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Does Parental Education have a Moderating Effect on the Genetic and Environmental Influences of General Cognitive Ability in Early Adulthood?

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Abstract

Hereditary influences account for a substantial proportion of the variance in many cognitive abilities. However, there is increasing recognition that the relative importance of genetic and

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environmental influences may vary across different socioeconomic levels. The overall goal of the present study was to examine whether parental education has a moderating effect on genetic and environmental influences of general cognitive ability in early adulthood (age 19.6 ± 1.5). Participants were 5,955 male twins from the Vietnam Era Twin (VET) Registry. Significant effects of parental education on mean level of general cognitive ability scores were found, but a model without moderating effects of parental education on genetic or environmental influences on cognitive scores proved to be the best fitting model. Some, but not all, previous studies have found significant moderating effects; however, no consistent pattern emerged that could account for between-study differences regarding moderating effects on genetic and environmental influences.

Keywords

Cognitive ability; Parental education; Moderator; Young adulthood; Twin study; Heritability

Introduction

Extensive research has been conducted examining genetic and environmental influences on both specific cognitive abilities and general intelligence throughout the lifespan (Finkel et al. 1995; Haworth et al. 2007; McClearn et al. 1997; McGue and Christensen 2002; McGue and Christensen 2001; Oliver and Plomin 2007; Petrill et al. 1995; Plomin et al. 1994; Polderman et al. 2006; Posthuma et al. 2000; Read et al. 2006; Thapar et al. 1994). Consensus in the field of behavioral genetics maintains that hereditary influences account for a substantial proportion of the variance in most cognitive abilities. However, there is increasing recognition that the relative importance of genetic and environmental influences may vary across ecological context (e.g., across different socioeconomic levels).

For example, Scarr (1992) posited that family environments have a greater impact whenever the environmental quality falls below a certain level of acceptability. Thus, for individuals experiencing less favorable environments, heritability would be low and shared environmental effects would be moderate to high. Similarly, Bronfenbrenner and Ceci (1994) postulated a greater influence of genetic factors in environments deemed beneficial. However, they did not support Scarr’s notion that environmental influences are more important only in environments considered to be below some quality threshold.

A number of earlier twin and adoption studies addressed this issue in children, yielding conflicting results concerning differences in heritability across socioeconomic backgrounds (e.g., Allen et al. 1973; Eaves and Jinks 1972; Fishbein 1980; Scarr-Salapatek 1971). However, the samples in these earlier studies were often quite small, limiting both the socioeconomic diversity in the sample, as well as the statistical power to detect moderating effects. More recently, a number of studies using large twin and twin/ sibling samples have examined the moderating effects of different indices of family socioeconomic background on the genetic and environmental influences on individual differences in various cognitive measures (Asbury et al. 2005; Harden et al. 2006; Kremen et al. 2005; Rowe et al. 1999; Turkheimer et al. 2003; Van den Oord and Rowe 1998). Rowe et al. (1999) demonstrated a moderating effect of parental education on heritability for receptive vocabulary (assessed by an abridged version of the Peabody Picture Vocabulary Test-Revised) in adolescent twin and sibling pairs from the National Longitudinal Study on Adolescent Health. Heritability estimates were lower for adolescents with parents of low education versus parents of higher education.

Similar results have been reported in relation to socioeconomic status (SES; based on parental education and occupation) and cognitive outcomes in children and adolescents. Turkheimer et al. (2003) utilized the Wechsler Intelligence Scale for Children (WISC) and assessed verbal, performance, and full-scale IQ among 7 year old twins from the predominantly low income National Collaborative Perinatal Project. They demonstrated that, in families of high SES, heritabilities were much greater for full-scale and performance IQ than in families of low SES in which heritability was negligible. Verbal IQ showed a similar pattern, although the statistical interaction was not significant. Additionally, Harden et al. (2006) found that genetic influences were stronger for cognitive performance (assessed by the National Merit Scholarship Qualifying Test) in adolescents from higher income homes compared to adolescents from low income families.

