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Examining Social Genetic Effects on Educational Attainment via Parental Educational Attainment, Income, and Parenting

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Higher parental educational attainment is associated with higher offspring educational attainment. In this study, we incorporated genotypic and phenotypic information from fathers, mothers, and offspring to disentangle the genetic and socioenvironmental pathways underlying this association. Data were drawn from a sample of individuals of European ancestry from the collaborative study on the genetics of alcoholism (n = 4,089; 51% female). Results from path analysis indicated that paternal and maternal educational attainment genome-wide polygenic scores were associated with offspring educational attainment, above and beyond the effect of offspring education polygenic score. Parental educational attainment, income, and parenting behaviors served as important socioenvironmental pathways that mediated the effect of parental education polygenic score on offspring educational attainment. Our study highlights the importance of using genetically informed family studies to disentangle the genetic and socioenvironmental pathways underlying parental influences on human development.

Keywords: social genetic effects, genetic nurturing, education, intergenerational transmission, polygenic association

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The intergenerational transmission of educational attainment is one of the most consistent findings within social science. Parents with higher levels of educational attainment tend to have children with higher academic achievement and educational attainment (Hertz et al., 2008; Huang, 2013). Because parents not only provide and shape the environments in which their offspring develop but also pass on genes to their offspring, traditional family studies that do not account for the genetic information cannot disentangle the underlying genetic and environmental effects and may potentially overestimate the impact of socioenvironmental pathways underlying parental influences on educational attainment. For example, prior research indicates that higher parental education is associated with higher offspring educational achievement, in part through positive parent–child relationship and parenting behaviors such as parental support and school involvement (Davis-Kean, 2005). However, given that educational attainment and parenting behaviors are both genetically influenced (Branigan et al., 2013; Klahr & Burt, 2014; Wertz et al., 2019), these associations may partly reflect genetic effects. Educational attainment is associated with a host of social and health outcomes (Conti et al., 2010; Zajacova & Lawrence, 2018), and thus understanding the pathways to educational attainment is important. Genetically informed designs that incorporate genotypic and phenotypic information from both parents and offspring offer a great opportunity to disentangle the genetic and socioenvironmental pathways underlying parental influences on offspring educational attainment.

Recent studies suggest that direct (i.e., genetic transmission) and indirect/social genetic effects, in addition to socioenvironmental pathways, contribute to the intergenerational transmission of psychosocial outcomes (Bates et al., 2018, 2019; Kong et al., 2018; Liu, 2018). One way that parents influence offspring educational attainment is through genetic transmission. There is a substantial degree of genetic influence on educational attainment. A meta-analysis of twin and family studies estimated that genetic factors account for about 40% of variation in educational attainment (Branigan et al., 2013). Recent genome-wide association studies (GWAS) have identified many genetic variants associated with educational attainment (Lee et al., 2018). Given that complex behavioral phenotypes like educational attainment are polygenic, that is, influenced by many genes of small effects (Lee et al., 2018; Plomin et al., 2009), an increasingly popular approach is to use genome-wide polygenic scores to capture individuals' aggregated genetic predisposition toward educational attainment. These scores can be carried forward into developmental and family studies to understand how genetic predispositions influence psychosocial outcomes (Bogdan et al., 2018; Dudbridge, 2016). Studies have shown direct genetic effects (i.e., effects of an individual's genotypes on their own phenotype) using educational attainment genome-wide polygenic scores. For example, higher education polygenic scores are associated with higher educational achievement and socioeconomic status (Bates et al., 2019; Belsky et al., 2016), fewer internalizing and externalizing problems (Jansen et al., 2018), and better interpersonal skills (Belsky et al., 2016).

In addition to genetic factors (i.e., offspring's own genotype), social genetic effects (also referred to as genetic nurturing effects) may also shape offspring outcomes (Domingue & Belsky, 2017). Social genetic effects refer to the notion that parents' genotypes, even those not transmitted to their offspring, play a role in influencing offspring development via socioenvironmental pathways (Bates et al., 2018, 2019; Kong et al., 2018; Liu, 2018). Evidence from meta-analysis demonstrates a consistent but small indirect/social genetic effect on educational outcomes (Wang et al., 2021). Parental genes related to educational attainment may be associated with offspring educational attainment via correlated environmental processes. Specifically, parents' genetic predispositions may influence their own educational attainment and related socioeconomic factors such as income, which in turn influences offspring educational attainment. In addition, several lines of evidence suggest that parenting behaviors may serve as an important socioenvironmental pathway through which parental genetic predispositions influence offspring educational attainment. First, prior research suggests that parenting behavior is an important pathway linking parental education to offspring outcomes. Parents with higher socioeconomic status, such as higher levels of education and higher income, tend to engage in positive parenting behaviors (Dubow & Ippolito, 1994) such as higher levels of monitoring, support, care, and involvement, which in turn are associated with better offspring psychosocial outcomes, including higher educational attainment (Davis-Kean, 2005). Second, parenting is genetically influenced, with both parents' and offspring's genotypes playing an important role (Klahr & Burt, 2014; Wertz et al., 2019). Third, prior research suggests that genetic predispositions toward educational attainment are associated with individuals' social environments. For example, adolescents with higher education polygenic score were more likely to grow up in more socially advantaged home environments (Belsky et al., 2016; Domingue et al., 2015), although these studies did not examine both parents' and offspring's education polygenic score and thus were not able to directly examine social genetic effects and disentangle passive versus evocative gene–environment correlations (rGE; Scarr & McCartney, 1983).

