Uncovering the genetic and environmental mediators of parent-offspring transmission of educational attainment: An adoption study

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ABSTRACT

While research has consistently found a strong, parent-to-offspring transmission of educational attainment, understanding the mechanisms underlying this relationship remains tentative. Genetically informative methods using a longitudinal, adoption sample was used to better understand possible mediators for this relationship. Data was drawn the Sibling Interaction and Behavior Study (SIBS) which consists of 409 adoptive and 208 nonadoptive families consisting of two offspring followed from adolescence into young adulthood and their rearing parents. Four domains of mechanisms by which parents might foster the educational achievement of the children they rear were examined: 1) skill enhancement; 2) academic support; 3) material advantage; 4) supportive family environment. Analysis revealed evidence for genetic mediation within the skills domain and shared, environmental mediation for academic expectations and family income.

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Turkheimer (2000) summarized a wealth of behavioral genetic research on the origins of individual differences in behavior in terms of three general laws. Namely, for individual differences in nearly all behavioral traits: 1) genetic factors matter; 2) the shared family environment is largely inconsequential; and 3) the non-shared environment is the major non-genetic contributor. The second law, the general absence of shared environmental influences, has been characterized as one of the most provocative and influential findings from behavioral genetic research (Plomin, 2011). Nonetheless, there are behavioral phenotypes for which the second law does not apply, including the phenotype on which we focus here, educational attainment. In a meta-analysis of relevant twins studies, Branigan, McCallum, and Freese (2013) concluded that over 30% of the variance associated with educational attainment could be attributed to shared environmental influences. Freese and Jao (2017) have argued further that the existence of a substantial shared environmental effect on educational attainment is a puzzle in search of a solution: Why does it not abide by Turkheimer's second law? Here we present an analysis of a unique adoption study that seeks to identify the mechanisms leading to shared environmental influences on educational attainment.

In addition to being one of a few phenotypes that breaks with the second law of behavioral genetics, educational attainment is widely viewed as a profoundly consequential phenotype. College education, in particular, is the basis of occupational success and by extension, a pathway to social mobility (McGue, Rustichini, & Iacono, 2017). The completion of a college degree has been associated with a variety of positive outcomes at both the individual (e.g., better health outcomes; Currie & Moretti, 2003), and societal (e.g., lower unemployment and welfare benefits along with higher tax

contributions; Trostel, 2010) levels. There is, consequently, a clear need to understand the factors that contribute to individual differences in educational attainment, and especially those that are potentially modifiable, such as factors underlying the shared environmental effect, in order to facilitate its advancement.

Parent factors constitute one potential source of shared environmental influence (Freese & Jao, 2017). Supporting that this may be especially true for educational attainment is evidence of strong parent to offspring transmission (Hertz et al., 2008). Nonetheless, the specific mechanisms that underlie this intergenerational transmission continue to be debated. Behavioral genetic research finds that educational attainment is moderately heritable (Branigan et al., 2013), indicating that genetic factors likely contribute to the parent-offspring transmission. Alternatively, adoption studies also report significant educational resemblance between adopted individuals and the adoptive parents who reared them (McGue et al., 2017), indicating that environmental factors also contribute to parent-offspring transmission. The existence of both genetic and environmental contributions to the intergenerational transmission of educational attainment imply the two are confounded in intact nuclear families due to passive gene-environment correlation (Plomin, DeFries, & Loehlin, 1977). To investigate the separate genetic and environmental mechanisms underlying parent-offspring transmission of educational attainment, alternative research designs are needed.

The present study uses an adoption-study design to explore the environmental mechanisms underlying parent-offspring resemblance for college attainment. We consider four, not necessarily independent, environmentally-mediated mechanisms by which college educated parents might facilitate the educational attainment of their

children. First, highly educated parents may provide a rearing environment that fosters the development of the skills needed for academic success. Second, parents might provide direct support of their children's academic efforts (e.g., help with homework). Third, highly-educated parents are likely to have greater economic resources than parents who are less well educated, and those economic advantages might allow them to create opportunities that promote the academic success of their children. Finally, highly-educated parents might be more likely to provide a stable and supportive family environment than parents who are less well educated.

General cognitive ability (GCA) is one of the strongest predictors of educational attainment (Marioni et al., 2014; McGue et al., 2017). Research has also consistently found heritable effects on GCA (e.g., using twin samples, van Leeuwen, van den Berg, & Boomsma, 2008; as well as adoptive and non-adoptive parent-offspring correlations; Petrill & Deater-Deckard, 2004), suggesting that the association between GCA and educational attainment may be genetically mediated. Nonetheless, in an investigation of the intergenerational transmission of educational attainment, Kendler, Turkheimer, Ohlsson, Sundquist, and Sundquist, (2015) reported that both biological and adopted offspring of parents with high levels of education had higher GCA than their peers whose parents had low educational attainment. Providing a rearing environment that promotes the development of GCA might be one mechanism by which parents influence the educational attainment of their children.

GCA is not, however, the only skill related to academic success. Non-cognitive abilities (sometimes referred to as "soft skills") encompass individual differences in a range of phenotypes such as personality traits, goals, motivations, and preferences

(Heckman & Kautz, 2012) that have been related to educational attainment (e.g., Borghans, Duckworth, Heckman, & Weel, 2008; Kuncel, Ones, & Sackett, 2010). For instance, personality traits, and in particular conscientiousness, have been associated with academic performance (Poropat, 2009). Other non-cognitive factors related to educational achievement include academic study skills, habits and attitudes (Credé & Kuncel, 2008).

Direct parent support of their children's academic efforts has generally been shown to be positively associated with offspring academic achievement (Wilder, 2014). However, parental academic support can take various forms, which are associated with different effect sizes with offspring academic achievement. For instance, while parental expectation of offspring academic achievement evidences a moderate, positive relationship, the benefits (or lack thereof) of homework assistance are mixed (Castro et al., 2015; Wilder, 2014). Jacob and Linkow (2011) found that parents appear to be more effective at shaping their offspring's academic expectations than schools are, and that these expectations for achieving educational attainment are a positive correlate of later educational attainment. Stable academic expectations through high school also appear to be more predictive of four-year degree attainment than expectations during senior year alone (Johnson & Reynolds, 2013).