In all of these more recent studies of children and adolescents, the variation in the relative importance of genetic versus shared environmental influences reflected two separate processes. First, the absolute magnitude of variance attributable to shared environmental influences decreased with higher levels of parental education or SES. This supports the notion that disadvantaged contexts have stronger environmental effects on cognitive development relative to more advantaged contexts. Second, the absolute importance of genetic variance on individual differences in cognitive outcomes increased in more advantaged environments. These two complementary processes resulted in higher absolute as well as relative genetic variance in more advantaged contexts (i.e., higher heritabilities), and higher absolute as well as relative shared environmental variance in more disadvantaged contexts. These findings also support the propositions laid out by Scarr (1992).

It should be noted that the reference to disadvantaged or advantaged environments is a bit of a simplification because parental education or SES reflects genetic as well as environmental influences. There is almost certainly some gene-environment correlation between parental education or SES and cognitive measures. Moreover, interaction effects in these moderator models address only the variance in the cognitive measures that is independent of parental education or SES.

Although the aforementioned studies have provided empirical support for the moderating effects of parental education and socioeconomic background on the relative importance of genetic and environmental influence on cognitive functions in children and adolescents, Rutter et al. (2006) pointed out that findings remain inconsistent and somewhat contradictory. Specifically, Asbury et al. (2005) reported an opposite moderating effect of SES in a large sample of 4 year old twins in the UK, showing that the heritability for verbal IQ was higher in the lowest 15th percentile of SES families than the heritability in the highest 15th percentile SES families. However, when SES was used as a continuous moderator in an analysis using the full sample, this opposite moderating effect of SES on variation in verbal IQ was not statistically significant. Van den Oord and Rowe (1998) examined the moderating effect of parental education on heritability of reading and math proficiency (assessed by the subtests of the Peabody Individual Achievement Test) in a large sample of full sibling, half-sibling, and cousin pairs from the National Longitudinal Study of Youth (NLSY) approximately 9.5 years of age and found no effect of varying levels of SES and/or parental education on the heritability of cognitive outcomes. However, the design of the NLSY sibling study is inherently less powerful than the classical twin design, which may have limited their power to detect moderating effects. Nevertheless, these findings do indicate that not all previous studies of children and adolescents have found significant moderating effects.

To our knowledge, only one published study has examined the moderating effects of family background characteristics on the heritability of cognitive outcomes in adulthood to date. Kremen et al. (2005) demonstrated that parental education moderates the heritability of reading ability (assessed by the Reading Subtest of the WRAT-3) in middle-aged men (mean age of 47.9 years). However, their data revealed that parental education moderated only the effects of shared environmental influence on variation in word recognition; the absolute magnitude of genetic influence did not vary across levels of parental education. Although the absolute genetic variance did not change, the importance of shared environmental factors was greatest among men with lower parental education, which resulted in a lower heritability. Conversely, as shared environmental factors decreased in importance with higher levels of parental education, the relative importance of genetic factors increased, resulting in a higher heritability with higher parental education. Thus, although this study also showed higher heritabilities with more enriched environments, only the studies of children and adolescents have found that enriched environments are associated with increased absolute magnitude of genetic influence on cognition.

The overall goal of the present study was to examine whether parental education has a moderating effect on genetic and environmental influences on general cognitive ability in early adulthood. To our knowledge, this would be the first study to examine this issue in young adults. Given the subtle differences in results between the studies of children and adolescents and the single previous study of middle-aged men, the results from the present study may increase our understanding of whether there may be ‘‘critical periods’’ in which genetic variance can be affected by family socioeconomic background.

Methods

Sample

Participants in the current study were a subset of 3,203 male twin pairs from the Vietnam Era Twin (VET) Registry (Eisen et al. 1989). The VET Registry consists of over 8,000 male twin pairs born between the years 1939 and 1957. Both twins of a dyad must have been on active military duty during the Vietnam Era (1965–1975) as a prerequisite for eligibility to participate in the Registry. According to previous studies, Registry members are representative of all twins who served in the military during the Vietnam era on a variety of socio-demographic variables (Eisen et al. 1989; Goldberg et al. 1987). The ethnic breakdown of the VET Registry is 87% for Non-Hispanic Caucasians, 6% for African

Americans, and 7% Unknown/ Other. A complete description of the construction of the VET registry has been previously reported (Eisen et al. 1987; Henderson et al. 1990).