There is an emerging literature demonstrating that parental genetic dispositions can influence offspring outcomes through indirect genetic effects, For example, mothers with higher education polygenic score are associated with offspring's early childhood development outcomes, including indicators of physical, social, and emotional development, and academic performance, even after accounting for direct genetic transmission, and this association was partly mediated by prenatal conditions indexed by mother's health and socioeconomic status during pregnancy (Armstrong-Carter et al., 2020). In addition, using a sample of families that represent the full range of socioeconomic conditions in Great Britain, mother's education polygenic score is associated with warm, cognitive stimulating parenting, which partially explains the association between mother's education polygenic score and offspring educational attainment at age 18 (Wertz et al., 2020). These results highlight the role of social genetic effects in offspring outcomes of typical interest in traditional family and developmental studies. However, research on genetics, parenting, and offspring outcomes has predominantly focused on mothers only, and it remains unclear the role of fathers' genetic dispositions in shaping their offspring outcomes.

The overarching goal of this study was to disentangle the genetic and social–environmental pathways underlying the intergenerational transmission of educational attainment. Specifically, we examined whether parental education polygenic score would be associated with offspring educational attainment, above and beyond the effect of offspring education polygenic score, and whether parental socioeconomic status and parenting would serve as socioenvironmental pathways linking parental education polygenic score to offspring educational attainment. Because socioeconomic status is a multidimensional construct (McLoyd, 1998), we examined the role of both parental education and income to capture different aspects of socioeconomic status (SES). We note that income is a good direct measure of household resources, but it might be more prone to error in reporting, compared to education (Kim & Tamborini, 2014). We examined parental bonding because theories indicate that support from parents could motivate students and help make academic-related tasks enjoyable, leading to higher academic achievement in offspring (Pomerantz et al., 2007). Empirical evidence indicates that parental warmth is linked with adolescent academic achievement (Chung et al., 2020; Pinquart, 2016). We hypothesized that (a) higher parental education polygenic score would be associated with higher offspring educational attainment, even after controlling for offspring education polygenic score; (b) higher parental education polygenic score would be associated with higher offspring educational attainment indirectly via offspring education polygenic score (direct genetic transmission), and through parental educational attainment, income, and parental bonding (social genetic effects). In this study, we used data from fathers, mothers, and offspring to examine whether patterns of associations are similar or different for fathers and mothers.

Method

Data

Data were drawn from the collaborative studies on genetics of alcoholism (COGA), a multisite, large, multigenerational family study that aims to identify genetic influences on alcohol dependence and related psychiatric phenotypes (Begleiter et al., 1995). Probands were identified through alcohol treatment programs at seven U.S. sites and were invited to participate if they had a sufficiently large family (usually sibships of more than three with parents available) with two or more members affected by alcohol use disorder in the COGA catchment areas. Population-based comparison families were also recruited. Data collection for COGA started in 1991 when adults in the extended families were invited to complete the semistructured assessment for the genetics of alcoholism (SSAGA), a comprehensive interview that assesses demographic factors, alcohol use disorders, and a variety of psychiatric phenotypes (Bucholz et al., 1994). In 2004, COGA launched the prospective study that aims to examine how genetic risks unfold across development and in conjunction with the environment. Specifically, offspring in the extended families who were between ages 12 and 22 and had at least one parent who completed a SSAGA in the original COGA waves were recruited for the prospective sample (Bucholz et al., 2017). About 86% of the eligible offspring participated in the prospective study. These offspring participants completed a SSAGA, or an adolescent Version of SSAGA (CSSAGA) if they were younger than 18 years old, at enrollment and were reinterviewed at approximately 2-year intervals. Prospective study participants also completed questionnaires related to their environmental experiences including parenting behaviors. All COGA participants were asked to provide a Deoxyribonucleic acid (DNA) sample via blood or saliva. The Institutional Review Boards at all sites approved this study, and written consent (and assent for adolescents) was obtained from all participants. COGA data are available through the National Institute on Alcohol Abuse and Alcoholism or the database of Genotypes and Phenotypes; dbGaP (phs000763.v1.p1, phs000125.v1.p1).

Genetic ancestry principal components were computed from GWAS data using Eigenstrat (Price et al., 2006) and the 1,000 genomes, Phase III reference panel. COGA participants were assigned an ancestry classification (European, African, or other) based on the first two principal components. In the present study, we focused on COGA participants of European ancestry (˜75%) because the sample of the discovery genome-wide association study (GWAS) we used to calculate education polygenic scores (see further details below) was primarily of European ancestry (Lee et al., 2018). Polygenic scores derived from discovery GWAS results of largely European ancestry perform poorly in samples of non-European ancestry (Martin et al., 2017). The primary analytic sample included 4,089 individuals of European ancestry who completed at least one SSAGA interview and provided information on educational attainment, had genomic data analysis for calculating education polygenic score, aged 18 or older, and had genomic data available for at least one biological parent. These individuals came from 840 extended families and 1,893 nuclear families. Offspring participants' age at the last interview ranged between 18 and 79 (M = 30.07, SD = 9.22; 51% female). Of these participants, there were 3,029 individuals whose biological father completed at least one SSAGA interview and 2,908 individuals whose biological father had genomic data available for analysis (fathers' age at last interview ranged between 21 and 91, $M \pm SD$ = 52.96 ± 12.96 years); there were 3,728 individuals whose biological mother completed at least one SSAGA interview and 3,635 individuals whose biological mother had genomic data available for analysis (mother's age at last interview ranged between 18 and 88, $M \pm SD$ = 50.79 ± 13.28 years). The secondary sample was a subset of the primary analytic sample, limited to offspring participants for whom data on the parental bonding measure were available (n = 642; see more details below).