Longitudinal data suggests that both family stability (measured by both parents presence through the offspring's adolescent years) and family cohesion (described as the love and care directed towards the offspring) are conducive to offspring educational attainment (Emonds & van Tubergen, 2015). Martin et al. (2015) found a variety of family related factors (e.g., effective child management, family conflict) were associated

with educational attainment. Johnson, McGue, and Iacono (2006) developed a family risk composite by summing a variety of individual level risk factors (e.g., low offspring birth weight; parent substance abuse) and family level risk factors (e.g., single parent household). Higher family risk composite scores were negatively associated with offspring secondary and high school grades.

Family income frequently appears in the literature as a possible mechanism for improving educational attainment. Doren and Grodsky (2016) argued that parents with economic resources not only contribute financially to their children's academic efforts but also likely have skills that support their children's academic development. Similarly, Willoughby, McGue, Iacono, Rustichini, and Lee (2019) used aggregate genetic scores predictive of educational attainment to demonstrate that parents make more than a genetic contribution to their offspring's educational outcomes.

Looking at how finances might influence academic outcomes, Kaushal, Magnuson, and Waldfogel (2011) noted that more highly educated parents spend more on enrichment experiences (such as recreation, non-college tuition, and child care) than less educated parents. However, the authors are careful to note causality is far from established, and that the actual impact of these investments on the offspring is unclear. Taking advantage of a natural experiment due to the opening of a casino, Akee, Copeland, Costello, and Simeonova (2018) found that Native American children from families that had received an unconditional cash transfer had improved well-being, increased conscientiousness, and decreased behavioral problems, outcomes that may contribute to later educational success. Nonetheless, Black and Devereux (2011) concluded findings from research on

the benefits of family income for child education are mixed and it is difficult to draw general conclusions.

Family income may also affect educational outcomes indirectly through the neighborhoods families live in and the schools their children attend (Freese & Jao, 2017). Certainly, regional and urban/rural differences in educational attainment have been identified (e.g., Byun, Meece, & Irvin, 2012; Ryan & Siebens, 2012). A large scale U.S. study also supported the impact of neighborhood influences on offspring educational by examining the outcomes of families who moved to better neighborhoods (Chetty & Hendren, 2018). Although the impact of school differences on academic achievement has been debated for more than 50 years - sparked in part by the controversial results of the Coleman report - on balance the evidence is consistent with a modest school effect.

Summary of current study

The goal of this paper is to identify the family factors that mediate parent-offspring environmental transmission of educational attainment. Four types of candidate mediating factors were considered: a) skill enhancement, b) academic support, c) material advantage, and d) supportive family environment. Moreover, by using a sample of adoptive and non-adoptive families, we were able to control for passive gene-environment correlation effects and so determine whether these mediating processes were due to genetic or non-genetic transmission.

METHODS

PARTICIPANTS

The sample consisted of participants in the Sibling Interaction and Behavior Study (SIBS), a longitudinal study of 409 adoptive and 208 non-adoptive families.

Adoptive families consisted of two genetically unrelated offspring and their rearing parents. Non-adoptive families consisted of two full biological siblings and their parents. For 124 of the 409 adoptive families, one of the offspring was the biological offspring of the parents but not genetically related to the family's other participating offspring; in the remaining 285 families both offspring were adopted. Families had been systematically ascertained either from adoption records from three large adoption agencies in Minnesota or, for non-adoptive families, from Minnesota state birth records. Additional details concerning the recruitment of the SIBS sample can be found in McGue et al. (2007). Inclusion criteria at the intake assessment included living within driving distance of our labs at the University of Minnesota and having no physical, intellectual or behavioral disabilities that would preclude completion of our in-person assessments.

SIBS participants completed up to three assessments. At the intake assessment, a total of 613 (99% of the target sample of 617) mothers and 551 (89%) fathers were assessed. Among the 1234 assessed offspring in the 617 families, two (in two different adoptive families) were judged to be ineligible after they had completed their intake assessment (one because she was found to be biologically related to her participating sibling and the other because her IQ test performance suggested mild intellectual disability, a study exclusion criterion). SIBS offspring were recruited for two follow-up assessments, on average approximately 3.5 and 7 years after their intake assessment. A total of 1158 (94%) and 1129 (92%; of the original and eligible sample) offspring completed the first and second follow-up assessments, respectively. Note, only 1125 individuals were included in the current study because of an additional inclusion criterion regarding educational attainment, specified below.

Offspring data used in the present study comes from their intake and follow-up assessments. Our sample consisted of the 638 adopted and 487 non-adopted individuals in 590 families (393 adoptive and 197 non-adoptive) who provided valid educational outcome data at the third assessment. These individuals had a mean age of 14.9 years (SD = 1.9, range = 11-21) at intake and 22.4 years (SD= 1.9, range 19-28) at the second follow-up. See Table 1 for demographics of offspring by family type.

Only those rearing parents for whom we had educational outcome data, either through self-report or spouse-report, were included in the sample. At offspring intake, the 549 parents from 277 adoptive families included in this study had a mean age of 48.9 years (SD=3.7); the 394 parents from 197 non-adoptive families had a mean age of 45.0 years (SD = 4.7); and the 232 parents from 116 mixed adopted/non-adopted families had a mean age of 47.6 (SD=3.7). Parent educational attainment varied by family type, with 63.6% of the adoptive family parents, 44.4% of non-adoptive family parents, and 59.9% of mixed family parents having completed a 4-year college degree.