Zygosity of VET Registry twins was assessed and ultimately assigned utilizing both blood group typing data (ABO and Rh) and a 20 item zygosity questionnaire. When compared to DNA analysis, this approach (originally implemented by Eisen et al. (1989)) has been shown to achieve approximately 95% accuracy (Nichols and Bilbro 1966; Peeters et al. 1998).

The subset of twins used in this analysis comes from 8,169 randomly selected VET Registry twins who were interviewed by telephone during the Harvard Drug Study conducted in 1992 (Tsuang et al. 2001). It is important to note that an effort was made to enroll all available VET Registry twins into the Harvard Drug Study; there was no selection on the basis of drug use or any other characteristics. Of the 8,169 twins interviewed, there were approximately 3,300 pairs in which both members of a twin dyad participated. For the present paper, data from 3,203 twin pairs (1,774 MZ pairs, 1,429 DZ pairs) with complete zygosity records were available for statistical analyses. The average age of study participants at the time of induction into the military was 19.6 ± 1.5 (range: 16–30 years) with 77.0% between the ages of 18–21.

Measures

Cognitive ability—The Armed Forces Qualification Test (AFQT) was used as an index of general cognitive ability. This test was administered to all VET Registry individuals just prior to their induction into military service and the AFQT induction scores were made available to the investigators during the Harvard Drug Study. AFQT scores at the time of induction were available for approximately 94.2% (n = 6,037) of the 6,406 twins utilized in this analysis. The AFQT is a 50-min paper-and-pencil test consisting of 100 multiple-choice items that assesses performance on arithmetic word problems, vocabulary, knowledge/ understanding of tools and mechanical relationships, and visuospatial processing (recognizing folded and unfolded box patterns) (Uhlaner 1952). Raw scores were converted to percentile scores based on a World War II cohort. Individuals scoring below the 10th percentile were excluded from the military. Average AFQT at induction score for this 6,037 participant cohort was 55.3 ± 23.5. For the purposes of genetic model-fitting the raw percentile scores were transformed to their corresponding normal deviates. Standard deviations of the transformed AFQT scores were examined by median split (median = .15) for twin A and B separately to confirm that the variance in AFQT scores was reasonably constant across its range.

The AFQT was intended as a measure of military trainability. It appears to be a highly *g*-loaded test that correlates well with traditional IQ measures. For example, McGrevy et al. (1974) found a correlation of .84 (after correcting for restriction of range) between AFQT and Wechsler Adult Intelligence Scale (Weschler 1955) scores. In addition, the AFQT had a test-retest stability of .81 in Vietnam veterans retested 15 years after military induction (Grafman et al. 1988).

Parental education—Parental education was assessed during the Harvard Drug Study. Parental education level was available for approximately 98.6% (n = 6,318) of the 6,406 twins utilized in this analysis. Each twin's self-report of the highest level of formal education attained by his mother and father (possible range of 0–19 years) was utilized to determine parental education. Within-pair correlations of mother's and father's education were (.72; .78, *p*'s < .01), respectively. We averaged the reports of mother's and father's education across twins. In this sample, father's mean level education was 10.9 ± 3.2 years and mother's mean level education was 11.5 ± 2.4 years (51.1% of fathers and 64.5% of mothers had at least a high school education). Mother's and father's education were also significantly correlated (.53; $p < .01$). Our measure of parental education for these analyses was the average of both mother's and father's educational attainment. The mean parental education (average of mother's and father's education levels) was 11.2 ± 2.5 with a range of 0–19 years of education and a skewness of –.31 and kurtosis of 1.02.