Measures

Educational Attainment

All participants reported their highest level of education by responding to the question "What is the highest grade in school you completed?" Responses were converted to the number of years typically required to complete that level of education and ranged from 0 to 17 years (primary or secondary school = actual year; technical school/1 year college = 13 years; 2 years college = 14 years; 3 years college = 15 years; 4 years college = 16 years; any graduate degree = 17 years). For individuals who completed multiple SSAGA interviews, the maximum reported educational attainment was used.

Parental Income

Parents reported on their current household gross income based on a 9-point scale ranging from 0 (*none*) to 9 (*$150,000 or more per year*). For parents who completed multiple SSAGA interviews, the maximum value was used.

Parental Bonding

A subset of COGA prospective study offspring participants who were between ages 12 and 17 completed the parental bonding instrument (Parker et al., 1979) at their baseline assessment. Adolescents responded to 12 statements about the degree of care, support, and communication with their mother and father figures during the past 6 months. Sample items included “spoke to me in a warm and friendly voice” and “was affectionate and loving to me.” Responses were made on a 4-point scale ranging from *usually or always to rarely or never*. Scores were summed across items and higher scores (ranged from 12 to 48) indicated higher levels of paternal or maternal bonding. This instrument was not administered across all COGA sites; thus only 650 adolescents reported on *maternal bonding* and 626 adolescents reported on *paternal bonding*. Some adolescents reported parental bonding of nonbiological mothers (n = 31, 4.8%) and fathers (n = 127; 20.3%) because they did not live with their biological mother/father at the time of assessment. Because we considered parental genetics in the present study, we coded those responses as missing and only used data reported on biological parents who lived with the child at the time of assessment (N = 642). Cronbach’s α for this scale is .88 for mothers and .89 for fathers.

Genotyping and Education Polygenic Scores

Participants’ DNA samples were genotyped using the Illumina Human1M array, the Illumina Human OmniExpress 12V1 array, the Illumina 2.5M array (Illumina, San Diego, California), or the Smokescreen genotyping array (Baurley et al., 2016). Data were imputed to 1,000 genomes Phase III, and single nucleotide polymorphisms (SNPs) with a genotyping rate <0.95 or that violated Hardy–Weinberg equilibrium ($p < 10^{-6}$) or with minor allele frequency <0.01 were excluded from analysis.

The polygenic scoring method uses results from a GWAS to aggregate the effects of genetic variants across the genome into a single continuous score for individuals in an independent sample. We used estimates from the social science genetic association consortium (SSGAC) GWAS of educational attainment (Lee et al., 2018), the largest published GWAS of educational attainment to date, to calculate education polygenic scores for all participants in our sample. We used PRS-CS (Ge et al., 2019) to calculate the education polygenic score. This approach employs a Bayesian regression and continuous shrinkage method to correct for the nonindependence among nearby SNPs in the genome (i.e., linkage disequilibrium, or LD), and includes SNPs in the construction of educational attainment genome-wide polygenic scores (Edu-PGS) regardless of their p value. In order to account for population stratification, we regressed education polygenic score on the first 10 genetic ancestry principal components (PC1-10) and used the standardized, residualized education polygenic score in all subsequent analysis.

Analyses

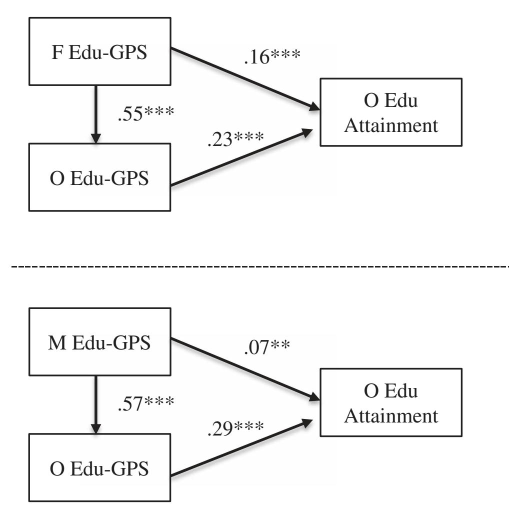
We conducted analyses using Mplus Version 7.31 (Muthén & Muthén, 1998–2012). Clustering within families was accounted for using the CLUSTER command in Mplus. All analyses included offspring’s sex and age at the last interview as covariates. In addition, given the wide range of age in our sample, we controlled for potential birth cohort effects by creating a cohort variable indexed using three dummy-coded variables derived from participant year of birth: [1902–1950], [1951–1970], and [1971–2000] (Grucza et al., 2008). Missing data were accounted for using full information maximum likelihood estimation method.

