12	−1.48 [−1.51, −1.45]	.03 [.00, .05]	−.15 [−.19, −.11]	−.04 [−.08, −.01]
Height development, 14	−.92 [−.96, −.89]	.04 [.01, .07]	−.17 [−.19, −.13]	−.03 [−.06, −.01]
PDS 12	−.38 [−.39, −.36]	−.04 [−.06, −.00]	−.21 [−.23, −.19]	.01 [−.00, .02]
PDS 14	−.53 [−.55, −.51]	.03 [−.00, .05]	−.18 [−.21, −.16]	−.01 [−.03, .00]
PDS 16	−.33 [−.35, −.31]	.13 [.07, .19]	−.15 [−.19, −.13]	−.04 [−.06, −.02]
All at once	Multiple	Multiple	−.12 [−.16, −.08]	−.08 [−.11, −.04]

Notes: The upmost row shows the total effect (c) of male sex on academic achievement with no mediation by puberty. Unadjusted is only adjusted for exact age at measurement. Adjusted is additionally adjusted for the following variables observed at age 7: teacher reported school performance, body mass index, standardized height, general cognitive abilities, maternal and paternal education, and non-European home language. Results from linear regression with generalized estimating equations. Bootstrapped confidence intervals.
PDS = Pubertal Development Scale.

social phenomena relate to genetic factors, and educational attainment appears to be influenced by many heritable traits [38]. Genetic factors related to puberty may be an overlooked but important source of variation in academic abilities.

Limitations

The strengths of this study include a large, population-based twin sample, preregistered hypotheses, longitudinal data, and final school grades as a non-subjective outcome. Nevertheless, some limitations must be considered. First, the PDS may not be comparable across the sexes and the height development measure may correlate differently with age at peak height velocity for boys and girls. However, the height development was identically operationalized in the two sexes, and we found similar results using both these puberty indicators. The results were also similar when using ranked rather than continuous measures, indicating that the findings were not due to extreme scores. Second, voluntary participation inevitably leads to some selective nonparticipation. Attrition was higher among children of parents with low education. However, parental education was not or only weakly related to the pubertal exposures, and we used multiple imputation to keep the sample as representative as possible. Third, although the hypotheses were preregistered, some adaptions had to be made after seeing the data. We shifted the focus from academic achievement at age 12, 14, and 16 to age 16 exclusively. Nevertheless, pre-registering is likely to reduce the risk of nonreproducible findings. Fourth, we found no sex differences in teacher reported school performance between ages 9 and 14. We expected sex differences in school performance to be smaller, but not absent at these ages [6,7]. Our teacher rated measures may have lower psychometric quality or reflect other abilities than GCSE. This does not mean that no sex differences existed at these ages. Fifth, some of the biometric models were relatively close in fit, but the results of the full models were consistent with our interpretations.

Implications and conclusion

Boys and girls with late puberty had lower academic achievement. The maturational differences have consequences for the examination scores that determine their educational paths. Grading students when they are immature may not accurately measure their academic potential. Governments and educational institutions should be aware of this when considering routines for grading and admitting students. Late puberty appeared to be a risk marker for low academic achievement, rather than a causal influence. This means that it is probably not the psychological experience of undergoing or having a late puberty that impairs academic achievement, but rather that there are shared biological mechanisms. Maturational differences in puberty explained around half of the sex difference in academic achievement. This is relevant for all populations where the educational sex difference is seen. We use the term sex because we studied a biological exposure, but our results may be as relevant for the literature on gender differences in education. Whereas we do not propose any intervention based on the present results, further studies should examine the mechanisms that link maturational development, both before and during puberty, to academic achievement. By identifying amenable mechanisms, it may be possible to derive interventions that can help all children to reach their academic potential. This will not only help boys, as we have shown that immaturity is an educational disadvantage also for girls. To benefit all individuals, interventions should target risk factors that exist independently of sex. These risk factors are bound to be more common among boys, but all members of society could benefit from having a well-educated population.

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Supplementary Data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jadohealth.2021.02.001.

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