MEASURES

COLLEGE STATUS. While offspring had a mean age of approximately 22 years, the youngest were 19 years at the time of the third assessment, and thus many were not old enough to have completed a four-year college degree. Offspring educational attainment was defined in the following way: offspring were considered to have achieved college if they had completed a four-year degree *or* they were in college and under the age of 25 years at their last assessment. Offspring were designated as not having achieved college if they were not attending college and without a degree *or* they were in college

but 25-years old or older[1]. Parent college status was coded as the number of parents in each family having completed a college degree.

Ten potential mediators of parent college effects were clustered in four domains: **skill enhancement** (parents fostered development of the skills offspring needed to succeed academically), **academic support** (parents set high academic standards and provided help in completing academic assignments), **material advantages** (parents were able to pay for experiences that increased the likelihood their children would succeed academically), **supportive family environment** (parents provided a stable, non-chaotic, and supportive home environment).

Skill enhancement was assessed through offspring attributes previously shown to be related to academic success and included a measure of general cognitive ability (GCA) and a non-cognitive skills composite (McGue et al., 2017). GCA was assessed via an abbreviated form of the Weschler Adult Intelligence Scale-Revised (WAIS-R) (Wechsler, 1981) for offspring age 16-years and older and the Weschler Intelligence Scale for Children-Revised (WISC-R) (Wechsler, 1974) for those 15-years and younger at intake. For both the WAIS-R and the WISC-R, the abbreviated form consisted of two performance (block design and picture arrangement) and two verbal (vocabulary and information) subtests. Previous research has shown a composite of these four subtests correlates .90 with IQ when based on all Weschler subtests (Kaufman, 1990).

Offspring noncognitive skill was assessed with the composite of six personality and behavioral scales shown previously to be predictive of educational attainment

[1] Eight participants who were included in this study were 25-years-old or older and still attending college, and were thus considered not having college attainment.

(McGue et al., 2017). The three personality scales were the Alienation, Aggression and Control scales from the Minnesota Personality Questionnaire (MPQ; Tellegen & Waller, 2008). The three behavioral scales included an 8-item mother-rated Academic Effort scale (e.g., "Turns in homework on time"); a three-item mother-rated Academic Problems scale (e.g., "Easily distracted in class") and an Externalizing Symptoms scale. The latter consisted of the number of symptoms of attention deficit/hyperactivity disorder, conduct disorder and oppositional defiant disorder as assessed by clinical interview of the mothers and their offspring. A noncognitive composite was formed by summing the six individual tests (with Alienation, Aggression, Academic Problems and Externalizing Symptoms being reflected) after each had been standardized. See McGue et al. (2017) for additional information on the noncognitive scales and composite, including how each is associated with academic attainment.

Academic support included two variables, both rated by the mother. Mother Academic Expectation was assessed at intake by the single item, "How far do you expect your child to go in school?", which mothers rated on a 6-point scale ranging from 1=Not completing high school to 6=College plus a professional degree. The Academic Expectation variable was adjusted by regressing out offspring academic skills (i.e., GCA and the noncognitive composite) and results reported here are all based on the regression residuals. Academic Help was a 7-item scale completed by the mother at the second assessment and included items covering parental involvement (e.g., "I keep close track of how this child is doing in school") and expectations (e.g., "I expect this child to be one of the top students in his/her class.")

Material advantages included mother reports of family income and neighborhood and offspring report of school environment obtained at the second assessment. Household gross annual income was reported on a scale that ranged from 1=Less than $10,000 to 15=More than $100,000. The neighborhood and school assessments were adapted from the scales developed by Ennett and colleagues (Ennett, 2002; Ennett, Flewelling, Lindrooth, & Norton, 1997). The four neighborhood scales were a 7-item Cohesion scale (e.g., “Most of the people there know each other”); a 6-item Intervention scale (e.g., “How likely are your neighbors to step in when they see teens damaging property”), a 6-item Crime scale (e.g., “People are afraid to come into my neighborhood”), and a 3-item Involvement scale (e.g., “How often have you socialized with your neighbors at your home or theirs?”). A Neighborhood composite was computed as the sum of the four individual neighborhood scales after each had been standardized. The two school scales were School Support, which consisted of 9 items (e.g., “Students treat each other with respect”, and “Teachers are really interested in the students”); and School Substance Use, which consisted of 8 items (e.g., “It is easy to get some marijuana from some kids at school”; reflected). An overall School composite was formed by summing the two school scales after they had been standardized.

The supportive family environment cluster included measures of parental involvement in the offspring’s life, degree of household structure, and parent disinhibitory psychopathology. Household structure was reported by the father at intake using the 5-item Structure scale (sample item, “I make it clear what I want my child to do or not to do”) from the Parent Environment Questionnaire (PEQ; Elkins, McGue, & Iacono, 1997). Parent involvement was assessed using the 12-item Involvement scale

from the PEQ ("My child talks about their concerns and experiences with me") as reported separately by mothers and fathers. A composite parental involvement score was computed by taking the mid-parent average. In cases where only one parent reported involvement, that score was used in place of a mid-parent average after the gender effect was taken into account. Parental disinhibition was a composite of father and mother self-reported symptoms of adult antisocial behavior, alcohol abuse and substance abuse obtained by clinical interview.

Table 1 provides descriptive statistics for the variables for adopted and non-adopted offspring by family type. Of the variables, only family income and family structure had notable missing data (23.9%, and 19.3% missing across all participants respectively). See Table 2 for percentage missing across variables by family type. For a breakdown of the variables by gender, see Supplement Table 3.

STATISTICAL ANALYSIS

The conceptual model that guided our analyses is given in Figure 1. Parent-offspring transmission of education is assumed to be mediated both genetically and environmentally in non-adoptive families but only environmentally in adoptive families. Parental environmental contributions to offspring educational attainment are modeled in two ways. First, parents can provide an environment that facilitates academic skill development in their offspring. Second, parents can provide academic support, material advantages, and a supportive family environment whose influences on educational outcomes can be both direct, through the creation of academic opportunities, and indirect, through academic skill development.