We first examined descriptive statistics and intercorrelations between key study variables. We then conducted a series of path models, separately for fathers and mothers, to test our hypotheses related to genetic and socioenvironmental influences on educational attainment. Specifically, we started by conducting path models to test for the presence of social genetic effects on offspring educational attainment. In these models (see Figure 1), parental education polygenic score was specified as an exogenous variable predicting offspring educational attainment and offspring education polygenic score. Offspring education polygenic score was also specified to predict offspring educational attainment. If parental education polygenic score is associated with offspring educational attainment above and beyond the effect of offspring education polygenic score, which would provide evidence that there are social genetic effects on educational attainment.

After establishing the presence of social genetic effects for educational attainment, we conducted path analyses to examine the roles of parental educational attainment, income, and parenting

Figure 1

Parental Genetics Influence Offspring Educational Attainment via Genetic Transmission and Social Genetic Effects



Note. n = 4,089. O = offspring; F = father; M = mother; Edu-GPS = educational attainment genome-wide polygenic scores. Standardized path coefficients are presented. All models controlled for offspring sex, age at last interview, and cohort. $\chi^2 = 139.02$, $df = 13$, $p < .001$; comparative fit index (CFI) = .92, root-mean-square error of approximation (RMSEA) = .05 for the father model; $\chi^2 = 57.73$, $df = 13$, $p < .001$; CFI = .97, RMSEA = .03 for the mother model.
** $p < .01$. *** $p < .001$.

(parental bonding) in mediating the social genetic effects. We started by conducting path models where parental educational attainment and income were specified as the mediating pathways for the social genetic effects (see Figure 2). In these models, parental education polygenic score was specified as predicting offspring educational attainment directly and indirectly through parental educational attainment and income, above and beyond the effect of offspring education polygenic score.

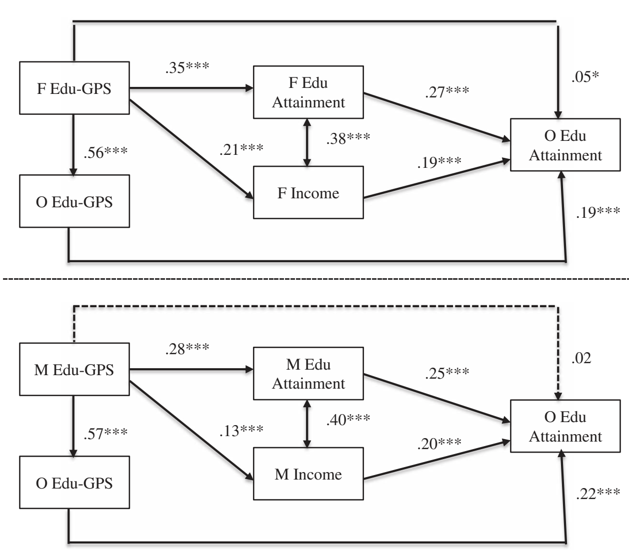
We then extended the path models to include parenting as an additional pathway through which social genetic effects occur (see Figure 3) for a subset of individuals for whom parenting variable was available. In these extended path models, parental education polygenic score was specified as predicting offspring educational attainment directly and indirectly through parental educational attainment, income, and parental bonding, above and beyond the effect of offspring education polygenic score. Parental educational attainment and income were also specified to predict parenting, which in turn predicted offspring educational attainment. Offspring education polygenic score was also specified to predict parenting to account for evocative gene–environment correlation (rGE) processes. As noted, these analyses were only conducted with a subsample of participants for whom data on paternal and/or maternal bonding was available ($n = 642$, offspring age ranged 18–30, mean = 22.63, $SD = 9.75$; 48% female).

Indirect effects of parental education polygenic score on offspring educational attainment via parental educational attainment, income, and parenting were tested using the MODEL INDIRECT command in Mplus, which provides a test of specific indirect effects in addition to the total indirect and direct effects of parental education polygenic score on offspring educational attainment. In cases where multiple indirect pathways are examined simultaneously, specified indirect effects reflect each of the specific pathways (e.g., parental education polygenic score → parental educational attainment → offspring educational attainment) while also accounting for the shared associations between them. Indirect effects were evaluated using bias-corrected bootstrapping (5,000 times) 95% confidence intervals (CI; MacKinnon et al., 2004), with CI not including zero indicating statistically significant indirect effects.

Finally, we conducted a series of sensitivity analysis to evaluate the robustness of our results. First, we reran all path analyses with a subsample of individuals aged 25 (typical age for finishing schooling in the U.S.; U.S. Census Bureau, 2018) or older. Second, we conducted exploratory analyses by including education polygenic score, educational attainment, and income from both fathers and mothers in the same model for analyses presented in Figures 1–2. For Figure 3, due to the small sample size and limited power, we ran a father and mother combined path model using the mean scores of parental education polygenic score, parental educational attainment, parental income, and parental bonding. In this model, for individuals who only had data available for one parent, the available parental data was used instead of mean scores. Finally, we conducted multigroup path analyses to examine whether the patterns of associations differed across offspring sex. This study was not preregistered.