As stated above, parents correlated .53 for education level ($p < .01$), indicating some degree of assortative mating for education level, a potential proxy for assortative mating on IQ. In standard twin designs, the presence of assortative mating would predict increased DZ correlations relative to MZ correlations, which may overstate the effects of common environment and underestimate the overall heritability of IQ (Fisher 1918; Neale and Cardon 1992). More importantly, assortative mating has the potential to bias the results of our moderation analyses if assortative mating is systematically associated with levels of our moderator variable. Although an extended-kinship design that uses IQ data from both twins and parents is required to formally estimate the effects of assortative mating (Neale and Cardon 1992), we can examine this issue indirectly by correlating the average of mother's and father's education with the absolute difference between mother's and father's education among those twin pairs who have data on both mother and father education ($N = 3{,}159$ pairs; 98.6% of the total sample). If there is a relationship between the absolute difference in mother's and father's education levels with the average level of parent education, this would indicate the presence of differential assortative mating at different levels of our moderating variable. The correlation between the average parental education score and the absolute difference in education level across mother and father was $r = -.08$ ($p < .01$), indicating virtually no relationship between level of education and difference in education across parents.

Statistical analysis

The standard twin (''ACE'') model estimates the proportion of total phenotypic variance attributable to additive genetic (a^2) effects, common/shared or familial environmental (c^2) effects, and unique or unshared environmental (e^2) effects. The e^2 parameter of the ACE model also includes error variance (Neale and Cardon 1992). Parameter estimates were derived utilizing the maximum-likelihood-based structural equation modeling program, Mx (Neale et al. 1999). One advantage of Mx is that it allows raw data to be fit to complex models, which facilitates the inclusion of measured variables that can be used as continuous moderators of genetic and environmental influences (Purcell 2002). This allows for a more precise index of any potential significant changes in overall phenotypic variance in addition to potential variations in estimates of the additive genetic, common, and unique environmental influences.

We examined the fit of four different models to determine whether parental education moderates means and variances in AFQT scores. For the subsequent analyses, the parental education variable was recoded to range from 0 to 1 to better estimate a^2, c^2, and e^2 when the moderator was 0 (lowest level of parental education) to 1 (highest level of parental education).

These models included a (1) *no moderation model* (standard ACE model), which models the assumption that AFQT means, overall variance, and genetic and environmental influences on variance in AFQT scores do not vary across different levels of parental education; a (2) *moderated means model*, which allows for different mean level AFQT scores across different levels of parental education, but assumes that the total phenotypic variation and the genetic and environmental influences on variation in AFQT do not vary across level of parental education; a (3) *scalar variance model* (moderating effects on overall phenotypic variance), which postulates that the total phenotypic variance in AFQT scores changes across different levels of parental education, but that the variation in genetic, shared environmental, and nonshared environmental influences is proportional, resulting in identical estimates of heritability and proportion of environmental influences across all levels of parental education; and a (4) *fully moderated ACE model* (moderating effects on the genetic and environmental contributions to variance), which allowed genetic and environmental influences to vary across levels of parental education. For further explanation of these models see Kremen et al. (2005) and Purcell (2002).

Because the four models are nested within each other (model 1 acts as the comparison model), with each subsequent model adding additional parameters to the previous model, we can compare how well each model fits through the Likelihood Ratio Test (LRT statistic). The LRT calculates a χ^2 value based on the difference in −2 log likelihoods (−2LL) between two nested models, with degrees of freedom equal to the difference in degrees of freedom between the two models. If the LRT shows a significant difference, this indicates that the model with more parameters is preferred. In addition, models can be compared on the basis of Akaike's Information Criterion (AIC; Akaike 1987) and Bayesian Information Criterion (Schwarz 1978) statistics. The AIC and BIC index both goodness-of-fit and parsimony of models, with lower values indicating preferred models.

Results

Descriptive analyses

Table 1 shows descriptive characteristics for this sample. The average age at induction was 19.6 ± 1.5 years. The average transformed AFQT score at induction was .17 ± .71 (range = −1.29 to 2.32; skewness = .24; kurtosis = −.50). The standard deviation for transformed AFQT scores in the lower half of the median split were .37 for both Twin A and B and .45 and .44 for transformed AFQT scores in the upper half of the median split for Twin A and Twin B, respectively. Transformed AFQT scores were more highly correlated in MZ pairs (r = .74) than in DZ pairs (r = .53; p's < .01) which indicates a putative genetic influence on AFQT scores in this cohort.