To establish environmental mediation, three findings are required in our analysis of adoptive and non-adoptive families: First, offspring educational attainment must be associated with parent degree attainment. Second, the potential mediator must be associated with offspring educational attainment. Third, parental education must be associated with the specific potential mediator. Further, when these conditions were met, a main effect within the adoptive families sample was taken as indicating support for environmental mediation, whereas an interaction between family type and parent college education reflecting a stronger parent college effect for non-adoptive than adoptive offspring was taken as evidence of genetic mediation.

To establish the first criterion, offspring educational attainment was regressed onto parent degree attainment in R using the *glmer* function. To establish the second criterion, offspring college attainment was regressed onto each of the potential mediators individually via the *glmer* function. To establish the third criterion, each candidate environmental mediating factor was regressed onto parent college degree attainment using the *lmer* function. When overall effects were observed, we further determined whether the effect existed within the sample of adoptive families (environmental mediation), and whether the magnitude of the effect was greater in non-adoptive than adoptive families (genetic mediation). All potential mediators were standardized in the overall sample to facilitate interpretation of the results. Each regression model contained age and sex of offspring as covariates. Familial clustering was accounted for via a random intercept for each family (i.e., a unique intercept for each sibling of a sibling pair).

We also examined the joint effect of candidate mediating factors to test for full mediation of the parent-offspring transmission of education, and the impact of missing data. We regressed offspring educational attainment on parent degree attainment and the possible candidate mediating factors via *glmer*. Missing data was imputed using the *mice* function. Three model types were run: an uncorrected model (offspring education regressed on parent college), identified mediation models (offspring education regressed onto parent college and identified mediating variables), and a full model (offspring education regressed onto parent college and all potential mediators simultaneously). Models were compared using the Bayesian Information Criterion (BIC) and odds ratios (ORs). Elimination of the parent college effect when the candidate mediators were included in the regression is consistent with complete mediation.

Results

We first investigated whether college attainment was transmitted in both adoptive and non-adoptive families. Number of college educated parents was significantly associated with offspring college attainment for all four types of offspring (i.e., adopted offspring from adoptive families, adopted offspring from mixed families, nonadoptive offspring from nonadoptive families, and nonadoptive offspring from mixed families), which implicated both genetic and environmental pathways. For each offspring type, we computed the OR between number of college-educated parents and offspring college attainment after taking sex, age at last follow-up, and family clustering into account. The estimated OR (95% CI) was 1.45[1.12, 1.87] p=.005 in adoptive families, 2.75[1.82, 4.14] p<.001 in non-adoptive families, 1.90[1.12, 3.22] p=.019 for adopted offspring in mixed families, and 3.74[1.40, 9.97] p=.009 for nonadoptive offspring in mixed families.

The effect of parent college in adopted offspring implicated an environmental effect. There was a significant interaction between adoption status and parent college on offspring education attainment (β=.52, 95% CI=[.17, .87]). The stronger transmission of educational attainment in non-adopted offspring compared to adopted offspring implicates genetic factors are involved. While these results provide evidence of both genetic and environmental medication, the focus of this paper is on environmental mediation. Supplement Figure 2 depicts the proportion of offspring attaining college by parental degree status and family type.

The strength of the parent college effect did not vary significantly either between the two adopted offspring groups (OR=1.20[.89, 1.61], *p*=.236) or the two non-adopted offspring groups (OR=1.41[.67, 2.96], *p*=.365). Consequently, we pooled these groups to form adopted offspring and non-adopted offspring samples to increase power in all subsequent analyses.

The second step in our analysis involved determining whether each of the individual potential mediators was associated with offspring college attainment in non-adoptive and adoptive families. The results of regressing offspring college attainment on each of the potential mediating factors are presented in Table 4. In both offspring samples, only family structure was not significantly associated with offspring college attainment in both adopted and non-adopted offspring. For none of the variables did we observe a statistically significant interaction between the predictor and adoption status. Nonetheless, parent disinhibition was significantly and negatively associated with college attainment among non-adoptive but not adoptive offspring, suggesting a genetic pathway. Of the remaining eight variables, help from mother had a negative association for both

offspring groups, while all other variables were positively associated with offspring college attainment in both offspring groups.

The third step in our analysis involved determining which of the potential mediators was associated with number of parents with a college degree in non-adoptive and adoptive families. The results of regressing each candidate mediating factor on parent college, adoption status, and a parent college by adoption status interaction are given in Table 5. Environmental mediation is implicated by a significant effect of parent college in the adoptive families. Genetic mediation is implicated by a mediator by adoption status by parent college interaction. Evidence in favor of at least partial genetic mediation is present for offspring skills (i.e., offspring general cognitive ability and noncognitive ability), neighborhood, parental disinhibition, parental involvement, and school. Evidence for at least partial environmental mediation existed only for family income (main effect for adopted individuals β=.30[.20, 40]) and adjusted mother expectations (i.e., controlling for offspring skills; β=.16[.04, 28]). Thus, these two variables represent environmental mediators of parent-offspring educational transmission, as they were the only potential mediating factors to meet the requirements of each of the three steps.