Figure 2

Parental Educational Attainment and Income as Pathways Linking Parental Genetics and Offspring Educational Attainment



Note. $n = 4{,}089$. O = offspring; F = father; M = mother. Edu-GPS = educational attainment genome-wide polygenic scores. Standardized path coefficients are presented. All models controlled for offspring sex, age at last interview, and cohort. $\chi^2 = 156.88$, $df = 15$, $p < .001$; comparative fit index (CFI) = .94, root-mean-square error of approximation (RMSEA) = .05 for the father model; $\chi^2 = 155.732$, $df = 15$, $p < .001$; CFI = .95, RMSEA = .05 for the mother model. Dotted lines represent nonsignificant paths.
* $p < .05$. *** $p < .001$.

Results

Preliminary Analysis

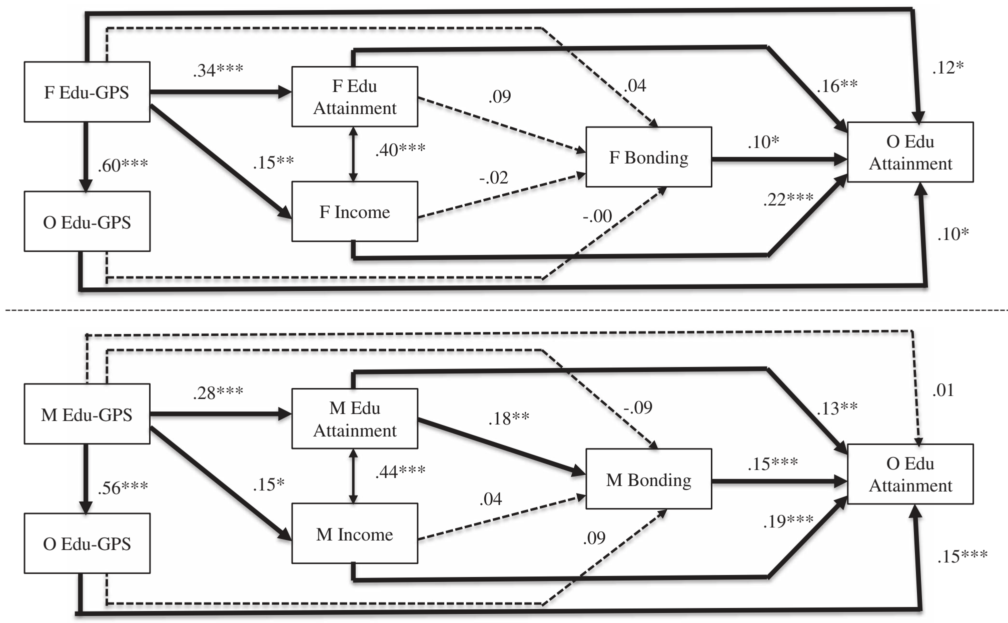
All participants had genomic or phenotypic data from at least one parent. A total of 912 participants had no genomic or phenotypic data from their father, and 209 participants were missing genomic and phenotypic data from their mother. Those missing father data were slightly older ($t = -2.27$, $df = 4{,}087$, $p = .02$) and reported lower educational attainment ($t = 9.10$, $df = 4{,}087$, $p < .001$) than individuals who had father genotypic or phenotypic data. Those missing mother data also reported lower educational attainment ($t = 2.33$, $df = 4{,}087$, $p = .02$) than individuals who had mother genotypic or phenotypic data.

Table 1 presents descriptive statistics and bivariate correlations between the key study variables. Maternal and paternal education polygenic scores were positively correlated with each other (indicative of assortative mating) and positively correlated with offspring education polygenic score and educational attainment. Maternal and paternal educational attainment and income were moderately and positively correlated with offspring educational attainment. Maternal educational attainment and mother-reported household income were positively correlated with maternal bonding, but paternal educational attainment and father-reported household income were not significantly correlated with paternal bonding.

Path Models Examining Pathways of Social Genetic Effects

Results from path analyses are summarized in Table 2. As shown in Figure 1, paternal and maternal education polygenic scores were both associated with offspring education polygenic score ($\beta = .55$, $p < .001$ and $\beta = .57$, $p < .001$ for fathers and mothers, respectively),

Figure 3
Parental Education and Parenting as Pathways for Social Genetic Effects on Educational Attainment



Note. $n = 642$. O = offspring; *F* = father; *M* = mother. Edu-GPS = educational attainment genome-wide polygenic scores. Standardized path coefficients are presented. All models controlled for offspring sex, age at last interview, and cohort. Statistically significant pathways are bolded. Dotted lines represent nonsignificant paths. $\chi^2 = 8.68$, $df = 6$, $p = .19$; comparative fit index (CFI) = 1.00, root-mean-square error of approximation (RMSEA) = .03 for the father model; $\chi^2 = 32.67$, $df = 6$, $p < .001$; CFI = .96, RMSEA = .08 for the mother model.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

which in turn significantly predicted offspring educational attainment ($\beta = .23$, $p < .001$ and $\beta = .29$, $p < .001$ in the father model and mother model, respectively). The indirect effects linking parental education polygenic score to offspring educational attainment via offspring education polygenic score were significant for both fathers ($B = .27$, 95% CI [.226, .319], $SE = .03$, $\beta = .13$) and mothers ($B = .35$, 95% CI [.311, .400], $SE = .03$, $\beta = .17$), indicating that parental education polygenic score influenced offspring educational attainment via genetic transmission. In addition, results indicated that both paternal ($\beta = .16$, p < .001) and maternal education polygenic score ($\beta = .07$, p < .001) were associated with offspring educational attainment above and beyond the effect of offspring education polygenic score, providing evidence for social genetic effects on educational attainment. In this model, 44.9% of the effect of paternal