Moderation analyses

Analyses were based on N = 5,955 individual twins with non-missing data on both AFQT and parental education (93.3% of the original 3,203 twin pairs). We examined the fit of our four genetic models to determine whether parental education moderates means and variances in AFQT scores. Table 2 lists the fit statistics, standardized estimates of a^2, c^2, and e^2, and the total variance of AFQT scores (as a function of parental education) for each theoretical model.

Model 1 (comparison model/standard ACE model) revealed that genetic influences account for approximately 47% (95% CI: .40–.56) of the variance in general cognitive ability assessed by the AFQT while the common/shared environment and unique environment accounted for 28% (95% CI: .20–.35) and 25% (95% CI: .23–.27) of the total variance, respectively.

Model 2 (moderated means model) proved to be the best fitting model by both AIC and BIC criteria. Moreover, inclusion of moderated means significantly improved the model fit (LRT = 232.71, df = 1, $p < .001$) relative to Model 1. The moderating effect was positive, indicating that mean levels of general cognitive ability were higher in families with higher levels of parental education. The correlation between AFQT and parental education was .24 in this sample ($p < .01$). The moderated means model further indicates that genetic influences account for one-half of the variance in general cognitive ability ($a^2 = .50$; 95% CI: = .42–.59) with shared and unique environmental influences accounting for 23% (95% CI: .15–.31) and 27%, (95% CI: .25–.29) of the variance, respectively. By including moderated means in the model, we are effectively controlling for any shared overlap (genetic or environmental) between AFQT and parent education. Thus, estimates of a^2, c^2, and e^2 from Model 2 are for the genetic and environmental influences on AFQT that are independent of parental education level. However, we note that the estimates for Model 2 are almost identical to those from our unmoderated model (Model 1), consistent with the relatively small overlap between AFQT and parental education.

The addition of moderating effects on overall phenotypic variance (Model 3) or on the genetic and environmental contributions to variance (Model 4) did not improve the overall fit relative to Model 2. Thus, these results suggest that while levels of parental education are related to mean level differences in general cognitive ability, they are not systematically related to magnitude of genetic and environmental determinants of general cognitive ability.

Discussion

The overall goal of this study was to examine parental education and its putative moderating effect on genetic and environmental influences of general cognitive ability in early adulthood. We found significant effects of parental education on mean level of AFQT scores, but a model without moderating effects of parental education on genetic or environmental influences on AFQT scores (Model 2) proved to be the best fitting model by all criteria. These results are in part consistent with the Kremen et al. (2005) study of reading (word recognition) in middle-aged male twins from the VET Registry, which found no change in genetic variance as a function of parental education level. This is in contrast to a number of studies of children and adolescents that indicated enriched environments are associated with increased genetic variance in other cognitive measures (Harden et al. 2006; Rowe et al. 1999; Turkheimer et al. 2003). In our earlier study of middle-aged male twins (Kremen et al. 2005), we found that lower levels of parental education were associated with increased effects of shared environmental variance on reading ability. In the present study, the shared environmental variance accounting for AFQT scores was virtually the same across levels of parental education (Table 2).

There are a number of possible reasons why the present study did not find any moderating effect of parental education on genetic variance in AFQT scores. Perhaps the most intriguing possibility is that there may be a ‘‘critical period’’ through adolescence in which gene expression is more malleable. This might explain the absence of parental education moderating genetic variance in our sample during early or middle adulthood. Thus, age may be a factor in whether or how these interactive effects manifest themselves. In particular, whereas the majority of recent studies have found increasing heritability of cognitive abilities as a function of higher parental education and/or higher socioeconomic background, part of the inconsistency is in whether the increase in heritability is due to an increase in genetic variance and/or a decrease in environmental variance across more advantaged family backgrounds. Many of the studies of children and adolescents have found that both mechanisms are present, whereas the two studies of adults indicate that the absolute genetic variance is unchanged. Because this study failed to find a significant G × E effect, we believe the idea that there are critical periods in which gene expression can be modified is an intriguing one, and fits well with animal literature on critical periods for epigenetic changes due to differences in early childhood experiences.