Table 6 presents results of models investigating the combined effect of potential mediators in the adoptive offspring sample with imputation of missing data (number of imputations = 100). Model 1 is a baseline model in which offspring educational attainment was regressed on parent college and covariates, yielding an OR=1.48 (95% CI of [1.19, 1.83], $p<.001$). In Model 2, the two potential mediators consistent with environmental mediation were added and resulted in an OR for the parent college effect of 1.27 ([0.99,1.63], $p = .057$, ΔBIC = -69.89). Finally, Model 3 included all potential

mediators and resulted in a parent college OR of 1.38 ([1.01, 1.87], p = .038, from model 2 to 3, ΔBIC =-129.46). In combination, these variables did not account entirely for the parent-offspring transmission of education effect

DISCUSSION

Our analysis of parent-offspring transmission of educational attainment in adoptive and nonadoptive offspring found that: (a) both shared environmental and genetic factors contributed to parent-offspring transmission; (b) while offspring with higher cognitive and noncognitive skills were more likely to achieve college attainment, highly educated parents were not increasing their *adopted* offsprings' college attainment through skill development; (c) the only environmental factors associated with increased odds of offspring college attainment were mother's academic expectations and family income. Our findings regarding the influence of both the shared environment and heritability (i.e., genetic effect) on educational attainment are in line with previous meta-analytic findings (Branigan et al., 2013). Additionally, the persistent parent-offspring transmission of educational attainment is consistent with other adoption studies (e.g., Bjorklund, Lindahl, & Plug, 2006).

Our findings show that family income partially mediated parent-offspring transmission of educational attainment in adoptive families. Nonetheless, family income was not associated with the cognitive and noncognitive skills of adopted offspring, so its benefit in regards to educational attainment must operate through other pathways. One way parent income might increase children's odds of college attainment is through direct financial aid for college expenses, which may be of increasing importance with the rising cost of higher education (CollegeBoard, 2018).

Parent income may also foster educational attainment through helping offspring achieve higher scores on college admission tests (e.g., SAT – a widely used test in American college admission) via preparation aids (Buchmann, Condron, & Roscigno, 2010) or re-testing opportunities (Vigdor & Clotfelter, 2003). While questions over the size of effect for the different test preparation methods (e.g., practice tests, private tutors) remain, the available literature indicates that preparation tends to improve scores (Montgomery & Lilly, 2012; Powers & Rock, 1999). Vigdor and Clotfelter (2003) show that students' scores on the SAT generally improve on subsequent testing, and additional test taking is associated with family income. It is worth noting, however, that SAT scores are not merely acting as proxies for family income in the admissions process (Sackett et al., 2012). Sackett and colleagues (Sackett, Kuncel, Arneson, Cooper, & Waters, 2009; Sackett et al., 2012) show that including family income in a model alongside SAT score only trivially diminishes the validity of the SAT score in predicting college academic performance.

In addition to potentially aiding offspring's ability to obtain higher admission-test scores or paying for college costs, parent income may also improve offspring's chances of college attainment indirectly. For instance, high-income parents may fund extracurricular activities or courses that enhance the student's college application. Kaushal, Magnuson and Waldfogel (2011) found that as families overall expenditures increased (a proxy for overall family income), more investment was made towards offspring enrichment, such as paying for dance lessons, organized athletics, preschool and private school, trips or electronics. Additionally, in more highly educated families, a

greater proportion of resources was devoted to enrichments such as books, lessons, and education (e.g., college, school supplies).

We found that mothers who expected their offspring would attend college (net the offspring's cognitive and noncognitive skills) had offspring with higher odds of college attainment. Like family income, mother expectations also partially mediated the parent-offspring transmission of education relationship. The nature of this relationship is not perfectly clear - the mother may be reacting to attributes of the offspring we have not measured, or the mothers' expectations may influence offspring educational attainment directly (i.e., by motivating the offspring to achieve more) or indirectly (e.g., by increasing child's expectations of educational attainment). Evidence that high school students' expectations of their own educational attainment is related to college enrollment certainly exists in the literature – though the authors caution against assumptions of causality (Jacob & Linkow, 2011). Rimkute, Hirvonen, Tolvanen, Aunola, and Nurmi (2012) found that parental educational expectations were related to offsprings' expectations as well as parental educational level and offspring academic achievement. Our current analyses do not tease apart the more complex nature of these relationships, and additional research is needed.

There are several limitations to our research design that should be taken into account when interpreting the results and generalizability of this study. Our sample was drawn from Minnesota, a U.S. state with higher rates of college attendance and lower rates of unemployment than many other U.S. states. Thus, the generalizability of the results to other areas of the country, and certainly to non-U.S. countries may be limited. Restriction of range in the socioeconomic background of adoptive families is well

known, and adoptive families reported higher incomes on average than non-adoptive families in our sample. Such restriction of range can lead to an underestimation of shared environmental influence estimates (Stoolmiller, 1999), however, previous analyses comparing the importance of the shared environmental effects in this adoptive and a twin family sample found limited differences between the two (McGue et al., 2017), limiting concerns of range restriction on the current estimates.

Finally, given the ages of participants (27% of offspring between 19 and 21-years-old at last follow-up), a number of offspring had not had the opportunity to complete a 4-year college degree by the last follow-up. Thus, educational attainment (completion of a 4-year degree or being enrolled in college and under the age of 25-years old) was used in place of college degree attainment.

Analyses of family units consisting of both adoptive and non-adoptive offspring highlights the importance of both genetic and environmental influences on the parent-offspring transmission of educational attainment. While cognitive and noncognitive skills are consistently associated with educational attainment across offspring types, more highly educated parents do not appear to be aiding their adoptive offspring by means of skill development. Rather, the mediators identified in the parent-offspring transmission of educational attainment are family income and expectations the mother holds regarding her offspring's educational attainment.

A notable finding was that the parent-offspring transmission of educational attainment could not be completely accounted for by the family and neighborhood factors included in this study. The question of what highly educated parents do to increase the odds of offspring educational attainment remains an open question. There are several

possibilities we postulate may be important, though our list should not be taken as exhaustive. First, direct modeling of educational attainment. Offspring who see that their parents have obtained a higher degree model after this accomplishment. Kendler and colleagues (2015) report a small effect of parent education on adopted offspring skill. Thus, a second possibility is that there are skills parents promote in their offspring that we did not assess. There may be other important family factors (e.g., father expectations, parent engagement in offspring college applications) related to parent educational attainment that promotes offspring educational attainment. It is also possible that there are important school environment factors we did not assess (e.g., academic climate, availability of AP courses). Or, that the peers of offspring and other neighborhood residents also serve as models for educational attainment achievement in offspring (e.g., see Chetty & Hendren, 2018).