Table 1
Descriptive Statistics and Bivariate Correlations Between Variables

Variable	*N*	1	2	3	4	5	6	7	8	9	10	11	12
1. Sex	4,089	—											
2. Age	4,089	−.01	—										
3. O Edu-GPS	4,089	−.00	.02	—									
4. F Edu-GPS	2,908	−.02	.01	.55**	—								
5. M Edu-GPS	3,635	.03	.05**	.57**	.16**	—							
6. O Edu attainment	4,089	−.08*	.06**	.34**	.31**	.24**	—						
7. F Edu attainment	3,029	.02	−.19**	.28**	.36**	.18**	.40**	—					
8. M Edu attainment	3,728	.00	−.29**	.29**	.27**	.26**	.36**	.53**	—				
9. F income	3,009	.02	−.25**	.19**	.22**	.11**	.32**	.47**	.41**	—			
10. M income	3,711	.02	−.32**	.18**	.20**	.12**	.30**	.41**	.47**	.68**	—		
11. F bonding	499	.01	−.15*	.02	.06	.05	.05	.08	.16**	.01	.15**	—	
12. M bonding	619	−.05	−.10*	.10*	.05	.04	.16**	.16**	.22**	.07	.13**	.48**	—
M	—	.49[a]	30.07	.00	.00	.00	13.59	13.30	12.99	5.13	4.87	39.63	41.29
SD	—	—	9.22	1.00	1.00	1.00	2.13	2.67	2.29	2.00	2.06	6.93	6.46

Note. O = offspring; F = father; M = mother; Edu-GPS = educational attainment genome-wide polygenic score. Age = age at last interview.
[a] sex was coded 1 = male, 0 = female; proportion of males in the sample is presented.
$^{*}p < .05$. $^{**}p < .01$.

Table 2
Parameter Estimates From Path Models Examining Social Genetic Effects on Educational Attainment

Paths	Father model				Mother model			
	B	*SE*	β	*p*	*B*	*SE*	β	*p*
Social genetic effects models (Figure 1)								
P Edu-GPS → O educational attainment	.33	.05	.16	<.001	.14	.05	.07	.007
O Edu-GPS → O educational attainment	.49	.05	.23	<.001	.62	.04	.29	<.001
P Edu-GPS → O Edu-GPS	.55	.02	.55	<.001	.57	.02	.57	<.001
Social genetic effects via parental education and income models (Figure 2)								
P Edu-GPS → O educational attainment	.11	.05	.05	.015	.04	.05	.02	.425
O Edu-GPS → O educational attainment	.41	.04	.19	<.001	.47	.04	.22	<.001
P Edu-GPS → O Edu-GPS	.55	.02	.56	<.001	.57	.02	.57	<.001
P Edu-GPS → P educational attainment	.95	.09	.35	<.001	.64	.07	.28	<.001
P Edu-GPS → P income	.44	.06	.21	<.001	.28	.06	.13	<.001
P educational attainment → O educational attainment	.21	.02	.27	<.001	.22	.02	.25	<.001
P income → O educational attainment	.20	.03	.19	<.001	.20	.02	.20	<.001
Social genetic effects via parental education, income, and parenting models (Figure 3)								
P Edu-GPS → O educational attainment	.24	.10	.12	.017	.03	.09	.01	.776
O Edu-GPS → O educational attainment	.20	.08	.10	.016	.30	.07	.15	<.001
P Edu-GPS → O Edu-GPS	.62	.04	.60	<.001	.59	.04	.56	<.001
P Edu-GPS → P educational attainment	.76	.14	.34	<.001	.63	.15	.28	<.001
P Edu-GPS → P income	.28	.11	.15	.009	.31	.12	.15	.012
P educational attainment → O educational attainment	.14	.05	.16	.004	.12	.04	.13	.002
P income → O educational attainment	.24	.05	.22	<.001	.19	.04	.19	<.001
P Edu-GPS → P bonding	.29	.52	.04	.575	−.59	.35	−.09	.097
O Edu-GPS → P bonding	−.02	.49	−.00	.974	.56	.39	.09	.157
P educational attainment → P bonding	.29	.20	.09	.156	.54	.17	.18	.002
P income → P bonding	−.10	.22	−.02	.666	.12	.17	.04	.491
P bonding → O educational attainment	.03	.01	.10	.016	.05	.01	.15	<.001

Note. P = parent; O = offspring; Edu-GPS = educational attainment genome-wide polygenic scores. All models controlled for offspring sex, age at last interview, and cohort and accounted for family clustering.

education polygenic score on offspring educational attainment was mediated by offspring education polygenic score; 71.7% of the effect of maternal education polygenic score on offspring educational attainment was mediated by offspring education polygenic score.