Second, parental education may not have moderated environmental variance in the present sample because it may not have contained enough twins from socioeconomically impoverished backgrounds. Other researchers (Scarr 1992; Harden et al. 2006) have suggested that the increase in shared environmental variance is seen only among the most impoverished environments. However, participants in the Kremen et al. (2005) reading study were a subset (N = 690) of those in the present analysis (N = 5,955); they had similar socioeconomic backgrounds, but Kremen et al. did find that parental education was a significant moderator of environmental effects. We also tested the AFQT models in that same 690 twin subset and found essentially the same results as in the present analysis. The consistency of the AFQT results combined with the fact that there was ample power to find significant moderating effects for reading in the smaller Kremen et al. sample suggests that lack of statistical power or lack of twins from low socioeconomic backgrounds can not explain our current results. In fact, the present sample size is substantially larger (N = 5,955 twins) than the Rowe et al. (1999) (N = 3,818 twins), Turkheimer et al. (2003) (N = 640 twins), or Kremen et al. (2005) (N = 690 twins) studies, which suggests that a lack of power does not pose a limitation to these analyses and/or results. Moreover, as mentioned earlier, the amount of variance accounted for by genetic or environmental variance at the high and low ends of parental education were virtually identical (Table 2).

A third possibility is that there may be differences across different cognitive tests that make certain assessments more or less amenable to moderating effects. However, it is difficult to see any consistent patterns in the results of studies conducted thus far. For example, in a study of VET Registry twins, interaction effects were found in reading ability in middle adulthood (Kremen et al. 2005), but Van Den Oord and Rowe (1998) did not find interaction effects on reading ability among adolescent siblings. We did not find moderating effects in the current study of general cognitive ability in early adulthood, but moderating effects of general cognitive ability among adolescents have been reported in at least two published studies (Harden et al. 2006; Turkheimer et al. 2003). The moderating effects in the latter studies were primarily for verbal ability, but no moderating effects on verbal IQ were detected in a sample of 4 year old twins (Asbury et al. 2005). Finally, Rowe et al. (1999) reported a significant moderating effect of parental education on receptive vocabulary in adolescent twins.

Finally, we note that prior studies (Rowe et al. 1999; Kremen et al. 2005) have used measures of parental education that were exactly the same as the present parental education measure (i.e., average years of mother and father education, obtained from averaging reports across twins). The same analytic approach utilized in the present study has also been used in several recent studies which did find evidence of interaction effects (Kremen et al. 2005; Turkheimer et al. 2003). Thus it is unlikely that method of assessing parental education or method of analysis can account for the lack of interaction effects in the present study.

Limitations

One limitation of these analyses is that using a variable such as parental education, which is influenced by both genetic and environmental influences, has the potential to cause problems with interpretation of interactions. However, unbiased estimates of interaction with parental education and similar twin-pair variables can be obtained, as long as the effect of the moderator is simultaneously regressed out of the outcome variable (Purcell 2002), as we have done here. On the other hand, because our best-fitting model regressed out the shared variance between parental education and AFQT, estimates for genetic and environmental influence on AFQT obtained for this model are for residual AFQT variance, i.e., variation in AFQT that is independent of parental education. It is important to note, however, that the correlation between parental education and AFQT was a modest .24; thus, the amount of shared variance was less than 6%. That, in turn, means that our analysis captures more than 94% of the overall variance in AFQT. One could argue that not being able to account for all of the variance is a limitation, but addressing over 94% of the variance is certainly meaningful. Moreover, the estimates of a^2, c^2, and e^2 from our best-fitting moderated means model are nearly identical to those obtained from the unmoderated model (variance component estimates differ by <.05), indicating that partitioning out the variance in AFQT that is related to parental education did not overly bias our results.