This study serves as a starting place for piecing together the puzzle described by Freese and Jao (2017). While a complete solution was not identified - mothers' expectations and family income only partially mediated the parent-offspring transmission of educational attainment - we hope this study serves as a springboard for additional research in identifying mechanisms associated with this phenotype.

Table 1 Descriptive Statistics for Demographics and Standardized Predictor Variables by Family Type and Adoption Status

	Adoptive Family	Nonadoptive Family	Mixed Family	
	Adopted Offspring	Nonadoptive Offspring	Adopted Offspring	Nonadoptive Offspring
Demographics				
Female %	58.8	52.3	46.8	62.5
College Attainment %	55.4	61.1	57.8	72.3
Age Intake M(SD)	14.9 (2.1)	15.1 (1.8)	15.5 (1.1)	14.2 (2.2)
Age FU1 M(SD)	18.2 (2.3)	18.4 (1.9)	19.0 (1.4)	17.7 (2.3)
Age FU2 M(SD)	22.3 (2.0)	22.5 (1.7)	23.0 (1.2)	21.5 (2.1)
Skill Enhancement				
GCA M(SD)	-.03 (.99)	.04 (0.87)	-.02 (1.13)	.23 (1.11)
Noncognitive M(SD)	-.02 (1.03)	.06 (0.98)	-.20 (0.89)	.23 (0.98)
Academic Support				
Expectations M(SD)	-.05 (0.99)	.06 (1.02)	-.01 (0.98)	.10 (0.99)
Help M(SD)	.05 (.0.97)	-.08 (1.07)	-.04 (1.02)	.00 (0.95)
Material Advantage				
Family Income M(SD)	.05 (0.98)	-.06 (1.01)	-.01 (1.01)	-.01 (1.00)
School M(SD)	-.02 (1.00)	.03 (.98)	-.07 (.98)	.22 (0.93)
Neighborhood M(SD)	.07 (0.91)	-.14 (1.08)	.05 (1.05)	.07 (1.04)
Supportive Family Environment				
Parent Involvement M(SD)	-.04 (1.03)	.06 (0.98)	-.11 (.88)	.22 (0.94)
Parent Disinhibition M(SD)	-.18 (0.79)	.23 (1.21)	-.02 (0.99)	-.05 (0.98)
Structure M(SD)	-.01 (1.15)	.01 (0.87)	-.07 (0.92)	.00 (0.83)

Note: GCA = General cognitive ability; Offspring college attainment = completing a four-year degree or in college at follow-up 2 and under 25 years old.
All potential mediators have been standardized to a mean of zero and a standard deviation of one to facilitate ease of comparison between mediators.

Table 2. Data Available for Each Independent Variable by Offspring Type (N; Percent)

	Adoptive Family	Nonadoptive Family	Mixed Family	
	Adoptive Offspring	Biological Offspring	Adoptive Offspring	Biological Offspring
Total N	529	375	109	112
GCA	527 99.6%	374 99.7%	109 100%	111 99.1%
Personality	529 100%	374 99.7%	109 100%	112 100%
Neighborhood	507 95.8%	360 96.0%	98 89.9%	101 90.2%
Family Income	437 82.6%	245 65.3%	86 78.9%	88 78.6%
Parent Disinhibition	529 100%	375 100%	109 100%	112 100%
Expectations	503 95.1%	351 93.6%	95 87.2%	95 84.8%
Help	505 95.5%	352 93.9%	96 88.1%	97 86.6%
Structure	470 88.8%	308 82.1%	95 87.2%	98 87.5%
Parent Involvement	524 99.0%	372 99.2%	106 97.2%	109 97.3%
School	492 93.0%	351 93.6%	100 91.7%	100 89.3%

Table 3 Descriptive Statistics for Standardized Predictor Variables by Gender and Adoption Status

	Adopted				Nonadopted			
	Male		Female		Male		Female	
	N	Mean (SD)	N	Mean (SD)	N	Mean(SD)	N	Mean(SD)
GCA	274	-.07(1.02)	362	.00(1.02)	220	.21(.92)	265	-.01(.94)
Personality	276	-.41(.96)	362	.22(.96)	221	-.24(1.03)	265	.38(.85)
Neighborhood	262	.09(.93)	343	.04(.93)	212	.00(.96)	249	-.17(1.15)
School	249	.01(1.02)	343	-.06(.98)	201	.08(.94)	250	.06(.999)
Family Income	231	.03(1.00)	292	.05(.98)	152	.05(.86)	181	-.12(1.12)
Expectations	259	-.10(.97)	339	.00(.99)	206	.17(.93)	240	-.01(1.07)
Help	261	.15(.96)	340	-.05(.98)	207	.04(1.03)	242	-.15(1.06)
Structure	254	-.01(.78)	311	-.02(1.33)	190	.03(.88)	216	-.01(.84)
Parent Involvement	274	-.16(.96)	356	.03(1.03)	219	.08(.93)	262	.11(1.01)
Parent Disinhibition	276	-.11(.84)	362	-.19(.82)	221	.13(1.17)	266	.20(1.16)

Table 4 Odds Ratios (95% CI) for Offspring College Attainment Regressed on Standardized Family Background and Skills Variables