As shown in Figure 2 and Table 2, parental education polygenic score was associated with higher parental educational attainment and higher parental income, which in turn was associated with higher offspring educational attainment, above and beyond the effect of offspring education polygenic score. The indirect path from parental education polygenic score to offspring educational attainment via parental educational attainment was statistically significant for both fathers (B = .196, 95% CI [.156, .246], SE = .028, β = .094) and mothers (B = .143, 95% CI [.106, .185], SE = .023, β = .068). Similarly, the indirect path from parental education polygenic score to offspring educational attainment via household income was also statistically significant for both fathers (B =.086, 95% CI [.062, .115], SE = .016, β = .041) and mothers (B = .055, 95% CI [.034, .079], SE = .014, β = .026). For fathers, paternal educational attainment explained 49.6% of the variance in the association between paternal education polygenic score and offspring educational attainment, and income explained 21.8% of the variance, after controlling for the effect of offspring education polygenic score. For mothers, maternal educational attainment explained 61.1% of the variance in the association between maternal education polygenic score and offspring educational attainment, and income explained 23.5% of the variance, after controlling for the effect of offspring education polygenic score. Paternal education polygenic score remained significantly associated with offspring educational attainment when paternal educational attainment and income were considered, suggesting that there are other socioenvironmental factors, in addition to paternal educational attainment and income, that serve as important pathways of social genetic effects. When maternal educational attainment and income were included in the model, maternal education polygenic score was no longer directly associated with offspring educational attainment.

Finally, results from the extended path models including parental educational attainment, income, and parenting as pathways through which social genetic effects occur are summarized in Table 2. This extended full model explained 50.25% and 48% of the variance in offspring educational attainment for the father model and the mother model, respectively. As shown in Figure 3, for both fathers and mothers, parental education polygenic score was not significantly associated with parental bonding. Neither paternal educational attainment nor father-reported household income was associated with paternal bonding. Maternal educational attainment, but not mother-reported household income, was associated with maternal bonding. Paternal and maternal bonding was both associated with offspring educational attainment. The indirect effect of parental education polygenic score on parental bonding via parental educational attainment was significant for mothers (B = .336, SE = .020, 95% CI [.165, .621], β = .050) but not for fathers (B = .216, 95% CI [−.025, .505], SE = .166, β = .031). In addition, the indirect effect from parental education polygenic score to parental educational attainment to parental bonding to offspring educational attainment was significant for mothers (B = .015, 95% CI [.007, .031], SE = .007, β = .008), which accounted for 10.1% of the effect of maternal education polygenic score on offspring educational attainment after controlling for the effect of offspring education polygenic score, but was not significant for fathers (B = .006, SE = .005, 95% CI [.000, .019], β = .003)

Robustness of Results

The patterns of associations from analyses with a subsample of individuals aged 25 years or older (n = 2,738) were largely consistent with what we found with the whole sample (individuals aged 18 years or older) in terms of direction and magnitudes of associations (see Supplemental Materials Table 1). However, several path coefficients (e.g., paternal bonding → offspring educational attainment; paternal education polygenic score → offspring educational attainment; parental education polygenic score → parental income) in the path models where parental education, income, and parenting were considered as mediators of the effects of parental education polygenic score on offspring educational attainment (Figure 3) became statistically nonsignificant, which was likely due to the reduction in sample size and statistical power. That the association between parental bonding and offspring educational attainment became nonsignificant in this subsample of offspring aged 25 years or older may also reflect developmental changes in parent–child relationships (Aquilino, 1997) and suggest a decline in the impact of parent–child relationship beyond emerging adulthood.

Results from the father and mother combined models were largely consistent with those from analyses conducted separately for fathers and mothers, also providing support for social genetic effects on educational attainment and indicating that parental educational attainment, income, and parental bonding serve as mediators of social genetic effects (see Supplemental Materials Table 2). Multigroup analysis by offspring sex did not show significant differences in path coefficients between males and females in all path models, except that the association between father-reported income and offspring educational attainment appeared to be stronger for females than for males (see Supplemental Materials Tables 3 and 4).

Discussion

The overarching goal of this study was to disentangle the genetic and socioenvironmental pathways underlying parental influences on educational attainment. Our findings indicated that parents influence offspring educational attainment through direct genetic transmission, social genetic effects, and socioenvironmental pathways. Specifically, parental education polygenic score was associated with offspring educational attainment, above and beyond the effect of offspring education polygenic score, providing evidence for social genetic effects on educational attainment. Parental educational attainment, income, and parenting behaviors served as important socioenvironmental pathways that mediated the effect of parental education polygenic score on offspring educational attainment. We observed a similar pattern of social genetic effects being mediated by parental educational attainment and income for fathers and mothers. However, parental bonding appeared to be a more relevant pathway of social genetic effects for mothers than for fathers.

It is well-established that both genetics and environments influence educational attainment (Branigan et al., 2013; Lee et al., 2018). We examined whether parental educational attainment polygenic scores were associated with offspring educational attainment. Building on the literature, our findings indicate that not only individuals' own genotypes, but also parents' genotypes play a role in influencing individuals' educational attainment, providing evidence of genetic nurture. This finding is consistent with recent studies demonstrating that parents' genotypes, both transmitted and non-transmitted to offspring, influence offspring educational attainment (Bates et al., 2018; Belsky et al., 2018; Kong et al., 2018). By incorporating parental genotypes and child genotypes in our analyses of offspring educational attainment, our findings add to the growing literature of the importance of both direct genetic effects and social genetic effects. The fact that parental education polygenic score predicted offspring educational attainment over and above the effect of offspring education polygenic score suggests that parental education polygenic score shape the family/social environments that influence offspring educational attainment independently of direct genetic transmission between parents and offspring.