Second, we did not control for age effects in this study, so some of the estimate of shared environmental influence could be due to the fact that twins were highly correlated for age when taking the AFQT ($r = .76$, $p < .001$). However, 77% of participants were between the ages of 18 and 21 suggesting that there are limited between-family differences in age. In addition, there is no empirical or theoretical reason to believe that the heritability of general cognitive ability would vary substantially across this extremely narrow age range. Most importantly, controlling for age has the potential to introduce other biases in this particular analysis. Participants varied in terms of age at induction in part due to whether they joined the military before or after (or instead of) going to college. Participants with higher cognitive ability would be more likely to have gone to college prior to entering the military, which would have delayed their age at induction. This is supported by the modest, yet significant correlation between age at induction and AFQT score ($r = .17$, $p < .01$) despite the narrow age range. Thus, controlling for age in these analyses would throw out meaningful variation in AFQT that, while appearing to be accounted for by age, is actually a reflection of cognitive ability. Doing so may introduce other biases into our estimates of a^2, c^2, and e^2. Finally, the sample is male and has limited racial and ethnic variability. Thus, the results of this study may not generalize to women, or to minority individuals.

Summary

The present study finds that parental education level does not moderate genetic and environmental variance in AFQT scores among young adults. After considering several factors including age, the cognitive measure used, the socioeconomic diversity of the sample, and sample size, no consistent pattern emerges that could account for the lack of moderating effects on genetic and environmental influences compared with prior research. The present study serves to highlight the fact that the phenomenon of parental education or SES enhancing or suppressing genetic influence on cognition may be more complex than previously thought. Further research will be needed before we can make broad generalizations about the implications of putative environmental or other moderators of the heritability of cognitive abilities.

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Table 1

Descriptive characteristics of the sample

Variable	Mean (SD)	Range	*n*
Age at induction	19.6 (1.5)	16–30	6,190
Twin education at enlistment	12.2 (1.4)	5–20	6,168
Parental education	11.2 (2.5)	0–19	6,318
AFQT percentile scores at induction			
Raw scores	55.3 (23.5)	10–99	6,037
Transformed scores	.17 (.71)	−1.29 to 2.32	6,037

Table 2

Model fitting for estimating changes in genetic and environmental variance components in general intelligence (as assessed by the Armed Forces Qualifying Test) as a function of parental education

	Fit statistics							Standardized estimates			Variance
	−2LL	df	LRT[a]	df	*p*-value	AIC	BIC	a^2	c^2	e^2	
(1)	11,155.87	5,951	n/a	–	–	−746.13	−18,395.9	.47 (.40; .56)	.28 (.20; .35)	.25 (.23; .27)	506.0 (485.3; 528.1)
(2)	10,923.16	5,950	232.71	1	<.001	−976.84	−18,508.2	.50 (.42; .59)	.23 (.15; .31)	.27 (.25; .29)	476.3 (457.0; 496.9)
(3)	10,923.11	5,949	.05	1	.82	−974.89	−18,504.2	.50↓ (.42; .59)	.23↓ (.15; .31)	.27↓ (.25; .29)	468.1↓ (392.3; 552.7)
								.50↑ (.42; .59)	.23↑ (.15; .31)	.27↑ (.25; .29)	482.1↑ (425.9; 543.3)
(4)	10,922.99	5,947	.12	2	.94	−971.01	−18,496.2	.56↓ (.22; .82)	.18↓ (.00; .53)	.26↓ (.17; .36)	471.3↓ (384.8; 596.4)
								.45↑ (.22; .70)	.28↑ (.05; .52)	.27↑ (.21; .34)	482.9↑ (418.2; 568.2)

(1) = no moderation model, which models the assumption that AFQT means, overall variance, and genetic and environmental influence on variance in AFQT scores remains stable across different levels of parental education; (2) = moderated means model, which allows for different mean level AFQT scores across different levels of parental education, but assumes that the total phenotypic variation and the genetic and environmental influences on variation in AFQT remains stable across level of parental education; (3) = scalar variance model, which postulates that the total phenotypic variance in AFQT scores changes across different levels of parental education, but that the changes in genetic, shared environmental, and nonshared environmental influences are proportional; (4) = fully moderated ACE model, which allowed genetic and environmental influences to vary across levels of parental education. ↓ = Estimates at lowest level of parental education (0 years); ↑ = Estimates at highest level of parental education (19 years)

[a] Likelihood Test Ratio statistic based on comparisons of adjacent, nested models, i.e., 2 vs. 1, 3 vs. 2, and 4 vs. 3