Predictor	Odds Ratio for Adopted Offspring	Odds Ratio for Non-Adopted Offspring	Predictor χ^2 on 1 df	Adoption status χ^2 on 1 df	Adoption status by predictor χ^2 on 1 df
Skill Enhancement					
GCA	2.25 [1.78, 2.84]	2.41 [1.76, 3.30]	83.80 *p*<.001	4.63 *p*=.031	.01 *p*=.937
Noncognitive	3.25 [2.43, 4.37]	4.39 [2.80, 6.90]	111.01 *p*<.001	2.90 *p*=.089	.34 *p*=.561
Academic Support					
Mother expectations	2.59 [1.97, 3.40]	2.44 [1.75, 3.40]	72.53 *p*<.001	5.68 *p*=.017	.64 *p*=.423
Help from mother	.64 [.50, .81]	.60 [.43, .84]	23.95 *p*<.001	7.46 *p*=.006	.13 *p*=.715
Material Advantage					
Family income	1.48 [1.19, 1.83]	1.79 [1.31, 2.44]	25.19 *p*<.001	7.89 *p*=.005	.77 *p*=.379
School	1.42 [1.17, 1.73]	1.51 [1.17 1.94]	21.62 *p*<.001	7.32 *p*=.007	.12 *p*=.724
Neighborhood	1.35 [1.09, 1.67]	1.39 [1.08, 1.79]	13.77 *p*<.001	10.62 *p*=.001	0.03 *p*=.867
Supportive Family Environment					
Parent involvement	1.75 [1.41 1.17]	2.16 [1.61, 2.90]	52.10 *p*<.001	5.62 *p*=.019	.86 *p*=.353
Parent disinhibition	.91 [.74, 1.13]	.72 [.58, .89]	7.99 *p*=.005	9.81 *p*=.002	1.84 *p*=.176
Household structure	.89 [.74, 1.06]	1.03 [.77, 1.38]	.97 *p*=.324	5.57 *p*=.018	.94 *p*=.332

Note: GCA = General Cognitive Ability; All analyses controlled for sex of the offspring, age at last follow-up, and family clustering

Table 5 Effect Sizes & 95% CI for Standardized Family Background & Skill Variables Regressed on Parent College and Adoption Status

	β for parent college in Adopted families	β for parent college in Nonadopted families	Parent college effect	Adoption status effect	Adoption status by parent college effect
Skill Enhancement					
GCA*	.09 [-.01, .19]	.35 [.25, .45]	27.20 *P*<.001	8.68 *p*=.003	11.22 *p*=.001
Noncognitive*	-.02 [-.12, .08]	.22 [.12, .32]	6.04 *p*=.014	9.95 *p*=.002	10.78 *p*=.001
Academic Support					
Mother expectations*	.16 [.04, .28]	.15 [.01, .29]	12.94 *P*<.001	4.49 *p*=.034	.01 *p*=.931
Help from mother*	-.01 [-.13, .11]	-.06 [-.20, .08]	.25 *p*=.615	2.32 *p*=.128	.11 *p*=.742
Material Advantage					
Family income**	.30 [.20, .40]	.35 [.19, .51]	56.86 *p*<.001	.18 *p*=.669	.30 *p*= .583
School*	.03 [-.09, .15]	.21 [.09, .33]	7.04 *p*=.008	3.99 *p*=.046	4.66 *p*=.031
Neighborhood**	.05 [-.03, .13]	.22 [.08, .36]	8.47 *p*=.004	6.25 *p*=.013	4.44 *p*=.035
Supportive Family Environment					
Parent involvement*	-.05 [-.17, .07]	.10 [-.02, .22]	0.19 *p*=.661	6.14 *p*=.013	3.56 *p*=.059
Parent disinhibition**	-.07 [-.15, .01]	-.22 [-.30, -.14]	11.00 *P*=.001	26.30 *p*<.001	3.98 *p*=.046
Household structure*	.02 [-.12, .16]	.03 [-.09, .15]	.13 *p*=.718	.21 *p*=.648	1.47 *p*=.225

Note: GCA = General cognitive ability; *Measured at the individual level controlling for family clustering using a random intercept, Wald on 1 *df* ; ** Measured at the family type (adoptive or non-adoptive) level, *F* statistic.

Table 6. Adopted Offspring College Attainment Regressed on Parent uncorrected

	Model 1: Parent College Predicting Offspring Education	Model 2: Mother Expectations and Family Income Mediation of Parent College Effect	Model 3 Full Model for Predicting Offspring Education
	OR[95% CI]	OR[95% CI]	OR[95% CI]
Parent College	1.48 [1.19, 1.83] *p*<.001	1.27 [.99, 1.64] *p*=.056	1.40 [1.03, 1.92] *p*=.031
GCA			2.03 [1.61, 2.57] *p*<.001
Noncognitive			2.97 [1.74, 5.07] *p*<.001
Mother Expectations		2.18 [1.76, 2.70] *p*<.001	2.51 [1.91, 3.30] *p*<.001
Help from mother			.81 [.63, 1.05] *p*=.110
Family Income		1.32 [1.03, 1.71] *p*=.011	1.31 [1.00, 1.72] *p*=.052
School			.98 [.76, 1.26] *p*=.891
Neighborhood			1.15 [.89, 1.48] *p*=.299
Parent Involvement			1.31 [1.02, 1.69] *p*=.045
Parent Disinhibition			.80 [.60, 1.08] *p*=.144
Household Structure			.90 [.73, 1.12] *p*=.355
BIC	876.84	805.89	672.35

conditions

Note: All models corrected for offspring age at last follow-up, sex, and family clustering