Social genetic effects reflect pathways through which individual differences may be transmitted from parents to offspring. We examined which socioenvironmental processes influence the associations between parental education polygenic score and offspring educational attainment by adding parental educational attainment and income to the models. Consistent with our hypothesis and previous findings (Bates et al., 2018, 2019), parental educational attainment and income mediated the effect of parental education polygenic score on offspring educational attainment. This finding is also consistent with prior research that education polygenic score is associated with not only educational attainment but also socioeconomic status more broadly (Belsky et al., 2016). That parental educational attainment and income were associated with offspring educational attainment above and beyond the effects of parental and offspring education polygenic scores suggest that these associations partly reflect social influences. Family SES such as educational attainment and income are associated with better home environments that may promote offspring educational attainment (Davis-Kean, 2005).

Parental educational attainment and income did not fully mediate the social genetic effects on offspring educational attainment (at least for fathers in our sample), suggesting that other psychosocial factors and socioeconomic status indicators (e.g., parental occupation) may serve as additional mediating pathways. This is not surprising, given robust evidence that educational attainment is influenced by many factors beyond parental educational attainment and income (Nagoshi et al., 1993; Ou & Reynolds, 2008). Our results indicated that parental bonding, an important aspect of positive parenting behaviors, was not significantly associated with parental education polygenic score and thus did not mediate the association between parental education polygenic score and offspring educational attainment. However, maternal educational attainment was associated with higher maternal bonding, which in turn was associated with higher offspring educational attainment. Our results indicated that the indirect pathway: parental education polygenic score → parental educational attainment → parental bonding → offspring educational attainment was statistically significant for mothers but not for fathers; thus, maternal bonding plays an important role in the pathway of social genetic effects. Although paternal bonding was associated with higher offspring educational attainment, it was not significantly associated with paternal educational attainment and income, and thus did not mediate the association between paternal education polygenic score, paternal educational attainment, and offspring educational attainment. It is possible that father's parenting is more influenced by their own mental health such as alcohol and drug problems (Su et al., 2018) rather than their socioeconomic status. We note that our sample size for the analysis involving a measure of parenting was relatively small, and thus this study might be underpowered in detecting the association between parental education polygenic score and parenting behaviors.

We found that individuals' own education polygenic score remained significantly associated with their own educational attainment, even in the extended path models where parental education polygenic score, parental educational attainment, income, and parenting were considered. This finding suggests the robustness of genetic effects on educational attainment and highlights the importance of further understanding how genetic and environmental mechanisms shape intergenerational transmission. Given the importance of genetic factors in intergenerational transmission of offspring outcomes, identifying mechanisms to improve prevention and intervention is important for modifying the associations between genes, environments, and developmental outcomes.

Contrary to previous findings between genetics and parenting (Klahr & Burt, 2014; Wertz et al., 2019), we did not find an association between parental education polygenic score nor offspring education polygenic score and parental bonding. There was, however, a significant and positive bivariate correlation between offspring education polygenic score and maternal parental bonding ($r = .10$). The lack of associations could partly reflect the reduced sample size for these analyses, limiting our power to detect an effect. In addition, our measure of parenting (parental bonding) was assessed during adolescent years (ages 12–17). Prior studies tend to focus on measures of parenting in early childhood or middle childhood years (e.g., before age 12; Wertz et al., 2019). It is plausible that the rGE processes surrounding parenting begin earlier in development and that offspring's genetic predispositions may influence their reports of parenting. Replicating our findings in larger samples is needed.

Strengths of this study include the use of a unique data set that includes genotypic and phenotypic data from fathers, mothers, and offspring to disentangle genetic and socioenvironmental influences on educational attainment and the application of a state of the science approach, namely genome-wide polygenic score approach, to characterize genetic predispositions toward educational attainment. Our sample included participants from a broad age range, with the majority of individuals passed through the typical period of completing a final educational degree. Incorporating genotypic data from both parents and offspring provided a unique opportunity to examine social genetic effects on educational attainment. Including fathers and mothers in our analyses also contributed to the limited literature on the role of fathers in influencing offspring development.

Despite these strengths, our findings need to be interpreted in view of several limitations. First, our analyses focused on a sample of European ancestry ascertained primarily from large extended families enriched for alcohol use disorders. Thus, generalizability of our findings to samples of non-European ancestry and community samples is unclear and additional research is needed to replicate our findings. Second, we only examined one aspect of positive parenting (i.e., parental bonding) due to the limited parenting measure available in COGA with good reliability and validity. Future studies should consider the role of other dimensions of parenting and home environment and across different developmental periods that may be more explicitly relevant and salient for promoting educational achievement (e.g., parents reading to offspring and helping with schoolwork), as well as other psychosocial and environmental pathways of the social genetic effects. In addition, our measure of parenting was based on offspring-report only and may be subject to bias. Future research is needed to replicate our findings using other methods to measure parenting behaviors (e.g., parent-report or observation).

In conclusion, our results show that parental genetic predispositions toward educational attainment influence offspring educational attainment not only through direct genetic transmission, but also via social genetic effects. Parental educational attainment, income, and parenting behaviors are important pathways by which parental genotypes influence offspring educational attainment. Our findings highlight the importance of including genotypic and phenotypic data from both parents and offspring to disentangle the genetic and socioenvironmental pathways underlying parental influences on human development.

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