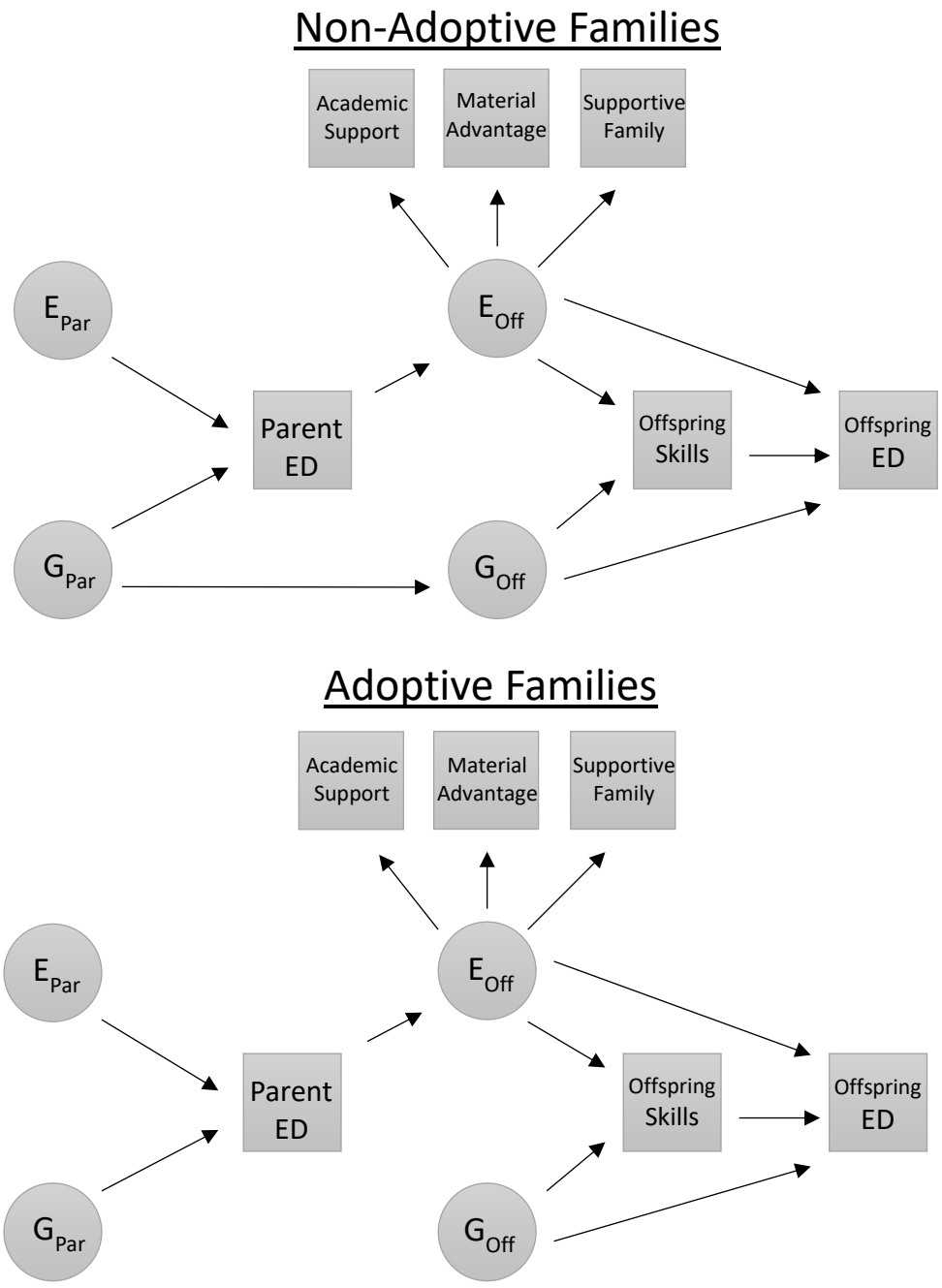

Figure 1: Conceptual model of parent-offspring transmission of educational attainment in adoptive and non-adoptive families. G = genotype, E = Environment, ED = Educational attainment

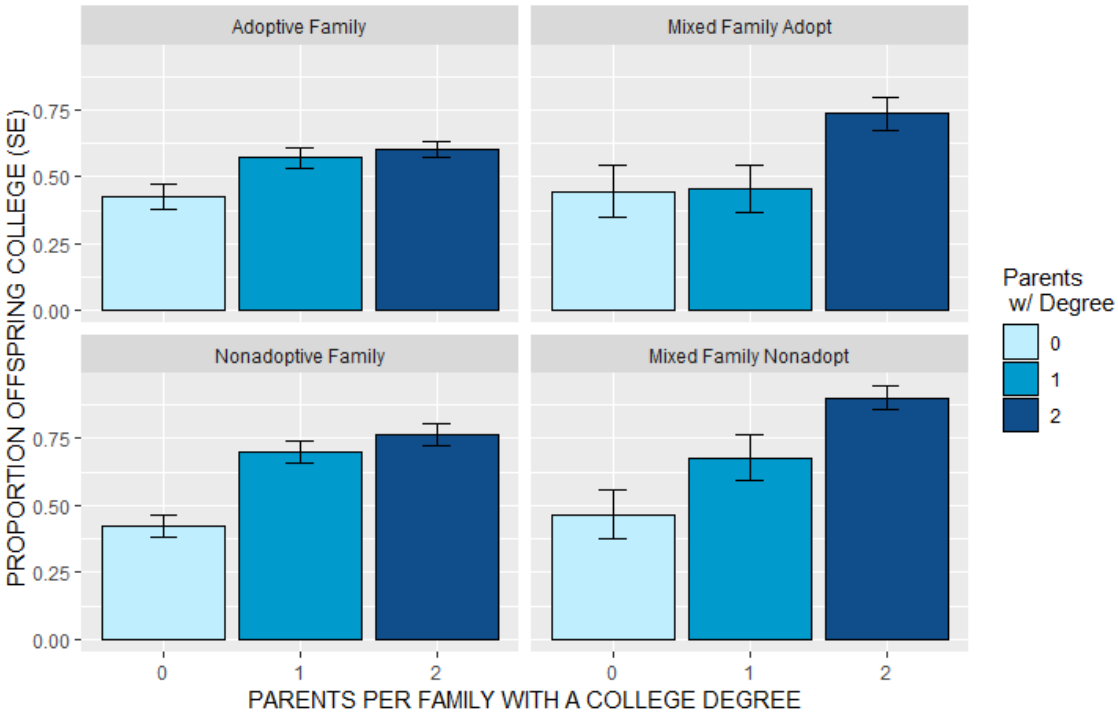

Figure 2: Proportion of offspring college attainment by parent college and family type

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